Report

Heavy Duty Vehicle (HDV) NO_x emission measurement with mobile remote sensing (Plume Chasing) and subsequent inspection of high emitters

A study in Denmark September / October 2020

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Content

Færdselsstyrelsen

1 Summary

This report summarises the result of a project for high emitter heavy duty vehicle (HDV) detection in Denmark (17.9. – 01.10.2020) and followed police inspection of the HDV with high and suspicious emissions. The project is carried out as a collaboration between the Danish Road Traffic Authority, the Danish National Police and Airyx.

For the emission measurement, the plume chasing mobile remote sensing equipment from Airyx, was installed in a vehicle from the Danish Road Traffic Authority. The new emission software directly indicates if the inspected vehicle is a low, suspicious or high emitter. So simple recommendations for inspections are provided. Measurements were carried out by the Danish Authority with support from Airyx on Danish highways and accompanied by Danish police cars to stop and inspect the selected HDV. Emission measurements could successfully be performed under all weather conditions ranging from warm, sunny and calm to cold, rainy and windy. No limitation on weather conditions for the plume chasing method could be observed. After a short measurement of 10 seconds in the plume (5 data points with CO_2 significantly above the prevailing CO_2 background) a first preliminary emission level is provided. If low emitters were identified, the measurement was usually stopped after a short measurement time to continue measuring on the next vehicle in order to increase the total number of measured HDVs. If the preliminary result indicated a suspicious or high emitter the measurement was continued for a longer period. An emission value is labelled as "valid" after 90 seconds (45 data points) of emission plume measurements are averaged (emission plume measurement is present if the CO_2 signal is min. 30ppm above the background concentration).

During the project in total NO_x emissions of 480 HDV were measured. 76% were identified as EURO VI, 20% EURO V and less than 4% the remaining EURO classes. Largest fraction was Danish (55%), followed by Polish (13%), German (9%) and Romanian (6%). The remaining HDV were mainly from other Eastern European countries. Similar to previous studies [2, 3, 6, 7, 8, 9], the derived emission values were classified to low emitters if they were below a certain limit. Different limits are applied for the different EURO classes, similar to previous studies (see Table 4). In this study, the HDV with average emission limits above the limit are further split to suspicious and if they are above a second limit as high emitters. In this study only 9,7% of the HDV were above the limit of suspicious + high emitters (6,3% and 3,4% respectively). This is almost a factor three lower than in the previous studies in Germany and Austria and indicate much lower fraction of high emitters in Denmark. HDV from Eastern European Union countries show a significant but not much higher fraction of high and suspicious emitters in comparison to the average. An analysis by brand indicate that all brands are affected with high emitters. For EURO VI MAN HDV show the highest ratio of suspicious or high emitters.

30 HDV with mainly suspicious or high emission limit were inspected. Two EURO V with emissions close to the limit of suspicious emitters were also inspected. Four were EURO III or IV HDV, so that 26 inspected EURO V and VI are further investigated. Six EURO V are labelled as potentially cold SCR with a still deactivated emission system (not a mal functioning system), as the HDV just entered the highway. They are first excluded in the analysis. Even if including them, just the fraction of cold SCR systems increases, but main conclusions remain:

- All the inspected HDV showed an error or deactivated emission cleaning system. Hence, **0% false positive rate** or a **100% hit rate** to find a high emitter with plume chasing
- For 67% of inspected HDV a defect or error was found
- For 24% of inspected HDV a manipulation was found
- For 10% of inspected HDV a cold SCR system was concluded as reason for the high emission
- High emitters with cold SCR were only observed for EURO V and not for EURO VI
- The two EURO V with an average emission limit of 2600 to 2700mg/kWh and thus below the set suspicious limit of 3.000mg/kWh were also identified as defective
- Manipulated HDV show in most cases very high emissions, while HDV with a defect or error often only have smaller emission increase.
- The current emission levels are likely to conservative and should be lowered for further studies

It was found that cold SCR systems for EURO V cannot completely be avoided even with longer measurement time. It is analysed how warm up can be identified on road in order to adapt and extend the measuring period and to reduce the effect of warm up on the final result. However, for some EURO V HDV under some circumstances with a low load and low engine power the SCR system does not reaches critical temperatures to operate normally. On the road these particular HDVs are often seen with a lifted back axle. This is currently the best recommendation to avoid these vehicles and thus avoid a high emitter inspection caused by a cold SCR system.

The data set of this project was used to further analyse the required plume chasing measurement duration. The aim was to reduce the measurement duration if possible to allow more measured vehicles in a certain time. Additionally, the limits to identify a defective or manipulated HDV are adapted so that all defective and manipulated vehicles are still identified while avoiding false classification as low emitters. We used the emission data of all measured HDV to estimate new thresholds and measurement duration (chapter 9). The concluded recommendations are compared to the parameters used in this study and are summarized in Table 1. The main results are:

- The limit to detect a high emitter should be lowered to 3.500mg/kWh and 2.200mg/kWh for EURO V and VI respectively
- The limit to detect a suspicious emitter should be lowered to 2.500mg/kWh and 1.200mg/kWh for EURO V and VI respectively
- The measurement duration to identify a high / suspicious emitter can be reduced to 60 seconds (time with plume signal)

- A measurement duration of 15 seconds is sufficient to identify a low emitter if its emissions are low (below limit for suspicious emitter). In this case a longer measurement is not needed, as a high emitter can very likely be excluded.

That means, a short measurement is sufficient to identify a low emitter (15 seconds), but a longer measurement (min. 60 seconds) is needed to reliable identify high (and suspicious) emitters. If an HDV shows emission not clearly classified as low or high, a longer measurement should be performed.

	used this study		**recommended**	
Classification	**EURO V**	**EURO VI**	**EURO V**	**EURO VI**
suspicious [mg/kWh]	>3.000	>1.400	>2.500	>1.200
high [mg/kWh]	>4.000	>2.400	>3.500	>2.200
Measurement duration for a valid emission classification of a high and suspicious emitter	90 s		60 s	
Measurement duration for a preliminary emission value to exclude a high emitter	10 s		15 s	

Table 1: Defined thresholds (limits) in this study and recommended new limits (main parameters).

Færdselsstyrelsen

2 Introduction

2.1 Background for the project

The project is a part of the Danish initiative on developing an efficient control with emissions system used on heavy-duty vehicle (HDV). This project is the direct continuation of the project “Plume Chasing – A way to detect high NOx emitting vehicles” conducted in 2019 by AVL and Danish Road Traffic Authority [1]. This report summarises an extended study where the full potential of the equipment is investigated for reliable high emitter HDV detection. For background information and technical introduction of the measurement method it is referred to the previous report from [1].

2.2 The content of the project

The two main objectives are: to share and increase competencies for people involved in the control effort and to evaluate the practical applicability of the plume chasing mobile remote sensing equipment from Airyx. The project is carried out as a collaboration between the Danish Road Traffic Authority, the Danish National Police and Airyx. Airyx provided and installed the complete “Plume Chasing” NOx vehicle emission measurement system in a vehicle from the Danish Road Traffic Authority. A sufficient training of Danish operators was provided in order to operate the equipment without on-site support from Airyx. In the first part Airyx supported the Danish authorities in performing NOx HDV emission measurements. In the second part the authorities performed the measurements independently. The measurements were performed in a way so the high emitters could be selected for further inspections by the police.

The project brings together high emitter detection with the remote plume chasing method and further detailed inspections. One of the goals was to investigate if inspections can effectively be supported using this measurement method. The emission limits to detect an inactive / defective emission system are investigated. Also a deeper study on the required measurement duration (time) to reliable detect a high emitter is performed.

3 Method

The plume chasing measurement system from Airyx is used in this study. The method is described in detail in other reports [1, 2, 3, 4, 5, 6] and we here only refer to the general principle and differences to previous studies.

3.1 Basic principle

Plume chasing measurements are performed by following a vehicle and measuring in the diluted exhaust plume, enabling the calculations of its emissions (here we focus on NO_x emissions). The fundamental principle is that the ratio between NO_x and CO_2 does not change, no matter how much the exhaust gas is diluted. Background concentrations of NO_x and CO_2 (outside the investigated plume) need to be corrected for. Specific NO_x emissions (in g/kWh) are calculated from the measured ratio applying an estimated engine efficiency of 40% for the relationship between emitted CO_2 and engine power.

A valid plume signal is defined by a CO_2 signal of min. 30ppm above the background concentration which is also retrieved from the plume chasing data from periods where no vehicle is monitored. Only these valid data points are used to derive NO_x emission values of HDVs.

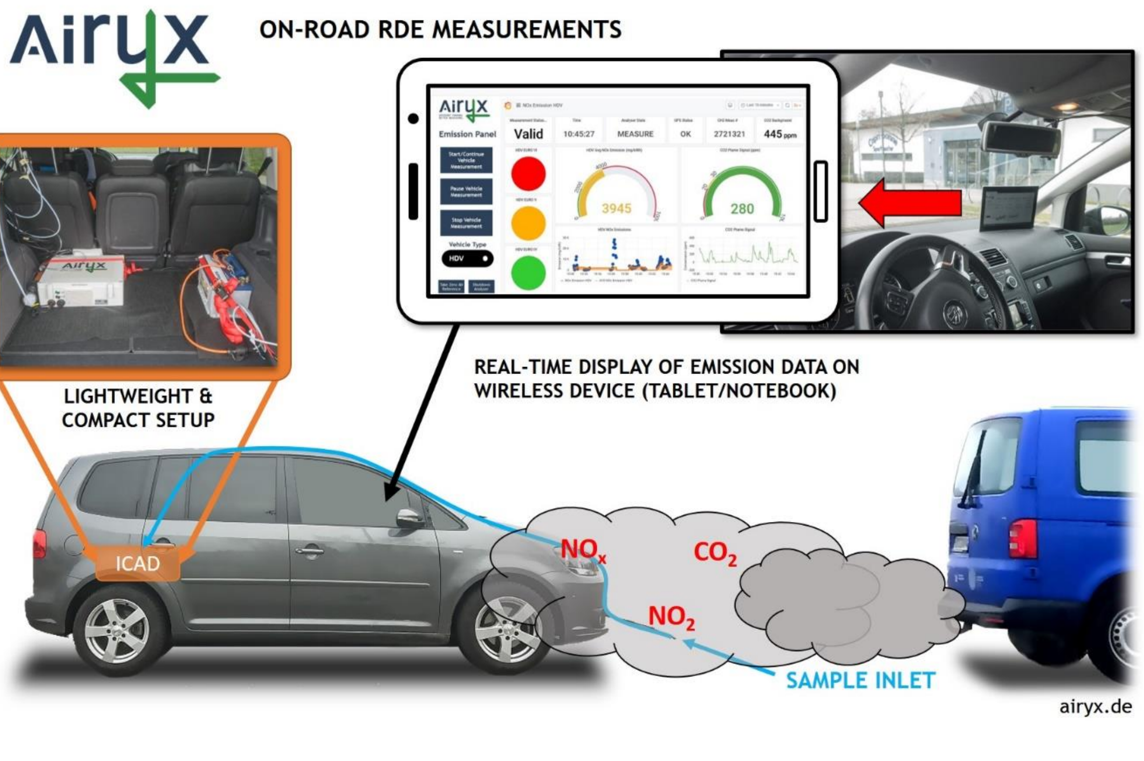


Figure 1: Basic sketch of plume chasing measurement principle from Airyx GmbH. The diluted exhaust gases are sampled and analysed. Different gases are measured with the ICAD instrument. From the ratio of the gases, emission factors of the followed vehicle are derived.

3.2 Chasing vehicle setup

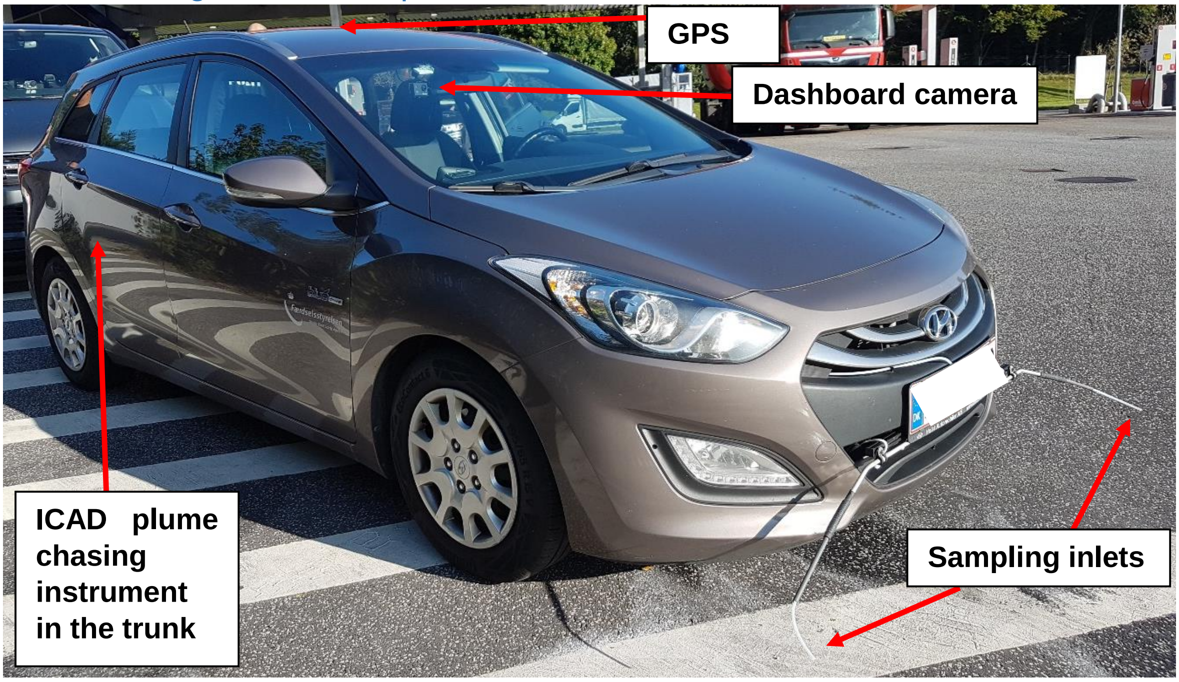


Figure 2: Plume chasing installation on the Danish authority car (outside view). Two sampling inlets are combined to one sampling hose to the ICAD plume chasing instrument in the trunk.

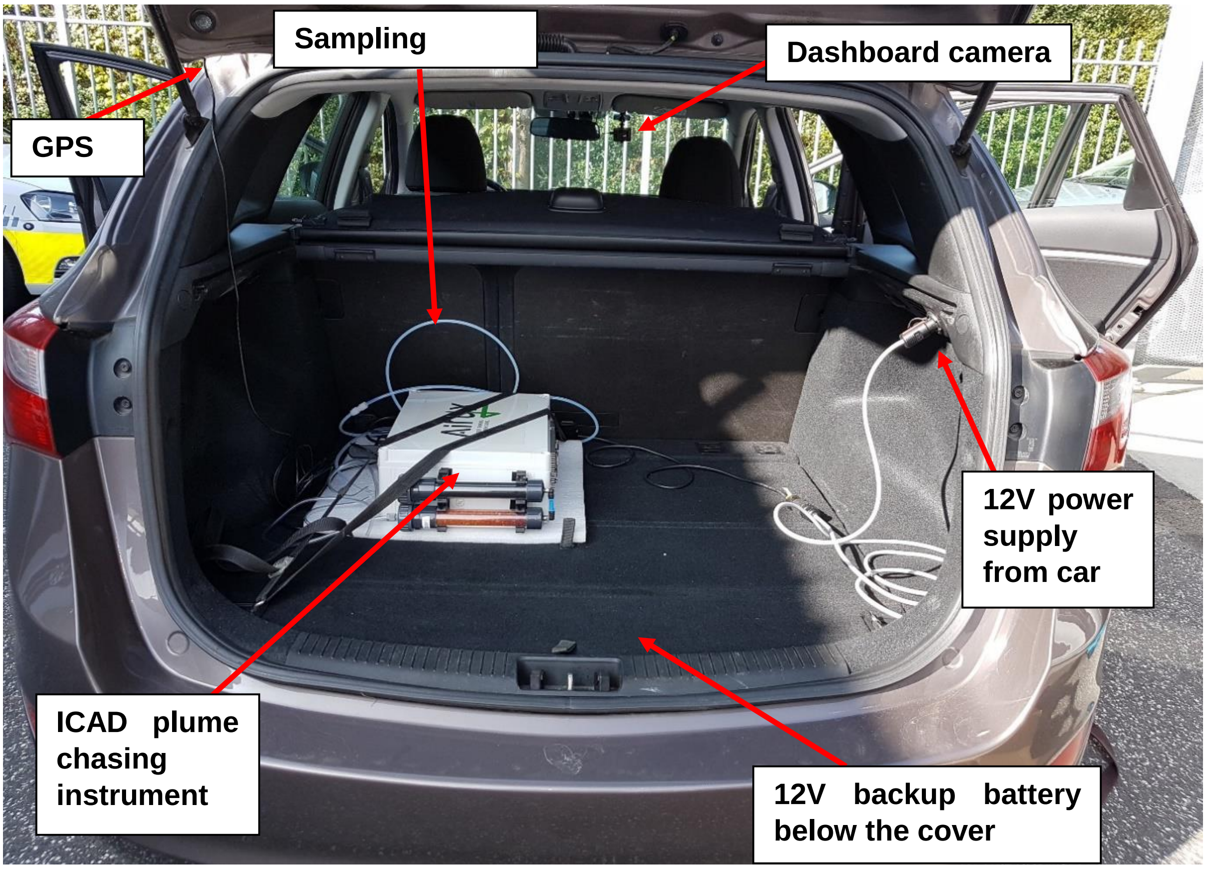


Figure 3: Plume chasing installation in the trunk of the Danish authority car. The sampling hose is guided through the cabin to the ICAD plume chasing instrument. The instrument is powered from the car 12V. A small 12V backup battery allow an interruption free instrument operation when the vehicle is shut off.

A Hyundai passenger car from Danish Road Traffic Authority was used as chasing vehicle. The setup could be installed within less than 3 hours.

Figure 2 shows the installation on the chasing vehicle. An aluminium construction mounted to the front bumper holds the sampling inlets. Two sampling inlets are installed on a flexible tubing to avoid injuries. Sampling hoses are made from 6mm PTFE. Different to the previous study [1], both inlets are merged to one sampling line. This allows a more reliable measurement of the plume independent of the exhaust location of the monitored vehicle and as well as meteorological effects like side winds. Also, the manual switching between the inlets during the measurements can be avoided. Disadvantage are possible slightly lower measurement signals but are so far not observed as a limitation.

The sampling hose is going through the motor compartment inside the car and then through the passenger cabin to the ICAD plume chasing instrument in the trunk. The total sampling hose length is ~6m.

The power consumption of the ICAD NO_x/CO_2 monitor is with 30W at 12V (max. 100W) low enough to be operated directly from the 12V outlet of the vehicle. Figure 3 shows the installation inside the trunk. To avoid voltage drops and to have a backup when the vehicle is switched off, a 12V backup battery was used.

Figure 4: Display installation in the cockpit. A tablet is used as display of the real time data connected via WiFi to the ICAD instrument. It allows operation and visualisation.

A GPS records the measurement locations and driving speed but is not necessarily needed for the measurements. A dashboard camera is mainly used for post-processing and documentation. By using the pictures, it is possible to check the measurement circumstances and other traffic conditions. The camera is not needed for the real time data analysis.

To visualise the emission results during the plume chasing measurements a display is installed in the cockpit also working as the user interface. Therefore, a tablet is used, connected via WiFi to the ICAD. Also other laptops and tablets could connect to the ICAD at the same time, so that multiple users can directly see the current measurements. Details on the display and user interface are described in section 3.3.

The ICAD instrument has a start-up time of <1min. At colder temperatures, it may need up to 15min to heat up to the minimum temperature of 25°C before measurements start. In this project the plume chasing car with the instrument was parked outside over night with temperatures often below 5°C. Therefore, a warmup of ~10 minutes was required in the morning.

The measurement configuration of an inspected HDV with the chasing vehicle in the exhaust plume is illustrated on the front picture of the report.

3.3 Emission software v2.0

The new plume chasing emission software v2.0 developed in the EU CARES project was applied in this study. It also containing improvements suggested from the study [1]:

- It provides a clear indication of high / suspicious / low emitter (for classification limits see chapter 6.1)
- The emission values are from the sampling simultaneously on the left and right side and no switching is needed.
- The software derives the background concentration of NO_x and CO_2 automatically.
- An average emission value is directly calculated between pressing “Start” and “Stop” of an individual emission measurement.

The new display is described in Figure 5.

The new software provides a simple operation during emission measurements with display of the most relevant parameters. Measurements of an individual vehicle are started with pressing “Start”. The “Measurement Status” indicate the status, first indicating “Acquiring” the first emission data are averaged. A “Prelim.” = preliminary result is provided after the first 5 valid measurement data points (10 seconds of data). If sufficient data points are collected (45 data points = 90 seconds) a “Valid” status is indicated. The measurement of an individual vehicle is ended by pressing “Stop”. The emission value is simple illustrated by a 3 step traffic light. Each light is for a EURO VI, V and IV and different due to different emission limits. The three colour indicate a clearly “high” (red) emitter, “suspicious” (orange) and “low” (green) emitter and thus make easy decisions for further inspections.

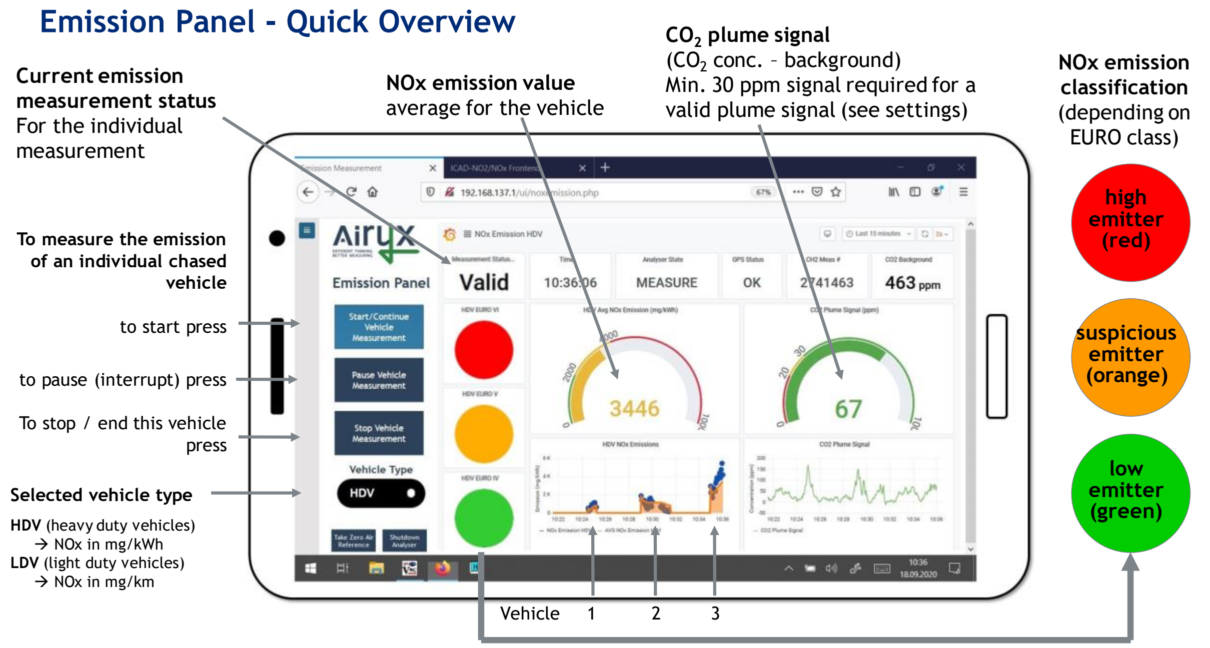


Figure 5: Emission display like visualised during measurements in the screen including explanations.

The fast indication of a preliminary result should help to focus on the high and suspicious emitters while the measurement of a preliminary low emitter may be aborted.

For each individual measured vehicle the average emission value is saved in a daily file.

3.4 Performing emission measurements

The measurements were performed on the Danish highways between 17th September and 1st October 2020. The plume chasing car followed different HDV as indicated in Figure 6. Additional police cars were accompanying the measurements and stop HDV for further inspections.

When the plume chasing car was behind a HDV the measurement was started by pressing “Start”. The CO_2 plume signal indicated if a sufficient signal from the exhaust plume is detected. Only measurement data points with min. 30ppm CO_2 above the derived background are considered as valid measurement signals = valid data points. During some driving situation no emission plume is present like deceleration, downhill or at strong side winds. The chasing vehicle followed until a sufficient signal is observed. After the first 5 valid data points (= 10 seconds) a preliminary emission value is indicated. If this indicates a low emitter (<1400mg/kWh), in most cases the measurement was stopped as it can be expected that this HDV will be a low emitter. Only for additional research purposes (chapter 9) sometimes the measurement was continued. If the emission value indicated a suspicious or high emitter, the measurement was continued until a valid emission value (after 45 valid data points = 90 seconds) was indicated.

The measurement was then stopped by pressing “Stop”, and the HDV was overtaken to record vehicle type, number plate and derive EURO class (from labels). To classify the EURO class also number plate and vehicle type are used. In some cases, the EURO class was already investigated by the additional police car.

Figure 6: Picture inside the plume chasing vehicle during measurements.

From the emission classification and the EURO class of the HDV it was then decided if the HDV was inspected by the police. The plume chasing car also stopped during the inspection. This limits the total number of measured HDVs per day as inspections could least several hours.

Due to logistical reasons not all HDV with suspicious or high emission level could be inspected.

Measurements were performed on 11 days. Weather conditions were very different ranging from warm, sunny and calm to cold, rainy and windy. During all weather conditions plume chasing emission measurements were performed successfully. No difficulties were observed during stronger rain. On days with stronger wind a weaker emission signal was observed, but still measurements could be performed.

4 Inspection

Inspections were performed by Danish police officers trained and experienced in detection of emission system defects or manipulations. Dedicated inspection tools were applied to identify the reason for the high emission level. The results of the inspection are used in this report.

Figure 7: Example of inspection by Danish police officers.

5 Statistics measured HDV

In total emission measurements of 480 HDV were performed. Measurements with less than 5 valid data points (<10 seconds), or where no information of the HDV obtained, are excluded.

5.1 Emission EURO classes

The largest fraction of the HDV are with 76%, EURO VI vehicles. 20% are EURO V and less than 4 % are older vehicles. Of 478, and thus almost all HDV a EURO class could be estimated.

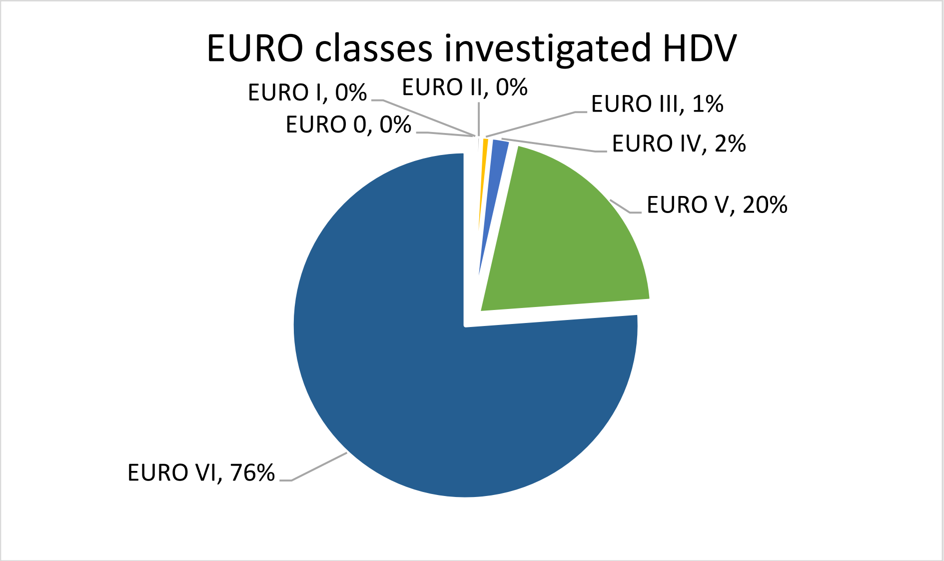


Figure 8: Distribution of EURO emission class between the measured HDV in percent.

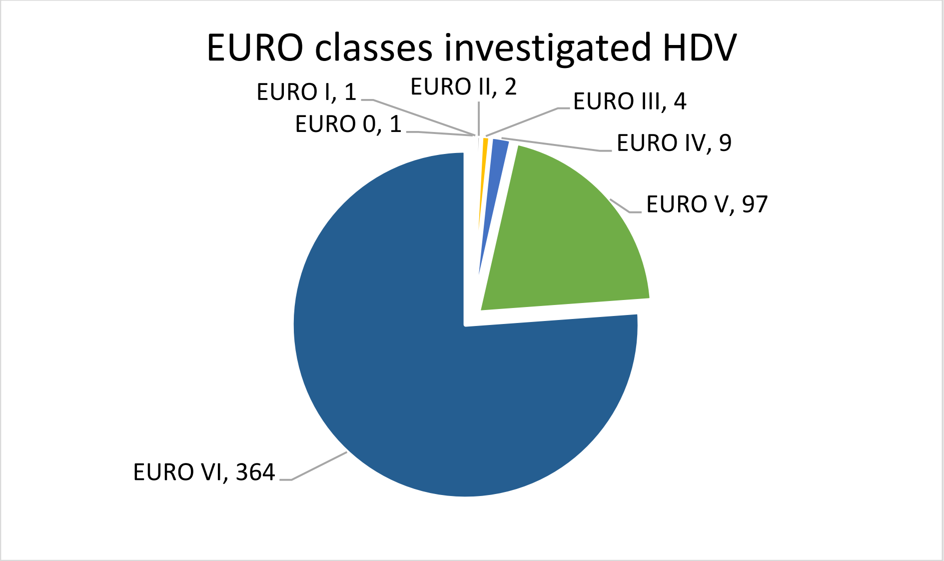


Figure 9: Distribution of EURO emission class between the measured HDV in absolute numbers.

Emission norm	No#	percentage
EURO 0	1	0,2%
EURO I	1	0,2%
EURO II	2	0,4%
EURO III	4	0,8%
EURO IV	9	1,7%
EURO V	97	17,8%
EURO VI	364	69,5%
Sum	**478**	

Table 2: EURO class of measured HDV

5.2 Country of origin

For 464 HDV a country of origin was read from the number plate. In some cases, the number plate could not be read. The largest group are Danish (55%) followed by Polish (13%), German (9%) and Romanian (6%) HDV.

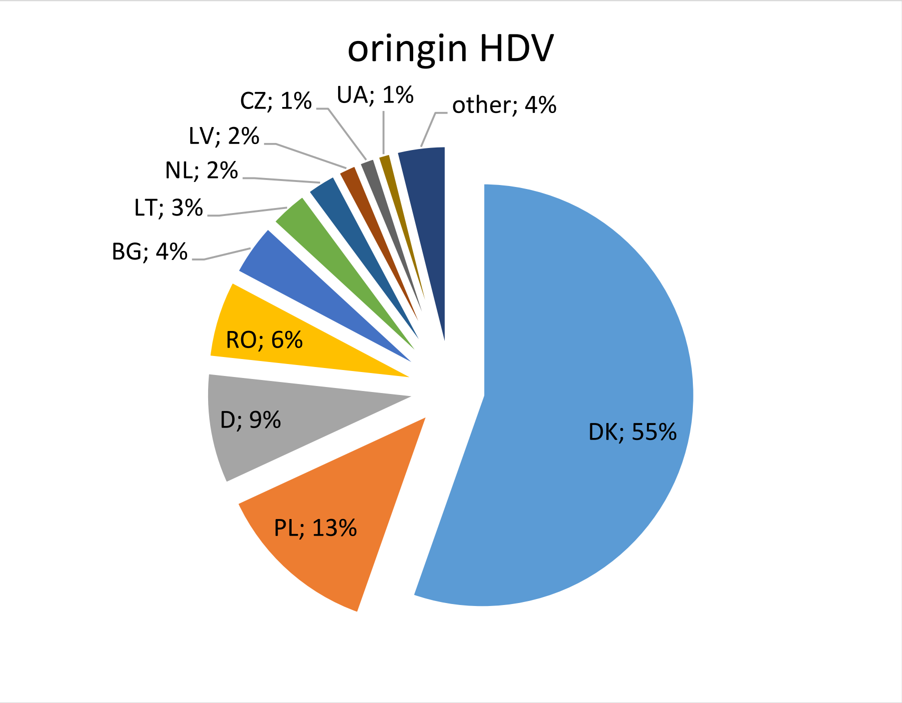


Figure 10: Distribution of origin of the measured HDV in percent.

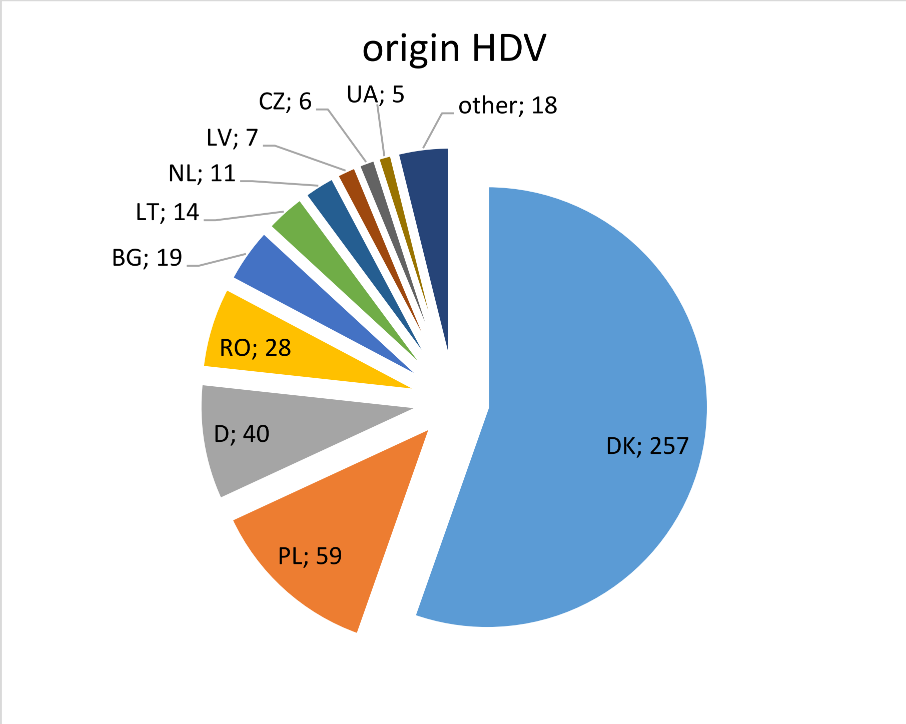


Figure 11: Distribution of origin of the measured HDV in absolute numbers.

origin HDV (sorted by percentage)	No#	percentage
DK	257	55,4%
PL	59	12,7%
D	40	8,6%
RO	28	6,0%
BG	19	4,1%
LT	14	3,0%
NL	11	2,4%
LV	7	1,5%
CZ	6	1,3%
UA	5	1,1%
SLO	3	0,6%
H	2	0,4%
HR	2	0,4%
SK	2	0,4%
EST	2	0,4%
SRB	2	0,4%
FIN	1	0,2%
N	1	0,2%
E	1	0,2%
MK	1	0,2%
RUS	1	0,2%
Sum	**464**	

Table 3: Country of origin of measured HDV. The country indicated is from the truck not the trailer.

5.3 Ratio of "preliminary" and "valid" measurements

A "valid" emission value is based on measurement of 45 data points equivalent to 90 seconds of data (see chapter 3.3). It is indicated by the software as a "valid" and reliable emission value. A shorter measurement with min. 5 data points = 10 seconds of data, still provides an emission value and is indicated as "prelim." = preliminary emission value. If a suspicious or high emission is observed, collection of data for a "valid" measurement is recommended as a low emitter can also have for short times a high emission. This avoids wrong classification due to emission variation.

For a low emitter a preliminary measurement is expected to be sufficient. The percentage of preliminary measurements is with 85% high as a large fraction of HDV showed low emission values and measurements were stopped before a valid value was achieved. If not otherwise stated, the results from preliminary plus valid measurements are used in the following chapters.

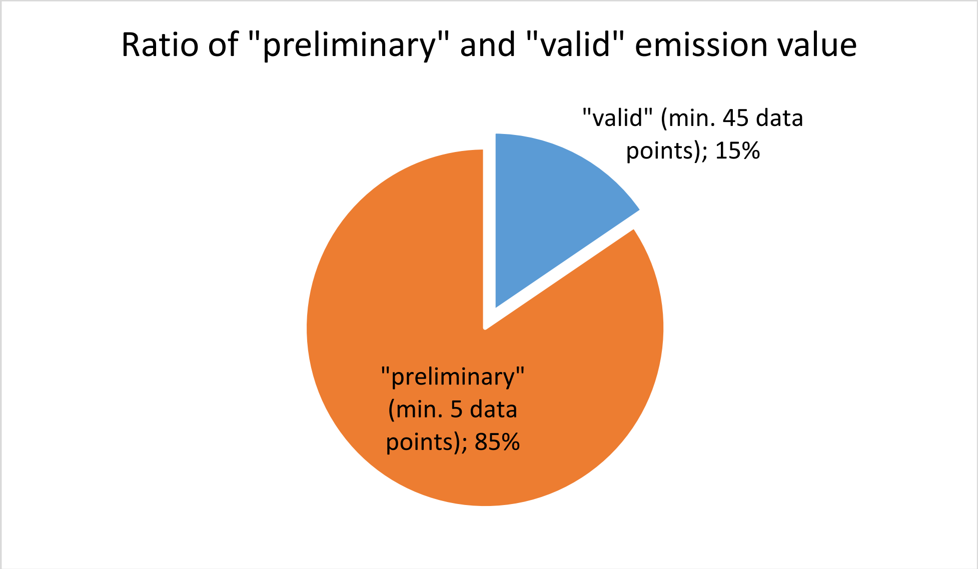


Figure 12: Ratio of measurements with a "preliminary" emission value (min. 5 data points) and a "valid" emission value (min. 45 data points).

6 Emission values

6.1 Classification of emission limits

To identify a suspicious or a high emitter a margin to the EURO norm emission limit is added. The limits are similar to previous studies [2, 3, 6, 7, 8, 9]. The quantification of these thresholds is further investigated with the measurement data in chapter 9.

	EURO III	**EURO IV**	**EURO V**	**EURO VI**
Classification	mg/kWh	mg/kWh	mg/kWh	mg/kWh
low	≤6000	≤4500	≤3000	≤1400
suspicious	>6000	>4500	>3000	>1400
high	>7000	>5500	>4000	>2400
EURO emission limit	≤5000	≤3500	≤2000	≤460
RDE conformity factor	-	-	-	1,5
EURO RDE emission limit	-	-	-	≤690

Table 4: Defined thresholds for emission classification used in this study.

6.2 Emission statistics

The derived emission values of each HDV are classified according to chapter 6.1. 90,3% are classified as low emitters. 6,3% of HDV is found to be suspicious, and 3,4% clearly as high emitters. The ratio of suspicious and high emitters is almost a factor of 3 lower than in previous studies in Germany and Austria [2, 3, 6, 7, 8, 9].

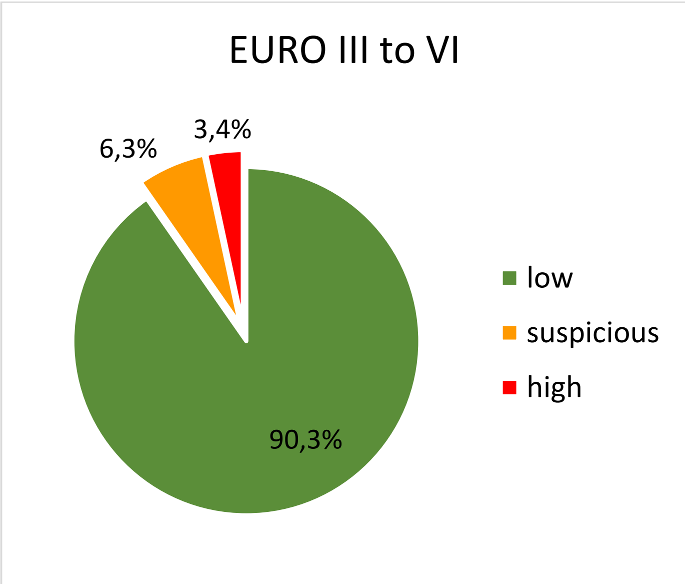


Figure 13: Statistics of emission classification.

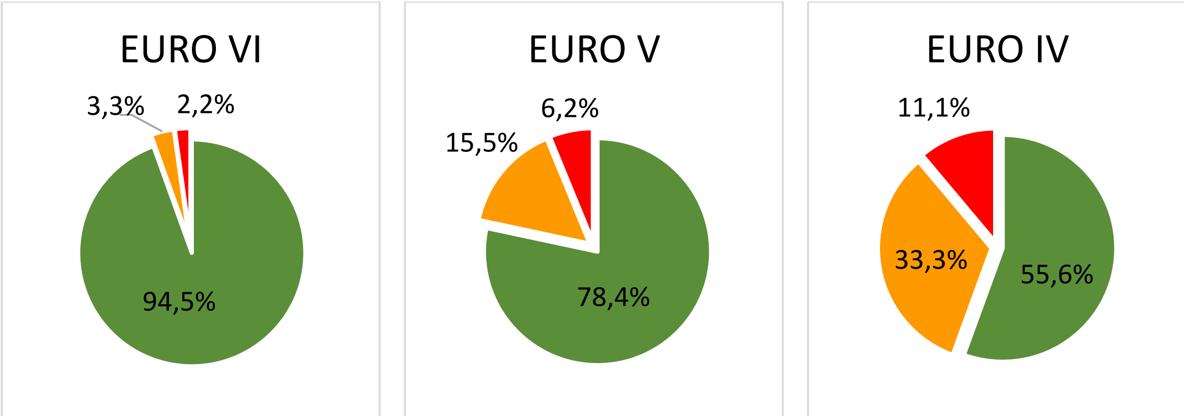


Figure 14: Statistics of emission classification separated for the EURO class.

Emission statistics	EURO III	EURO IV	EURO V	EURO VI	All
low	3	5	76	344	428
suspicious	0	3	15	12	30
high	1	1	6	8	16
low [%]	75,0%	55,6%	78,4%	94,5%	90,3%
suspicious [%]	0,0%	33,3%	15,5%	3,3%	6,3%
high [%]	25,0%	11,1%	6,2%	2,2%	3,4%

Table 5: Statistics of emission classification. First total numbers, and below in percent.

The separation for the different EURO classes indicate lowest ratio of suspicious and high emitters for EURO VI. EURO IV show relatively high ratios, however it should be considered that the number of measured EURO IV HDV is low (Table 5) and these are quite old HDV with high mileage where the emission system may not work properly any more.

The ratio of suspicious and high emitters for EURO V is significant higher than for EURO VI.

6.3 Analysis by country – Denmark

Same analysis like in chapter 6.2 is performed only for the Danish HDV. Slightly lower suspicious and high emitters for EURO VI but slightly higher amount for EURO V are observed, which may be caused due to a higher probability of EURO V cold engines due to local transport (see chapter 0).

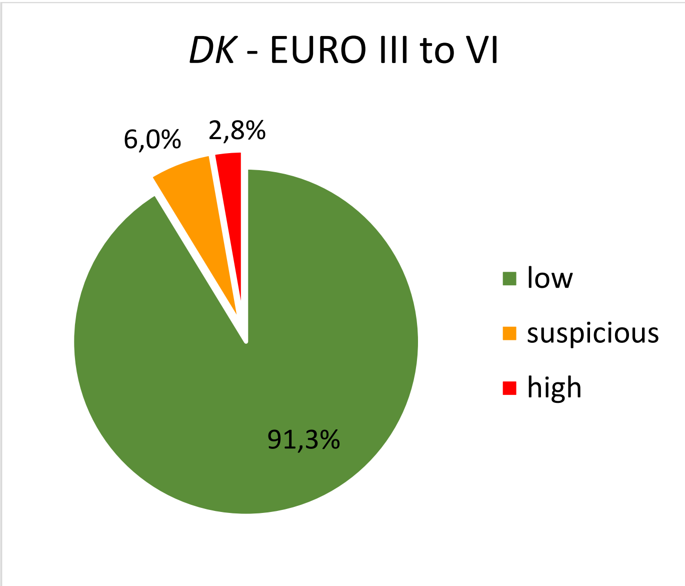


Figure 15: Statistics of emission classification only for Danish HDV.

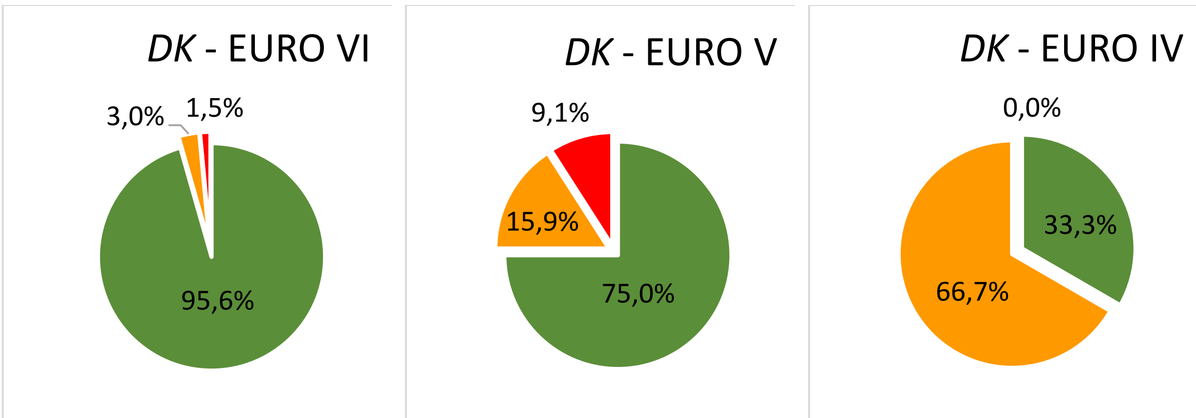


Figure 16: Statistics of emission classification separated for the EURO class only for Danish HDV.

Emission statistics - DK	**EURO III**	**EURO IV**	**EURO V**	**EURO VI**	**All**
low	2	1	33	194	230
suspicious	0	2	7	6	15
high	0	0	4	3	7
low [%]	100,0%	33,3%	75,0%	95,6%	91,3%
suspicious [%]	0,0%	66,7%	15,9%	3,0%	6,0%
high [%]	0,0%	0,0%	9,1%	1,5%	2,8%

Table 6: Statistics of emission classification only for Danish HDV. First total numbers, and below in percent.

6.4 Analysis by country – Poland

Same analysis like in chapter 6.2 is performed only for the Polish HDV. Slightly higher amount of EURO VI high emitters, but less suspicious emitters are observed. In general, HDV from Poland do not show a significant higher amount of high emitters in this study.

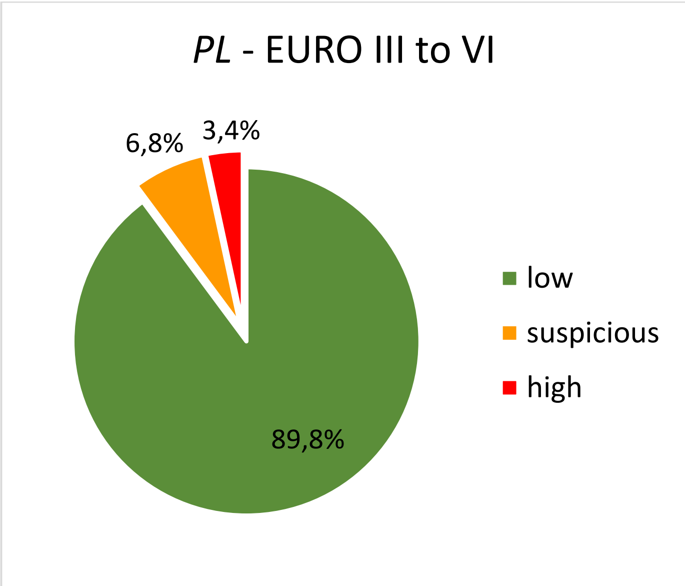
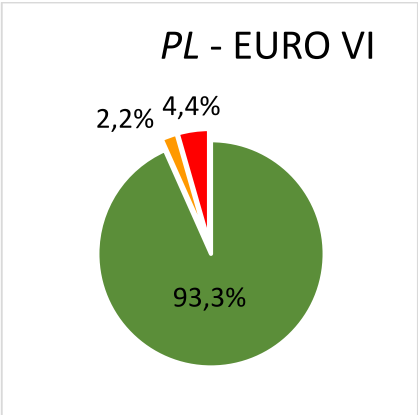


Figure 17: Statistics of emission classification only for Polish HDV.



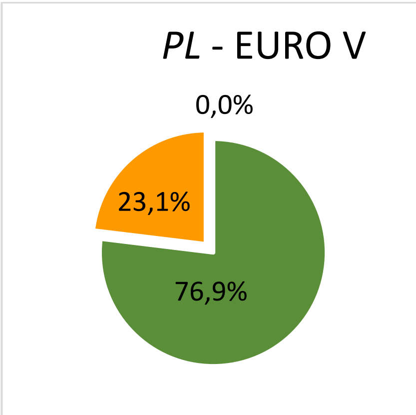


Figure 18: Statistics of emission classification separated for the EURO class only for Polish HDV.

Emission statistics - PL	EURO III	EURO IV	EURO V	EURO VI	All
low	1	0	10	42	53
suspicious	0	0	3	1	4
high	0	0	0	2	2
low [%]	100,0%	0,0%	76,9%	93,3%	89,8%
suspicious [%]	0,0%	0,0%	23,1%	2,2%	6,8%
high [%]	0,0%	0,0%	0,0%	4,4%	3,4%

Table 7: Statistics of emission classification only for Polish HDV. First total numbers, and below in percent.

6.5 Analysis by country – German

Same analysis like in chapter 6.2 is performed only for the German HDV. No clear high emitter between German HDV was observed and a small amount of suspicious EURO VI HDV.

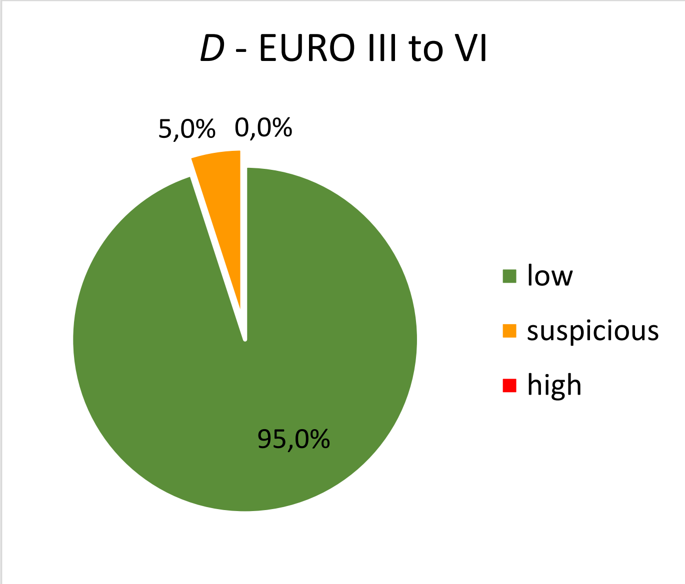


Figure 19: Statistics of emission classification only for German HDV.

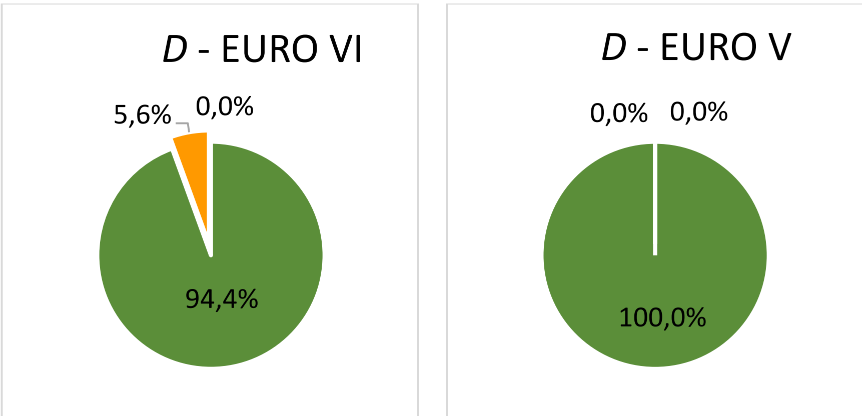


Figure 20: Statistics of emission classification separated for the EURO class only for German HDV.

Emission statistics - PL	EURO III	EURO IV	EURO V	EURO VI	All
low	0	0	4	34	38
suspicious	0	0	0	2	2
high	0	0	0	0	0
low [%]	0,0%	0,0%	100,0%	94,4%	95,0%
suspicious [%]	0,0%	0,0%	0,0%	5,6%	5,0%
high [%]	0,0%	0,0%	0,0%	0,0%	0,0%

Table 8: Statistics of emission classification only for German HDV. First total numbers, and below in percent.

6.6 Analysis by country – remaining eastern EU countries (RO, BG, H, SLO, HR, CZ, SK, LT, LV, EST)

Same analysis like in chapter 6.2 is performed for the HDV of the remaining eastern European Union (EU) countries. As each group is too small to perform an own sufficient statistic, the countries are treated as one group.

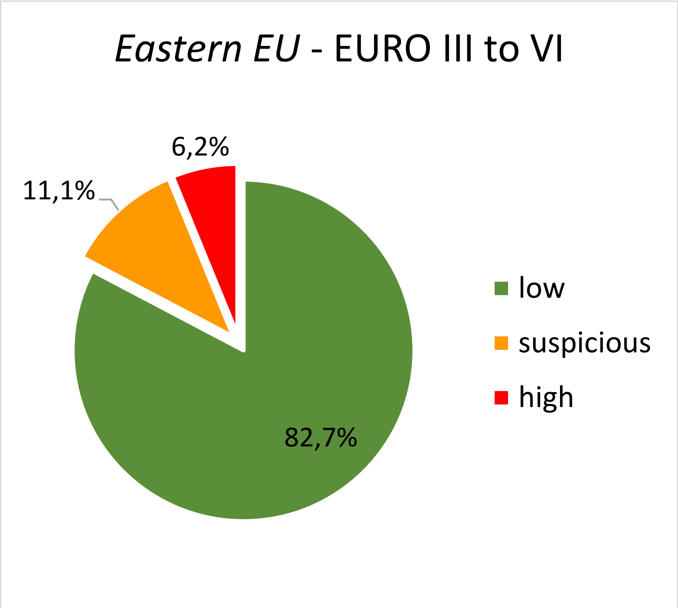


Figure 21: Statistics of emission classification only for the sum of the remaining eastern EU countries (RO, BG, H, SLO, HR, CZ, SK, LT, LV, EST).

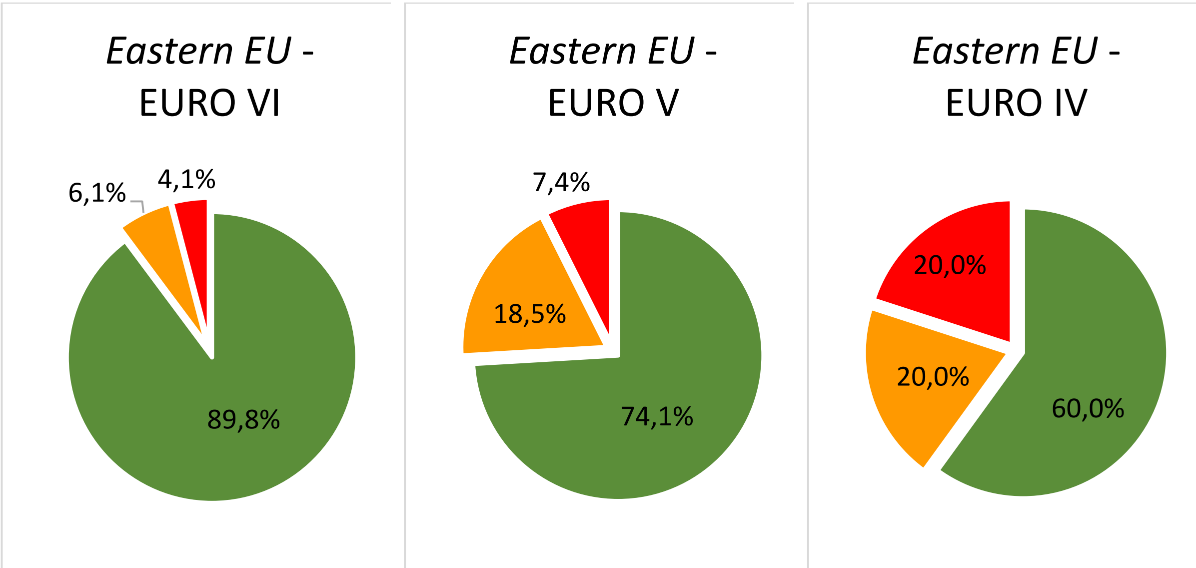


Figure 22: Statistics of emission classification separated for the EURO class only for the sum of the remaining eastern EU countries (RO, BG, H, SLO, HR, CZ, SK, LT, LV, EST).

Emission statistics – Eastern Europe	EURO III	EURO IV	EURO V	EURO VI	All
low	0	3	20	44	67
suspicious	0	1	5	3	9
high	0	1	2	2	5

low [%]	0,0%	60,0%	74,1%	89,8%	82,7%
suspicious [%]	0,0%	20,0%	18,5%	6,1%	11,1%
high [%]	0,0%	20,0%	7,4%	4,1%	6,2%

Table 9: Statistics of emission classification only for the sum of the remaining eastern EU countries (RO, BG, H, SLO, HR, CZ, SK, LT, LV, EST). First total numbers, and below in percent.

In this group a slightly higher amount of high and suspicious emitters is observed. The higher amount in this group is in agreement to previous studies [7], but still with a lower total amount. For EURO IV the statistic is very low and should not be over-interpreted. But for EURO VI and EURO V a clearly higher amount of suspicious and high emitters is observed than for the average.

6.7 Analysis by brand

The analysis by brand show that for all brands suspicious and high emitters are observed (Table 10). For Iveco and Renault and for Mercedes EURO V, the relative percentage is not representative due to the low number. DAF, Scania and Volvo indicate relatively high percentage of suspicious and high emitters for EURO V. This is also as these brands are especially affected by cold SCR systems for EURO V (see chapter 8.2). Scania has the highest amount of EURO V with suspicious and high emissions (35%), but seem to perform best for the EURO VI (3%). MAN is the opposite way. While the fraction of suspicious and high emitting HDV for the EURO V is low (0%), the ration for EURO VI is the highest with 11%.

Brand	total measured		suspicious and high emitters		percentage	
	EURO V	**EURO VI**	**EURO V**	**EURO VI**	**EURO V**	**EURO VI**
DAF	16	39	4	2	25%	5%
IVECO	4	10	2	1	50%	10%
MAN	17	57	0	6	0%	11%
Mercedes	3	60	0	3	0%	5%
Renault	3	13	0	1	0%	8%
Scania	23	88	8	3	35%	3%
Volvo	26	82	7	4	27%	5%

Table 10: Separation by brand of HDV. First the totally measured HDV per brand and EURO class. In the following columns the number of the HDV with suspicious and high emission values.

6.8 Histograms of emissions

To study the distribution of the emission values, histograms are plotted in Figure 23, Figure 24 and Figure 25. Clearly most of the HDV show low emissions below 1000mg/kWh. Still a significant fraction of HDV with values above 3000mg/kWh is observed.

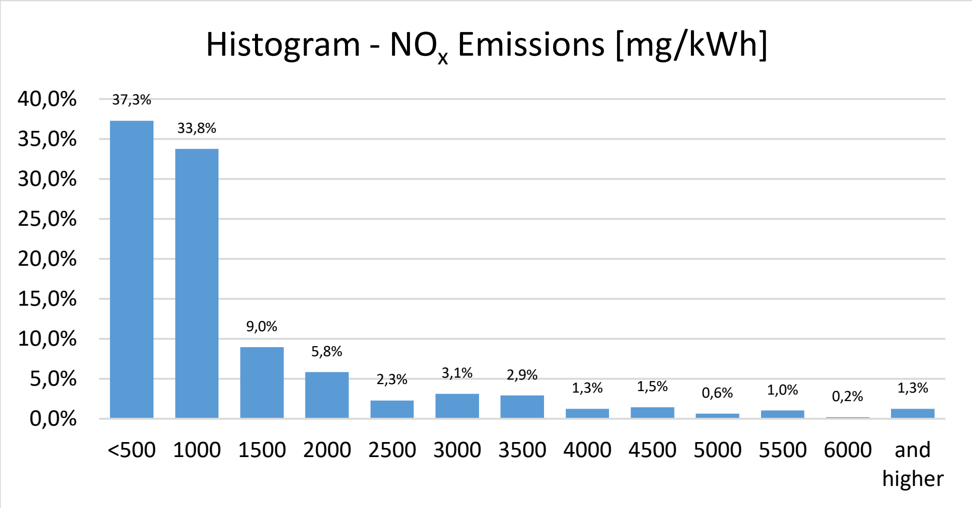


Figure 23: Histogram of observed emissions for all HDV.

When studying only EURO VI HDV, in general lower emission values are observed (Figure 24). A large fraction is within the EURO Norm for real driving emissions (RDE) of 690mg/kWh. Most HDV are still within 1000mg/kWh. From the histogram a lower threshold of 1000mg/kWh for a suspicious emitter seem to be reasonable.

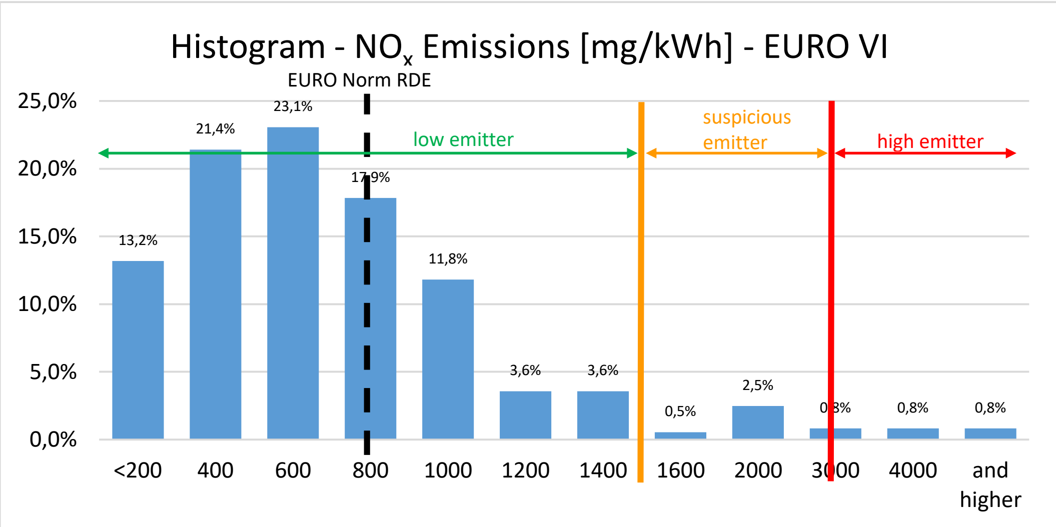


Figure 24: Histogram of observed emissions for EURO VI HDV.

A similar plot only for the EURO V is shown in Figure 25. The distribution indicates a strong decrease above 3500mg/kWh. However, EURO V HDV are more affected by cold engines which may overlay.

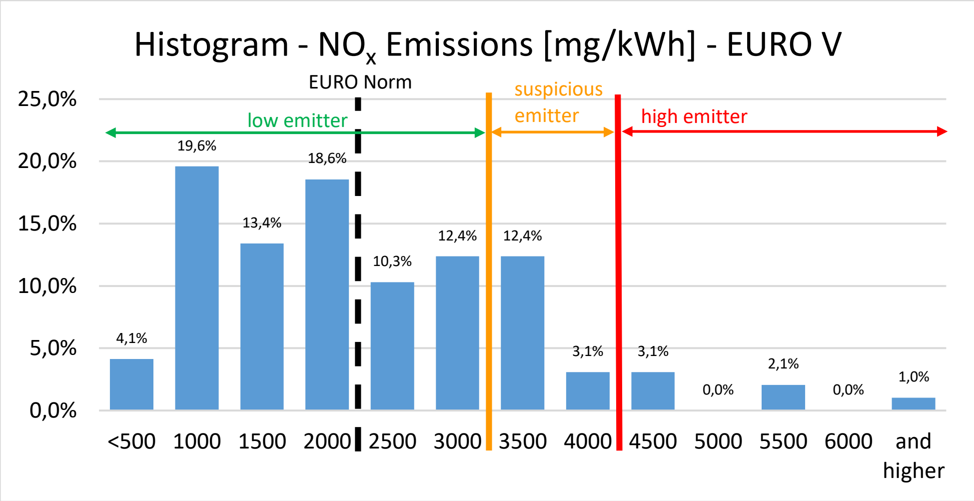


Figure 25: Histogram of observed emissions for EURO V HDV.

If the set thresholds for suspicious and high emitter are properly selected is further analysed in chapter 9.5.

7 Inspections

In total 30 HDV with mostly high or suspicious emission levels were inspected and inspection results are available. Six (all EURO V) were indicated as “expected” cold SCR / cold engine as the truck just entered the highway. Inspections were still performed to validate if the higher emission value arise due to a cold non full working SCR.

For ten HDV only a shorter preliminary emission measurement was achieved (less than 45 data points = less than 90 seconds data) before the truck was inspected. A longer measurement was sometimes not possible due to logistical reasons.

7.1 Emissions of inspected HDV

The emission classification of the inspected HDV is shown below. Also HDV classified as low emitters were partly investigated. The reason is that some were just identified as older HDV after they were stopped for inspection and are thus classified for the older EURO class as a low emitter. Also it happened that the emission limit was close to the limit and an inspection was still decided.

	EURO III	EURO IV	EURO V	EURO VI	sum
low	2	1	3	0	6
suspicious	0	1	8	2	11
high	0	0	5	8	13
sum	**2**	**2**	**16**	**10**	**30**
HDV with expected cold SCR	0	0	6	0	6

low [%]	100%	50%	19%	0%	20%
suspicious [%]	0%	50%	50%	20%	37%
high [%]	0%	0%	31%	80%	43%

HDV with expected cold SCR	0%	0%	38%	0%	20%

Table 11: Emission classification of the inspected HDV.

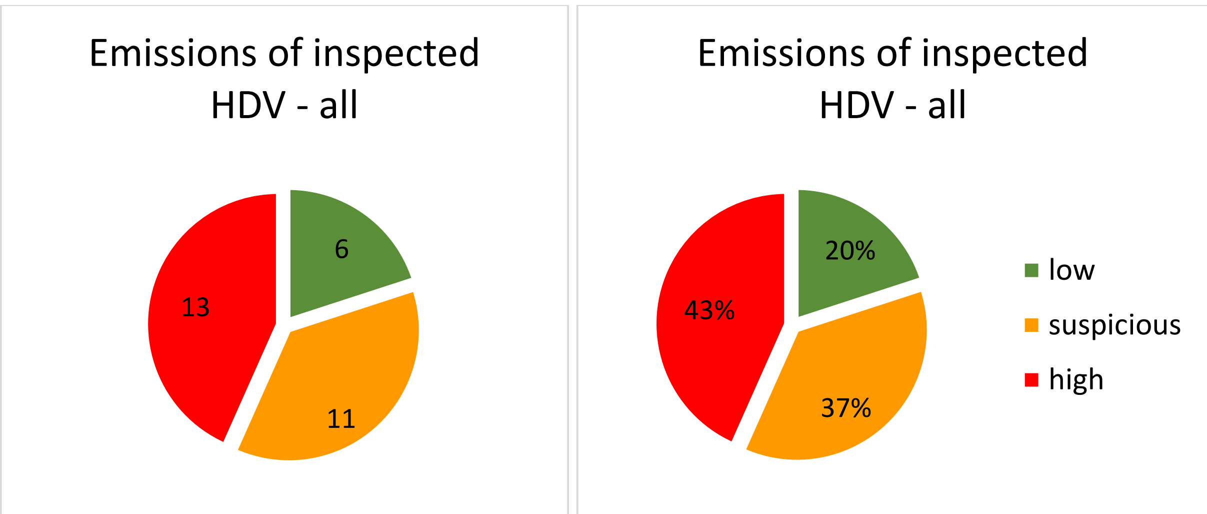


Figure 26: Emission classification of the inspected HDV. Left total number, right percentage.

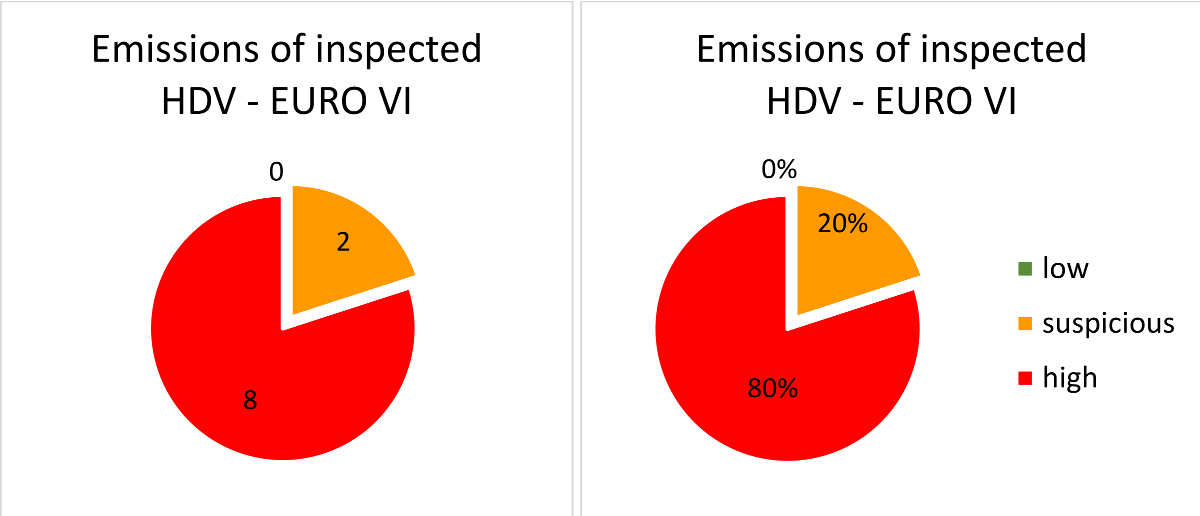


Figure 27: Emission classification of the inspected EURO VI HDV. Left total number, right percentage.

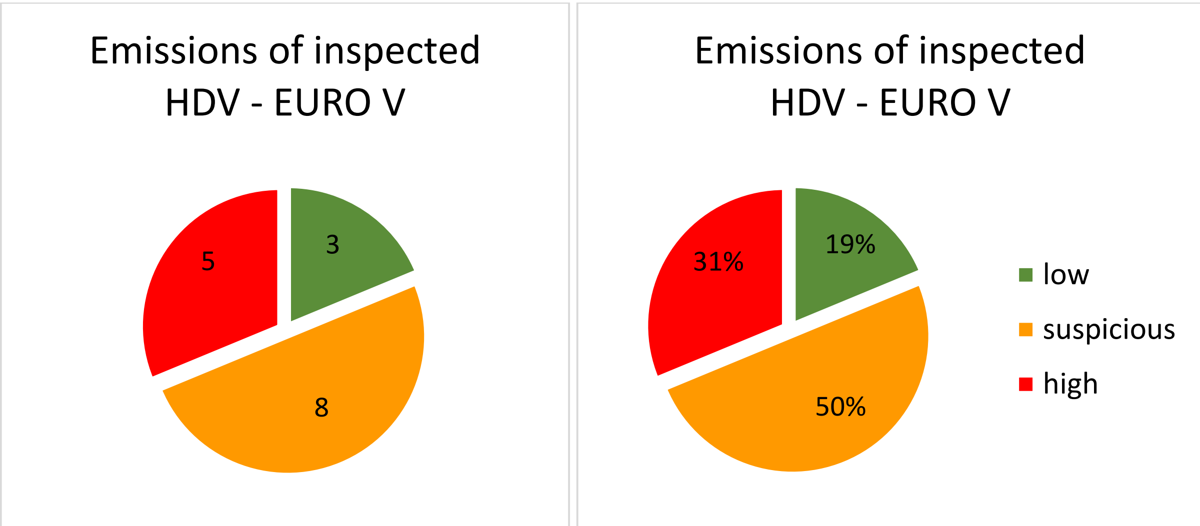


Figure 28: Emission classification of the inspected EURO V HDV. Left total number, right percentage.

7.2 Conclusions inspections (excluding expected cold SCR HDV)

In this chapter the conclusion of the inspected HDV is summarised. The expected cold SCR HDV (six EURO V) are excluded as they would typically not be inspected.

The conclusion of the inspection has four categories: no error, a defect / error, manipulation (emulator, software, temp. sensor, NO_x sensor de-activation) and a cold SCR. The cold SCR indicates, in principle, also not an error of the HDV, but still a correct estimation of a high emission by the plume chasing method and high emissions caused by an emission reduction system in an inactive state. Additional the cold SCR can relatively simple be investigated during the inspection. Strategies how to avoid cold SCR are investigated in chapter 8.2 and 8.3. Multiple conclusions for one HDV were possible like a cold SCR in combination with a defect / error or a defect in combination with a manipulation. In the following analysis the focus is on EURO V and EURO VI HDV (in total 26 HDV), as older HDV are allowed to have higher emissions and only limited possibilities for inspection of the emission system.

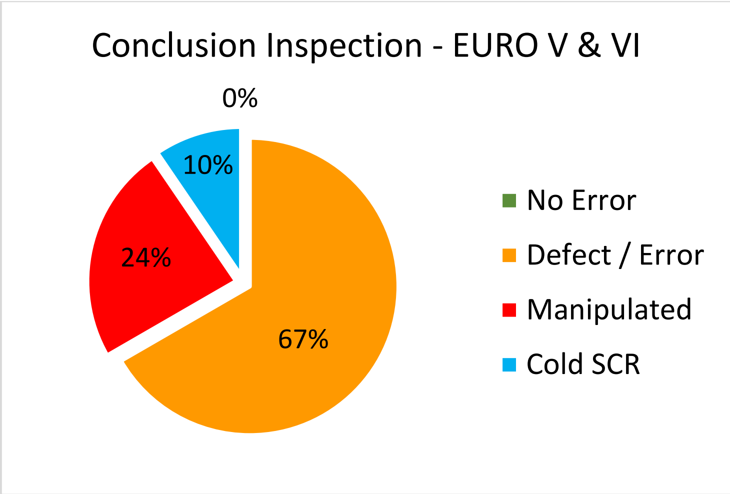


Figure 29: Conclusion of the inspected HDV for EURO V and VI. The percentage is relative to the investigated HDV in this category not to all measured HDV.

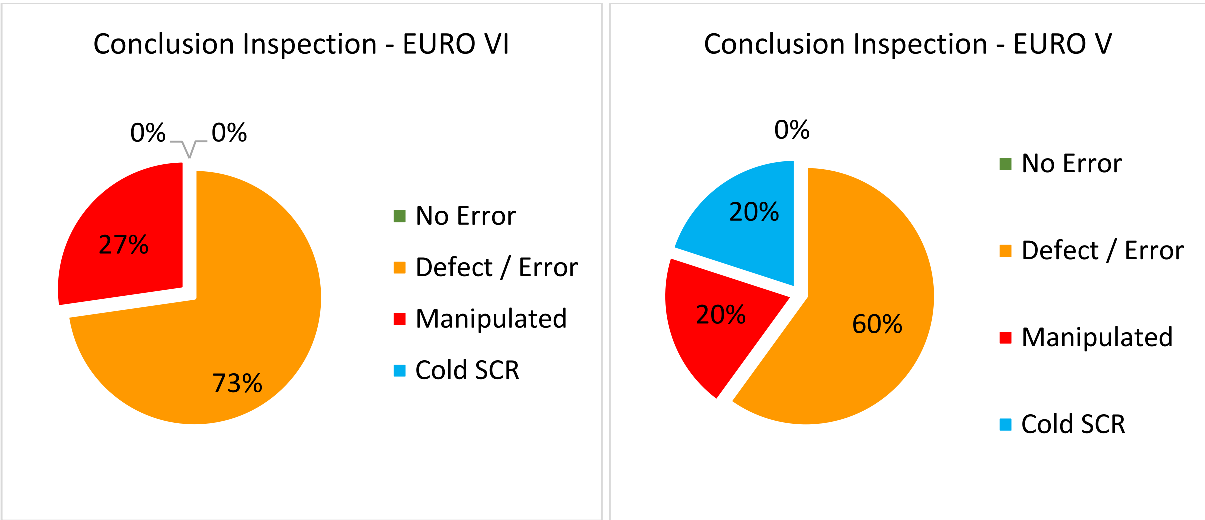


Figure 30: Conclusion of the inspected HDV, left for EURO VI and right for EURO V.

From Figure 29 it can be seen that for none of the inspected HDV no error was observed. That means that for all HDV that were chosen for inspection based on plume chasing data, a reason for high NOx emission could be found during inspection. This indicates a 100% hit rate or, in other words, a 0% false positive detection. Even two EURO V which were rated as low emitters as their emission value (2.600 to 2.700mg/kWh) was close to the limit of a suspicious emitter (3.000mg/kWh) were classified as defective.

For 67% of the inspected HDVs a defect or error in the emission system was found. For 24% a manipulation of the emission system was proven. For 10% a cold SCR / cold engine was estimated to be the reason for higher NO_x emissions. If studying Figure 30, it can be seen that only EURO V are affected by cold SCR. No EURO VI with high NO_x emissions fall in this category. For EURO V and EURO VI a large relative similar fraction with a defect or error is observed. It should be considered that for two HDV a multiple conclusion of a cold SCR plus a defect / error was found. This is for example the case if a bad temperature sensor indicates often to cold SCR temperatures. For other two HDV a multiple conclusion of defect / error plus a manipulation was found.

As indicated in 7.2.1 and 7.2.2, the conclusion of the inspection is similar when selecting the classified high emitter or suspicious emitter. One small difference can be found, manipulated HDVs are mainly found for high emitters (Figure 31 and Figure 32). The percentage is lower in the group of suspicious emitters. Also, HDVs with detected cold SCR / cold engine are mainly in the group of high emitters. Vice versa the ratio of defects and errors is higher in the group of suspicious emission classification. This result is understandable, as a defect or error does not mean that the emission system is completely deactivated but may only work less efficient. While a manipulated or a cold SCR will have likely a complete deactivated SCR system and thus higher NO_x emissions.

	only EURO V				only EURO VI				EURO V & VI			
Emission classification	**No Error**	**Defect / Error**	**Manipulated**	**Cold SCR**	**No Error**	**Defect / Error**	**Manipulated**	**Cold SCR**	**No Error**	**Defect / Error**	**Manipulated**	**Cold SCR**
low	0	2	0	0	0	0	0	0	0	2	0	0
suspicious	0	3	1	0	0	2	0	0	0	5	1	0
high	0	1	1	2	0	6	3	0	0	7	4	2
sum	**0**	**6**	**2**	**2**	**0**	**8**	**3**	**0**	**0**	**14**	**5**	**2**
low [%]	0%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
suspicious [%]	0%	75%	25%	0%	0%	100%	0%	0%	0%	83%	17%	0%
high [%]	0%	25%	25%	50%	0%	67%	33%	0%	0%	54%	31%	15%
sum [%]	**0%**	**60%**	**20%**	**20%**	**0%**	**73%**	**27%**	**0%**	**0%**	**67%**	**24%**	**10%**

Table 12: Result of inspections excluding HDV with expected cold SCR. The inspection results are split up depending on the emission classification. First the total numbers are given and below the percentage.

7.2.1 Conclusion of inspections only for the high emitters

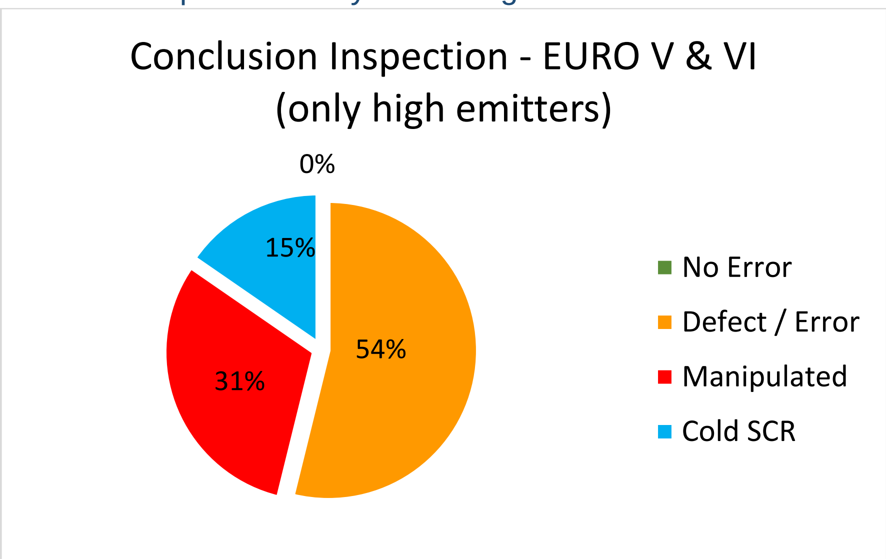


Figure 31: Similar to Figure 29 but selected for only the classified high emitters.

7.2.2 Conclusion of inspections only for the suspicious emitters

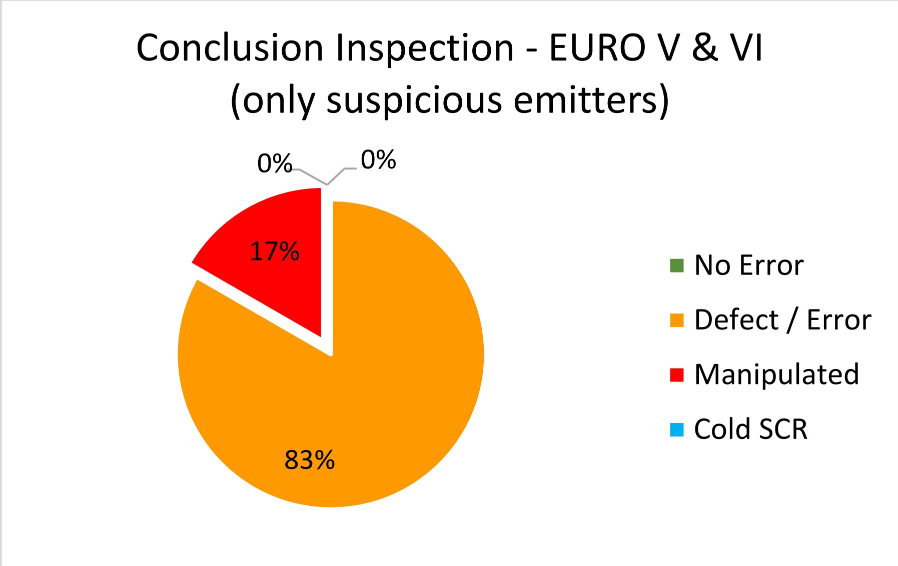


Figure 32: Similar to Figure 29 but selected for only the classified suspicious emitters.

7.3 Conclusions inspections (incl. expected cold engines)

For completeness the results are also provided when the HDV are included where a cold SCR was expected. In this case the ratio of "Cold SCR" increases. But still only EURO V HDV are affected.

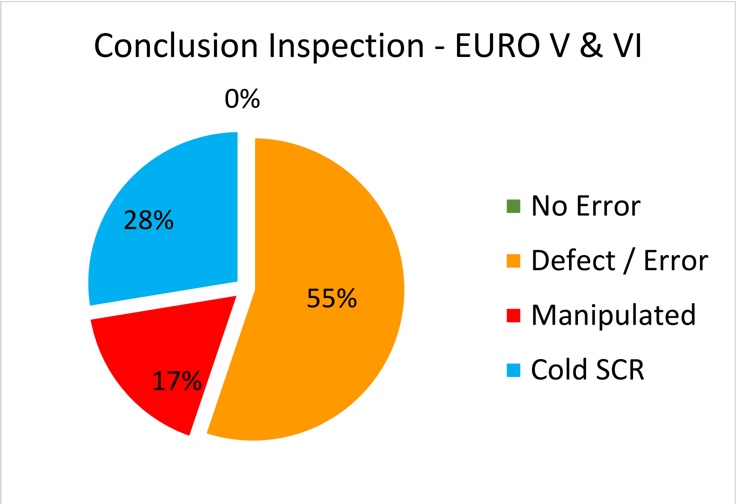


Figure 33: Similar to Figure 29 but including also vehicles where a cold SCR / engine is expected.

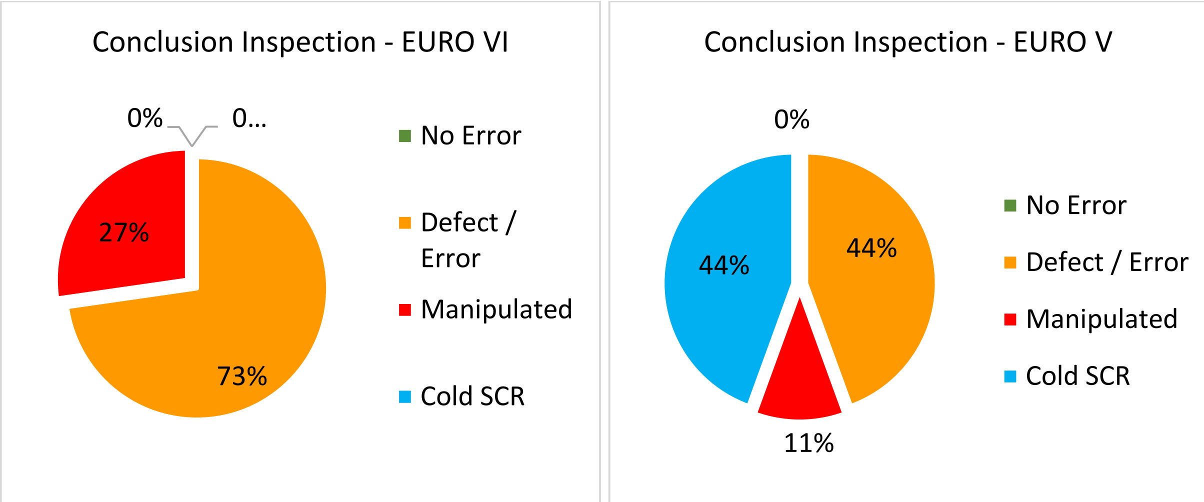


Figure 34: Similar to Figure 30 but including also vehicles where a cold SCR / engine is expected.

	only EURO V				only EURO VI				EURO V & VI			
Emission classification	**No Error**	**Defect / Error**	**Manipulated**	**Cold SCR**	**No Error**	**Defect / Error**	**Manipulated**	**Cold SCR**	**No Error**	**Defect / Error**	**Manipulated**	**Cold SCR**
low	0	2	0	1	0	0	0	0	0	2	0	1
suspicious	0	5	1	4	0	2	0	0	0	7	1	4
high	0	1	1	3	0	6	3	0	0	7	4	3
sum	**0**	**8**	**2**	**8**	**0**	**8**	**3**	**0**	**0**	**16**	**5**	**8**
low [%]	0%	67%	0%	33%	0%	0%	0%	0%	0%	67%	0%	33%
suspicious [%]	0%	50%	10%	40%	0%	100%	0%	0%	0%	58%	8%	33%
high [%]	0%	20%	20%	60%	0%	67%	33%	0%	0%	50%	29%	21%
sum [%]	**0%**	**44%**	**11%**	**44%**	**0%**	**73%**	**27%**	**0%**	**0%**	**55%**	**17%**	**28%**

Table 13: Similar to Table 12 including also vehicles where a cold SCR / engine is expected.

8 HDV with cold SCR / engine

Cold SCR / engines can cause a deactivated emission reduction system and thus high NOx emissions which are not related to a defect / error or manipulation. As shown in chapter 7.3, these HDV can especially for EURO V be responsible for a significant amount of the detected high emitters. Even if HDV excluded where a cold SCR / engine is expected, as they just entered the highway, some HDV are identified as cold SCR vehicles. From the data it is analysed how cold SCR and warm up are identified. Additional it is discussed how vehicle with long term cold SCR / engine are identified.

8.1 EURO V SCR / engine warm-up

When the engine and the SCR system warm-up it starts to work and emissions decrease. This can also be observed in some of the measurements (Figure 35).

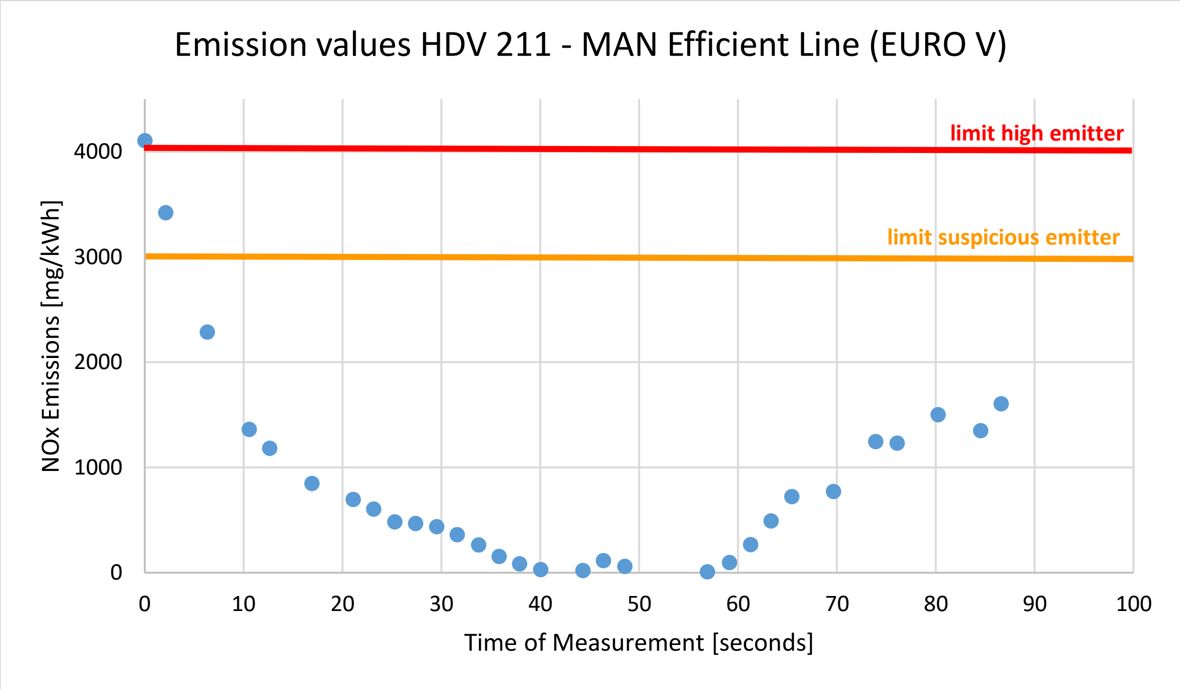


Figure 35: Time series of NOx emission factor for measured HDV no 211 (EURO V) with SCR warm-up. Each data point represents the instantaneous emission value, not the averaged emission over time. The limit indicates the used limits for the average emission value in this study to identify a suspicious and high emitter.

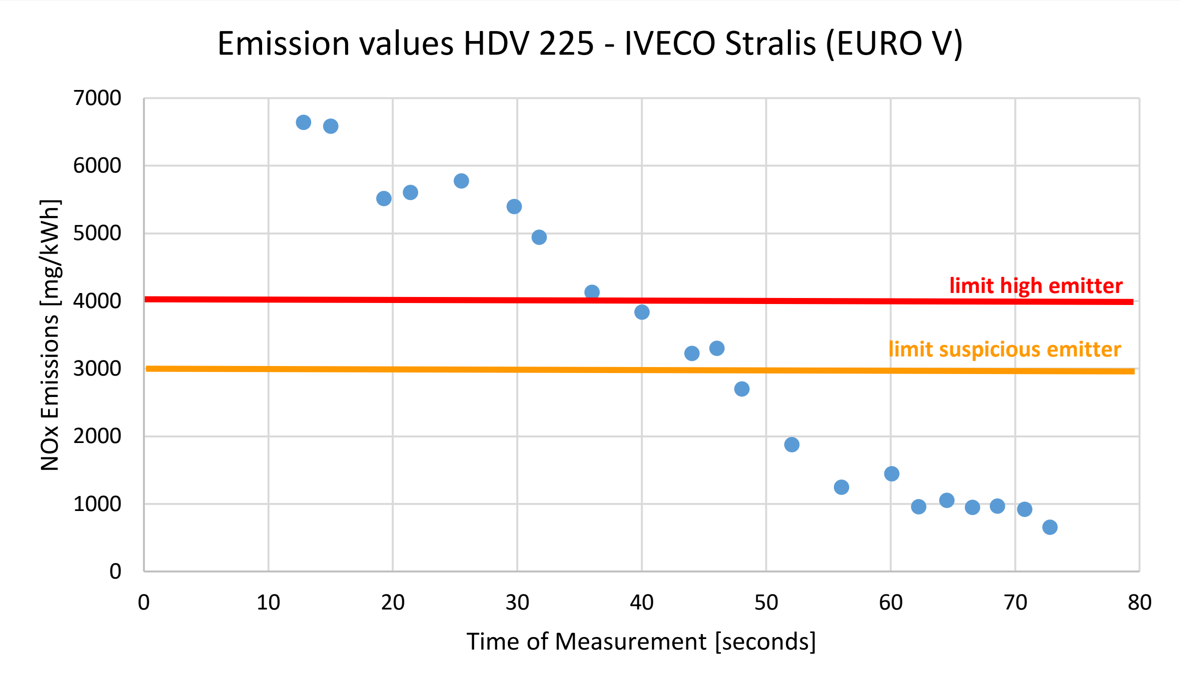


Figure 36: Time series of NOx emission factor for measured HDV no 225 (EURO V) with SCR warm-up (similar to Figure 35). The HDV was empty and only slowly warming up.

After high emissions at the beginning, they quickly decrease and finally average out on a level below the EURO V limit of 2.000mg/kWh. If such strong decreases of the emission factor observed during the measurement, it should be continued to investigate if the high emission at the beginning was just a warm up phase and the HDV show lower emissions on average. A too fast decision for an inspection should be avoided in these cases.

8.2 EURO V SCR / engine which do not warm-up

From this study it was observed that cold SCR / engines which do not quickly warm-up are easily misinterpreted as defected or manipulated HDV. This was only observed for EURO V. Even if this is observed in the inspection the goal is to identify these cases and avoid an inspection.

The high emissions arise due to a cold SCR which do not warm up as the engine load is too low (e.g. no weight) and the engine and emission system is constructed to large. The emission system would work if the HDV is fully loaded, but will not reach sufficient working temperature if it is nearly empty, driving slightly downhill or just recently started to drive. This will occur more often for local transport than for long range transport and thus in this study Danish HDV are more often affected than foreign long range transport.

In Figure 37 and Figure 38 two examples of EURO V NO_x emission factor measurements are shown which were identified as cold SCR in the police inspection. HDV no. 146 was even brought to a workshop where a full functioning SCR system was proven when it reaches it working temperature under higher load. It was concluded, that the large engine of this HDV (560 horse powers) and the empty truck cause an insufficient temperature that the SCR was not working on the road and responsible for the high emissions.

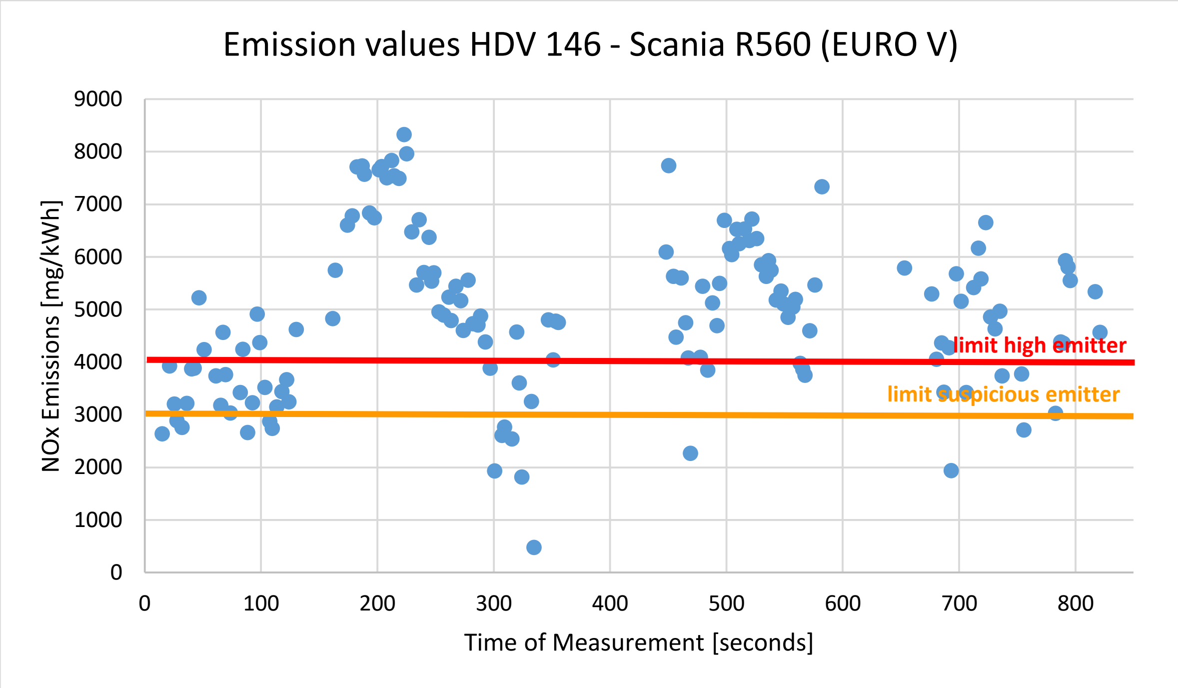


Figure 37: Time series of NOx emission factor for measured HDV no 146 (EURO V) without SCR warm-up (similar to Figure 35).

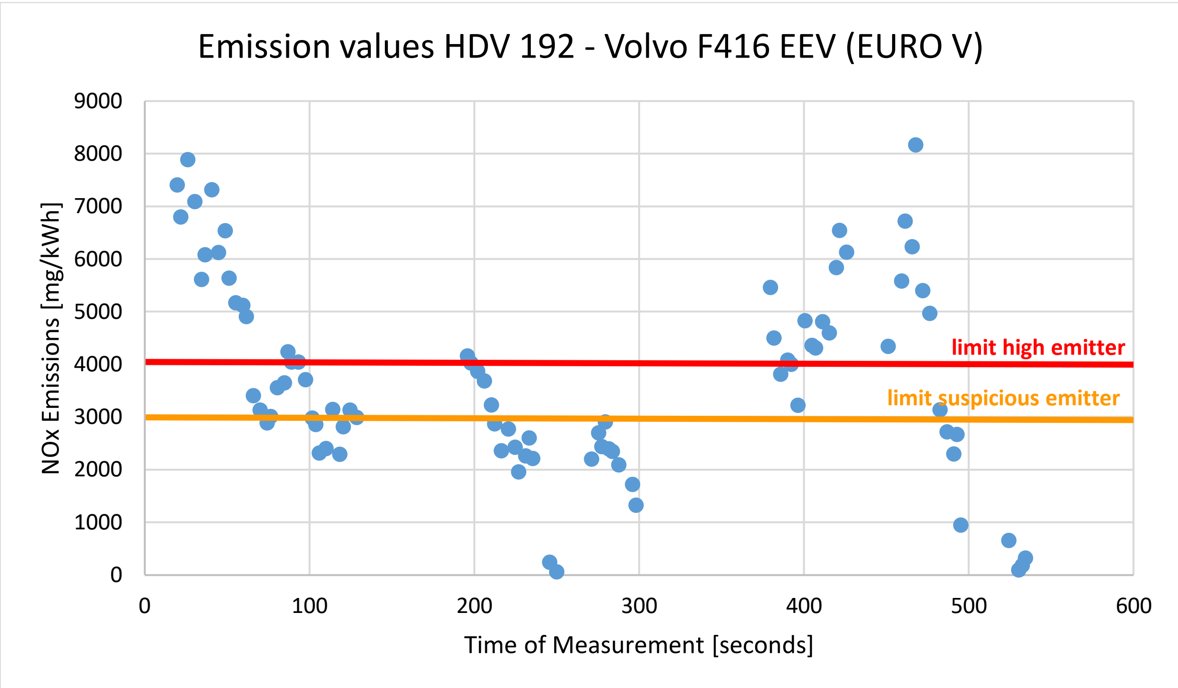


Figure 38: Time series of NOx emission factor for measured HDV no 192 (EURO V) without SCR warm-up (similar to Figure 35).

HDV no 192 (Figure 38) was also identified as cold engine in the police inspection. The HDV had only a light weight. Here a higher variability of the emission values is observed. It looks like the SCR is slowly warming up, but after a short down-hill section (after 300 seconds) again high emissions are observed as the SCR system cooled out again. After 480 seconds a second reduction is observed which can be caused by a slowly warm-up of the SCR longer driving.

8.3 Visual identification of HDV with potential cold SCR / engines

For all HDV, where the cold SCR / engine was the reason for the high NO_x emissions (except those just entered the high way), showed an empty or only light weight trailer. A longer measurement of these HDV will not cause a lower average emission value if the SCR never get to working temperature. However, these HDV can in most cases be identified by a lifted axle like shown in Figure 39. In practice an identified EURO V high emitter with a lifted axle can likely be a cold SCR and may be excluded from an inspection.

Figure 39: Picture of a lifted axle if HDV is driving with low weight (image from https://de.wikipedia.org/wiki/Liftachse#/media/Datei:Airlift_axle_002.JPG).

8.4 EURO VI SCR / engine warm-up

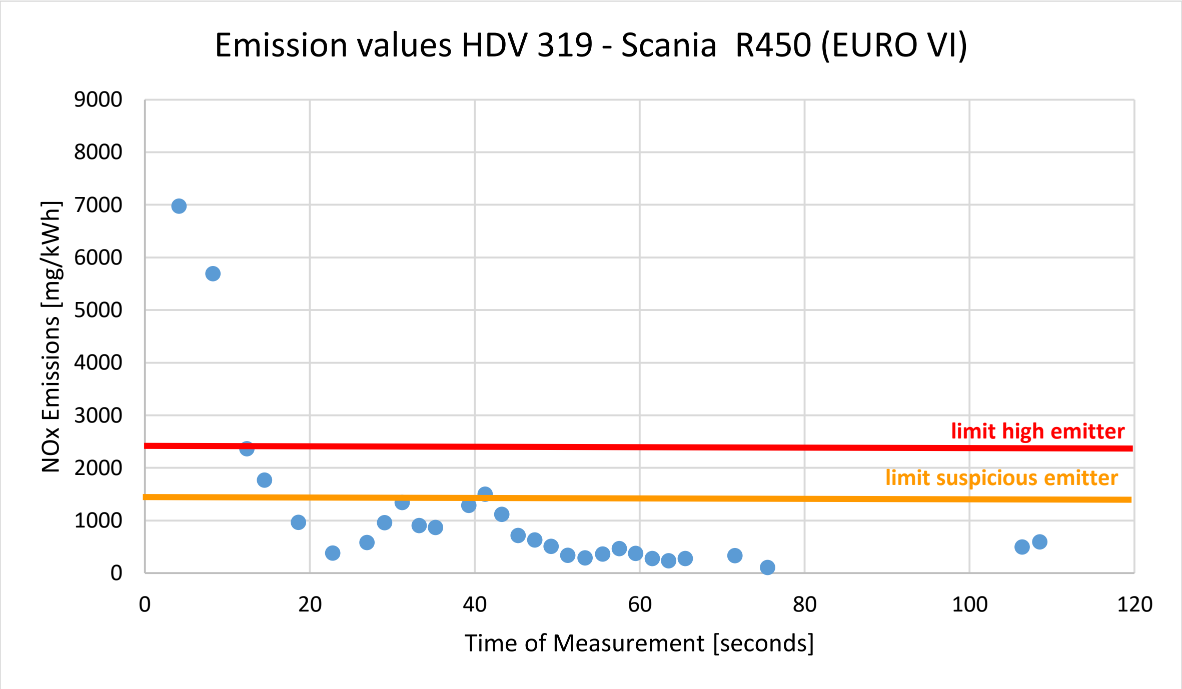


Figure 40: Time series of NOx emission factor for measured HDV no 319 (EURO VI) with SCR warm-up (similar to Figure 35).

EURO VI HDV have in principle the same issues that the SCR needs first to warm up before it works and reduce NO_x emissions. Due to stricter rules for EURO VI certification, the system warm-up faster and work under a larger temperature and engine range. Cold SCR /engines are thus not observed during the inspections (chapter 7.3). Only very randomly warm up of SCR on EURO VI was measured. For example, when a EURO VI just starting from a parking place, low emissions are observed from beginning. So no warm up could be seen, as the SCR system was likely still sufficient warm. Still in some cases a warm up of the SCR can be observed in the measurements (Figure 40). The same recommendation like for EURO V is also valid for EURO VI: If such strong decreases of the emission factor are observed during the measurement, it should be continued to investigate if the high emission at the beginning was just a warm up phase and the HDV show lower emissions on average. A too fast decision for an inspection should be avoided in these cases.

9 Analysis of required plume chasing measurement duration and adaption of emission classification

The required plume chasing duration and its influence on the emission result is studied by comparing the change of the measurement duration (averaging time) of the emission value for each vehicle. An example is shown for EURO VI HDV classified as low emitters in Figure 41.

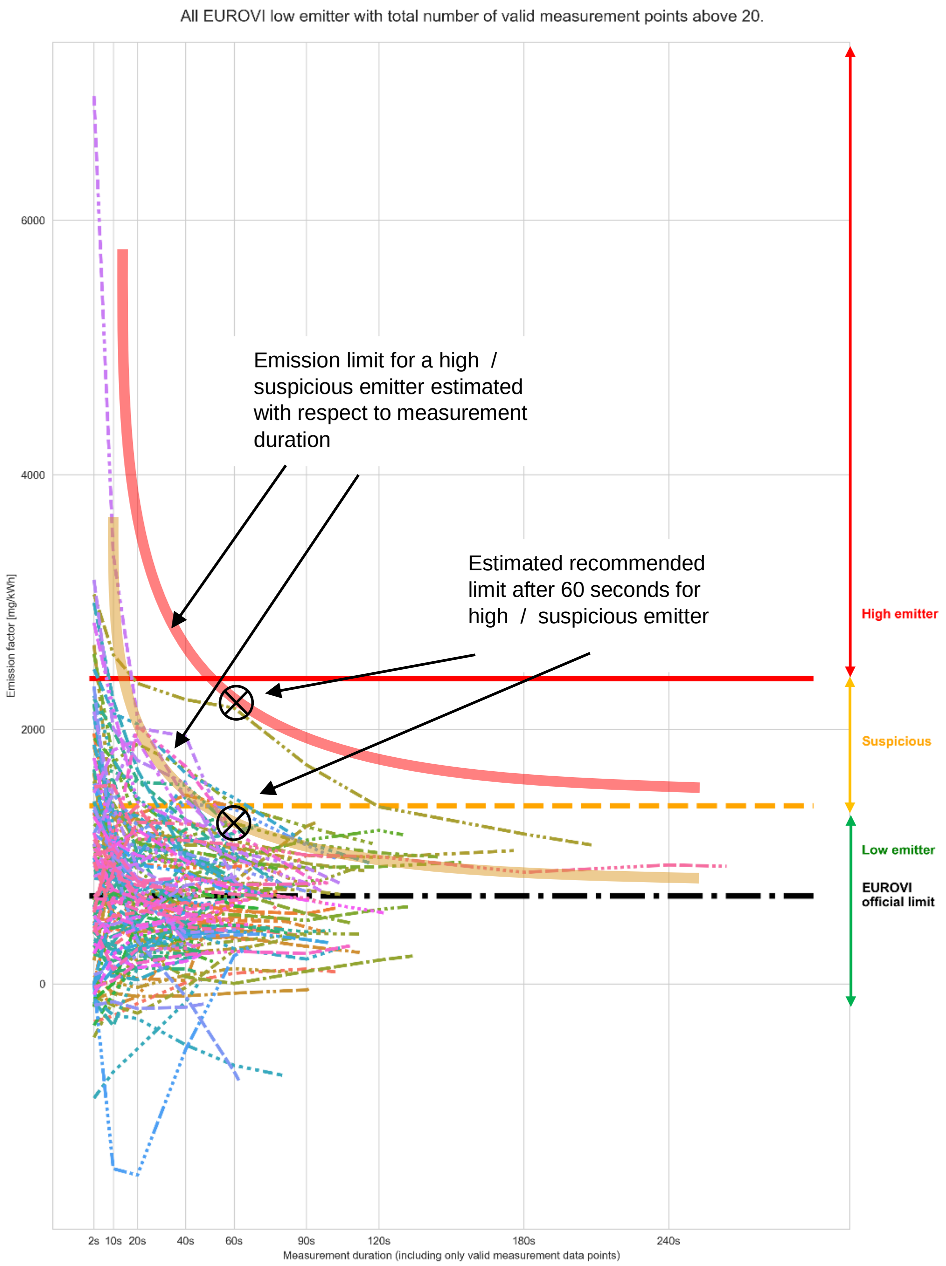


Figure 41: Average NO_x emission value for EURO VI HDV classified as low emitters in dependence of the averaging time (x-axis). Each line represents one individual measured HDV. An envelope of the estimated maximum emissions for a high / suspicious emitter are drawn and the cross indicate the recommended limit after a measurement period of 60 seconds.

Only valid data points are considered (sufficient emission signal: CO_2 min. 30ppm above background, see chapter 3.1). Periods where no emission signal is recorded (e.g., no plume) are excluded. Thus, the x-axis of the plots does not represent the true measurement duration, but rather the time period while measuring within the plume exclusively. Depending on the measurement conditions, this can be close to the real measurement duration, but sometimes also much longer (e.g., when driving downhill or only a weak emission signal is observed). For better visualisation the results are split for the EURO classes and separated into classified low emitters (Figure 41 and Figure 43) and suspicious + high emitters (Figure 42 and Figure 44). The plots do not show the instantaneous emission values for each data point (like Figure 40), but instead, the average emission value since measurement of the individual HDV started. This is equivalent to the value the software returns in real time during the measurements on the road and, which is used to decide if a HDV is a low, suspicious or high emitter.

The analysis in this chapter cannot exclude a long-term cold SCR system of a EURO V (chapter 8.2). They have to be avoided like discussed in the according chapter.

The first plotted data point in Figure 41 to Figure 44 is for 2 seconds data and would be representative for cross road remote sensing. By comparing the figures for low and high emitters it is obvious that the first data points have a large overlap between these two groups. It is clear, that a short measurement time will require a high limit to reliable identify a high emitter without misidentifying a low emitter as high emitter. On the other hand, this will result in missing many high emitters.

9.1 EURO VI Low Emitters

In Figure 41 the dependency of the average NO_x emission factor on the measurement durations is shown for all HDV which were finally classified as low emitters (with a final average emission value below the limit of 1400mg/kWh).

It cannot be excluded that this plot still contains HDV with a defective or manipulated emission system, as these vehicles were not inspected. The main relevant information in the plot arises from the time when all lines cross a relevant limit. For short averaging times a large variability is observed, as expected.

After 60 seconds, the majority of all HDV, excluding one exception, reached the average NO_x emission below the set limit of 1400mg/kWh. This would result in a recommended plume measurement duration of minimum 60 seconds. When the limit is lowered a longer averaging time may be needed. A curve is sketched representing the typical high range of average emissions versus averaging time (orange line) which represent the limit for the suspicious emitter detection. The red line indicates the clear high emitter detection. Both lines are estimated from the set of derived emission curves.

9.2 EURO VI High Emitters

Here, similar to chapter 9.1, only the finally classified suspicious and high emitter are plotted and analysed. Strong emission variations are observed also for longer measurement durations. Additional, at measurement start the emission values are already all on a higher level, above the limit for a suspicious emitter. With longer averaging time, high emission value remains. This confirms the strategy that a short measurement duration (10 seconds) with a low emission level already allow to identify a low emitter. A curve representing the minimum averaging emission level versus averaging time is plotted by a green line.

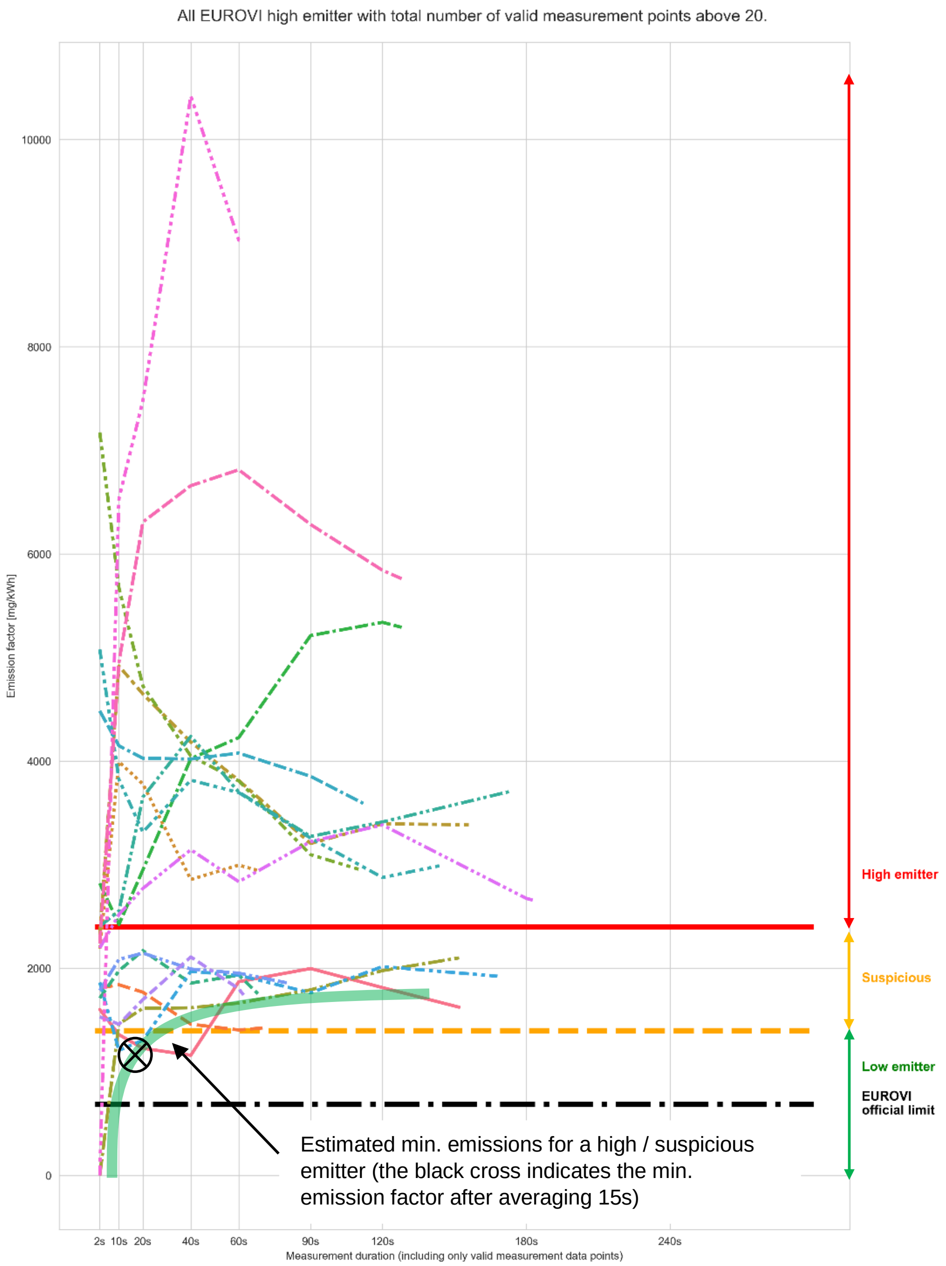


Figure 42: Average NO_x emission value for EURO VI HDV classified as suspicious or high emitters in dependence of the averaging time (x-axis). Each line represents one individual measured HDV. An envelope of the estimated minimum emissions for a high / suspicious emitter are drawn and the cross indicate the recommended estimated limit after 15 seconds (recommended time for preliminary emission value).

9.3 EURO V Low Emitters

Similar to chapter 9.1 here the classified EURO V low emitters are plotted. EURO V which are found to have a defect from inspection (chapter 7.2) are excluded. Similar behaviour like for EURO VI is observed just on a higher level. At short measurement duration a high variability is observed. After 70s the average emission limit of most HDV is already below the suspicious limit (3.000mg/kWh). Three HDV remain which just reach the level below the limit after 100 and 130 seconds. It is likely that some of these higher emitters are defective, manipulated or have a cold SCR. Other EURO V HDV with similar average emissions 2.600 to 2.700 mg/kWh showed during inspections a defect (chapter7.2). Thus, there is no constrain that all HDV will be below a defined limit or below the enveloping curve a longer averaging time must not include all plotted HDV. A recommended minimum averaging time can here also be concluded to 60 seconds.

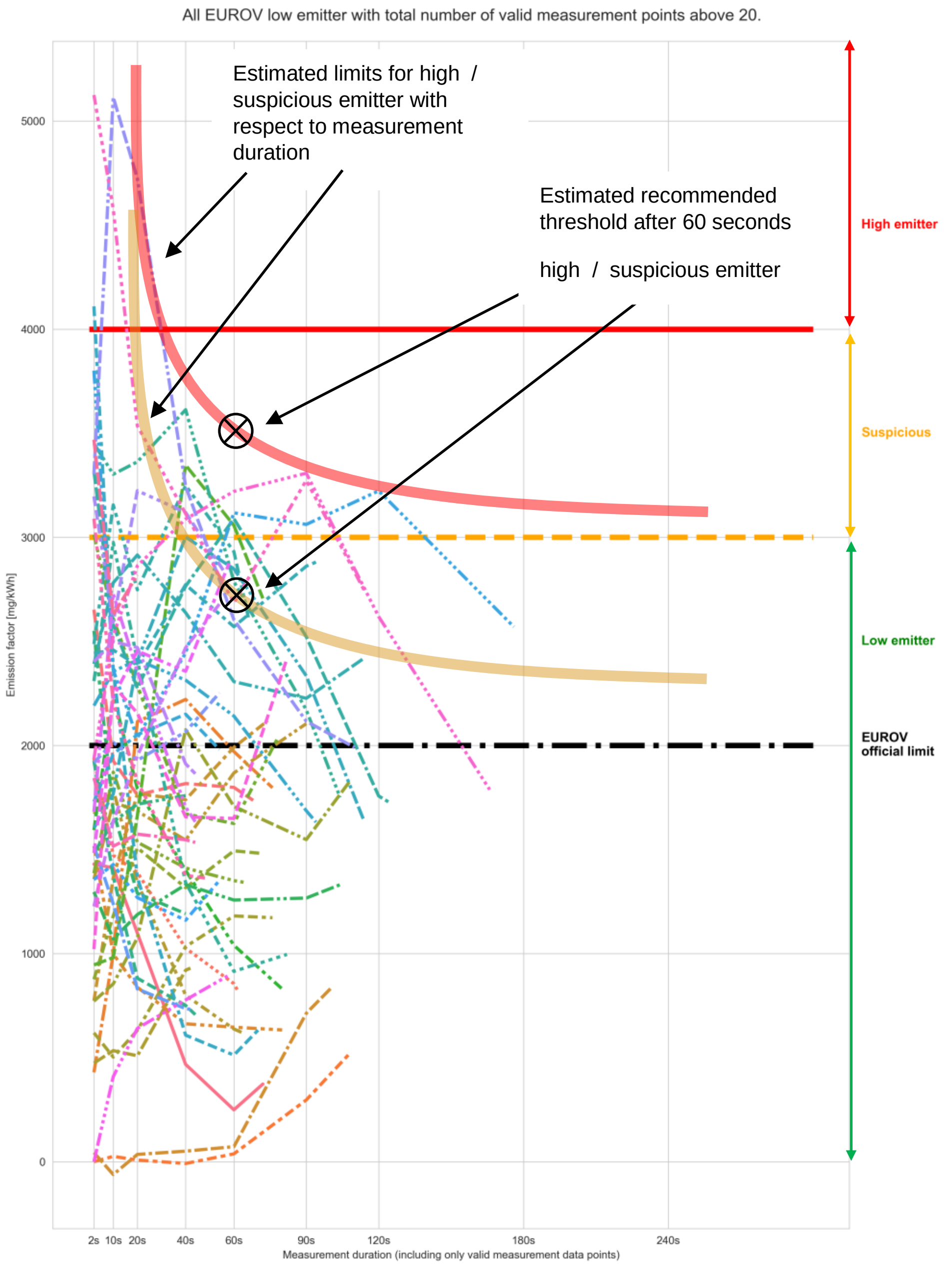


Figure 43: Average NO_x emission value for EURO V HDV classified finally as low emitters in dependence of the averaging time (x-axis). Each line represents one individual measured HDV. An envelope of the estimated maximum emissions for a high / suspicious emitter are drawn and the cross indicate the recommended limit after a measurement period of 60 seconds.

9.4 EURO V High Emitters

Here the EURO V suspicious and high emitters are analysed. They show a very high variability also for very low measurement duration. Even low emissions are observed for some HDVs for the first data points and then the average emission level increases with longer measurement duration. A longer measurement duration is required for EURO V to avoid missing a suspicious or high emitter. For a limit of 3.000mg/kWh a minimum of 40 seconds is required. If the limit is lowered to 2500mg/kWh about 15 seconds are sufficient. That means, after 15 seconds a HDV with a value below 2.500mg/kWh can likely be excluded as a suspicious or high emitter. This would bring the recommended minimum measurement in agreement with the EURO VI (chapter EURO VI Low Emitters). If the emission value is above 2.500mg/kWh after 15 seconds of measurements, a longer measurement period would be required to clearly identify it as high, suspicious or low emitter.

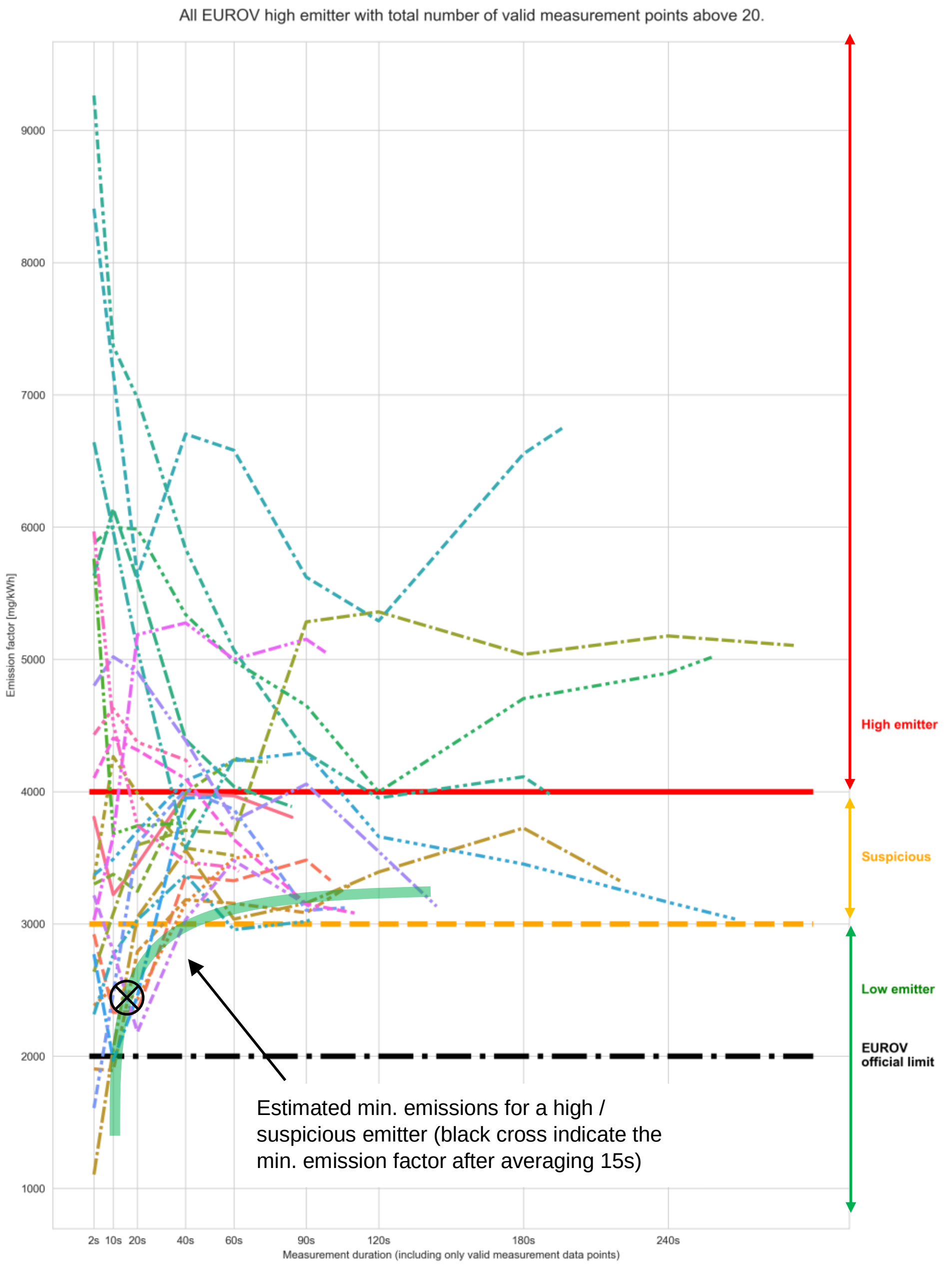


Figure 44: Average NOx emission value for EURO V HDV classified finally as suspicious or high emitters in dependence of the averaging time (x-axis). Each line represents one individual measured HDV. An envelope of the estimated minimum emissions for a high / suspicious emitter are drawn and the cross indicate the recommended estimated limit after 15 seconds (recommended time for preliminary emission value).

9.5 Recommendation for new plume chasing measurement duration and emission limits

The applied limits of this study for a suspicious and a high emitter are illustrated in Table 4 and Table 14. From the inspections (chapter 7.2 and 7.3) it was concluded that for all HDV in these two categories the emission system was in an inactive state. For two inspected EURO V HDV a defect was observed during inspection, even their emission values (2.600- 2.700 mg/kWh) were slightly below the limit for a suspicious emitter (3.000mg/kWh). For both of these HDV only a short measurement could be realised before inspection (18 and 25 data points corresponding to 36 and 50 seconds, respectively) and thus a higher average emission level could be possible for longer measurement. However, this indicates that a defect / error can cause an emission increase within a range resulting in a low emitter classification (with the currently applied limits). It can be concluded that the used limits / thresholds are rather too high than to low and potentially defective / manipulated HDV will be missed. As all classified suspicious emitters are approved to be high emitters, the limit is recommended to be lowered.

Additionally, it was observed that high emitters due to a cold SCR / engine cannot be avoided with a high threshold as shown in chapter 7.2.1 and chapter 8.2. These engine states of mainly EURO V show one of the highest emission values and have to be identified by other means than a higher limit (chapter 8.2). Such vehicles are not considered for the estimation of new limits.

Changing the limits and measurement duration have two motivations. First, the limits should be selected that all defective and manipulated HDV are identified, and no correct working HDV are labelled as high emitter. Second, a request is to reduce the measurement duration to investigate more vehicles in a certain time. Both aspects are not independent as a shorter measurement time result in a higher variability of the derived emission value and thus higher limits. We use the above analysis (chapter 9.1 to 9.4) on average emission value over time to estimate recommended measurement duration and limits. However, consider that there is no proof if the classified low emitters are indeed all correct working HDV or if also some of them with slightly increased emissions are also already defective / manipulated. As almost all suspicious and high emitters were inspected it is unlikely that there is a wrong classification in this group.

A new limit for high and suspicious emitters is derived from Figure 41 and Figure 43 (EURO VI and EURO V respectively) where the observed emission value for all classified low emitters is plotted. From the plot we recommend a combination of reduced measurement time and reduced limits. A reduced measurement time of 60 seconds is estimated as this still allow a slight reduction of the applied limits. From the enveloping curve this result in a threshold for EURO VI of 2.200mg/kWh for a high emitter and 1.200mg/kWh for a suspicious emitter. For EURO V we derive 3.500mg/kWh and 2.500mg/kWh respectively. These limits would agree with the inspections of this study. All defective HDV would at least be identified as suspicious.

From Figure 42 and Figure 44 where the classified suspicious and high emitters are plotted, a lower limit is estimated. From these plots an averaging time is concluded, when a high emitter can be excluded or at least is unlikely. We use the above derived limits for a suspicious emitter. It can be concluded that with these limits all classified high emitters are after 15 seconds identified as high or suspicious emitter. Vice versa it means, that a HDV identified after 15 seconds as low emitter is very unlikely a high and still unlikely a suspicious emitter. This validates the measurement strategy of this study. If a low emission value is derived within 15 seconds, the HDV will likely be a low emitter. The preliminary emission value displayed by the plume chasing system (see chapter 3.3) can be used to stop the measurement of these vehicles. This increases the efficiency of inspections significantly. Only for the reliable identification of a high emitter a longer measurement is required. The concluded new limits and averaging times are summarized in the following table:

	EURO V used this study	**EURO V recommended**	**EURO VI used this study**	**EURO VI recommended**
Classification	mg/kWh	mg/kWh	mg/kWh	mg/kWh
low	≤3.000	≤2.500	≤1.400	≤1.200
suspicious	>3.000	>2.500	>1.400	>1.200
high	>4.000	>3.500	>2.400	>2.200
Measurement duration for a valid emission classification of a high and suspicious emitter (equivalent to # data points)	90 (45)	60 (30)	90 (45)	60 (30)
Measurement duration for a preliminary emission classification to exclude a high emitter (equivalent to # data points)	10 (5)	15 (7 -8)	10 (5)	15 (7 -8)
EURO emission limit	≤2.000		≤460	
EURO RDE emission limit	-		≤690	

Table 14: Defined thresholds (limits) in this study and recommended new limits.

As no data of the real condition of all the measured HDV is available, it is clear that the estimation of the new limits and measurement duration cannot be tested and proven. They have to be tested in new studies to investigate if they cause false high / suspicious classifications.

10 Further implementation and Improvements

During this project several recommendations and improvements were identified:

- Implement numbering of measured vehicles in the software
- Create a measurement result protocol for each inspected vehicle
- Implement methods to identify cold SCR / engines
- A longer field application by Danish Authorities and Danish Police is recommended. The plume chasing emission system can directly be installed in a Danish police car so that one vehicle is sufficient to perform the measurement and the inspection
- More HDV with only slight emission increase should be inspected to derive better a realistic emission limit of healthy HDV

11 References

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