Deutsche Umwelthilfe

Determination of real NO_x emissions of heavy duty vehicles in driving operation on European motorways

Study period: January 2020 - September 2021

Project Manager
Dr. A. Friedrich

Deputy project manager
S. Annen

Authors
S. Annen, R. Helmerich

Berlin, 14th of October 2021

Table of Contents

List of Figures

List of tables

1. Preface

For many years, Deutsche Umwelthilfe (DUH) has been fighting for clean air, which is essential for our health and quality of life. In addition, the reduction of air pollutants is essential for climate protection. Road traffic is a major contributor to air pollution. Against this background, DUH founded the Emissions Control Institute (Emissions- Kontroll-Institut EKI) at the beginning of 2016 in order to determine and provide reliable and transparent information on actual pollutant emissions from road traffic.

Already in November 2020, DUH presented its own first measurements and pointed out the problem that emission values of trucks in real-world operation can be significantly higher than those measured during registration or than permitted by the exhaust emission standard, which is now confirmed by further measurements in real operation. This is not only a major problem for reasons of air pollution control, but also undermines the objective of truck tolls, which in many European countries are only levied on the basis of the official registration values (or exhaust emission standards).

The data from the measurements presented in this report on European motorways of a wide variety of heavy-duty vehicles (HDVs) from all relevant manufacturers and emission standards provide a comprehensive overview of the nitrogen oxide (NO_x) emissions they actually cause in real-world driving conditions. This provides a solid database based on around 700 individual measurements. The report identifies a cause of high NO_x immissions and shows ways to reduce them.

This report will show that a minority of HDVs are responsible for a significant proportion of NO_x emissions from all road freight transport. To counteract this, effective controls are needed to identify them, as well as effective sanctions for technically inadequate or manipulated HDVs.

2. Introduction

DUH has been measuring exhaust emissions from vehicles in real-world operation at its Emissions Control Institute for more than five years. The plume chasing method used in this project makes it possible to measure a large number of HDV and reliably identify vehicles with inadequate, defective or manipulated exhaust gas aftertreatment. The background to these measurements is, in particular, available information on intentionally manipulated exhaust gas purification systems in HDVs, which enable haulage companies to gain an unjustified competitive advantage. In this case, the urea consumption is decreased or reduced to zero by changes in the exhaust system, in the vehicle software or by the installation of a so-called AdBlue emulator. The cost savings have dramatic consequences: without the necessary urea for exhaust gas aftertreatment, NO_x emissions increase dramatically.

In our measurements, the emissions were determined with a mobile ICAD distance measurement system from the company AirYX. In this way, the individual emissions of each HDV could be used to classify them into the different categories according to their Euro emission standard.

The HDV measurements were technically supported by the company AirYX and contributed to the further development and optimization of the plume chasing method.

3. Measuring method

The measurements of the NOx emissions of the HDV are carried out according to the "Plume Chasing" method[1] using an ICAD NO_x and CO_2 analyzer from AirYX GmbH.

Figure 1 AirYX ICAD $NO_{2/x}$ Analyzer

The basic principle of plume chasing measurement is to follow an HDV at a moderate distance for a few minutes with the measurement vehicle and to guide part of the exhaust-air mixture from the exhaust plume of the HDV in front into the measurement device. For this purpose, any vehicle can be equipped with the mobile measuring device. To extract the exhaust-air mixture from the exhaust plume of the HDV in front, a thin NO_x-resistant PTFE tube serving as a measuring sensor is attached to the front bumper of the measuring vehicle and directed through a side window into the measuring device inside the vehicle, see Figure 2.

[1] Pöhler et al. 2019, NOx RDE measurements with Plume Chasing - Validation, detection of high emitters and manipulated SCR systems, Proceedings of the Transport an Air Pollution Conference, https://www.tapconference.org/assets/files/previous-conferences/proceedings/2019_Proceedings.zip, 2019.

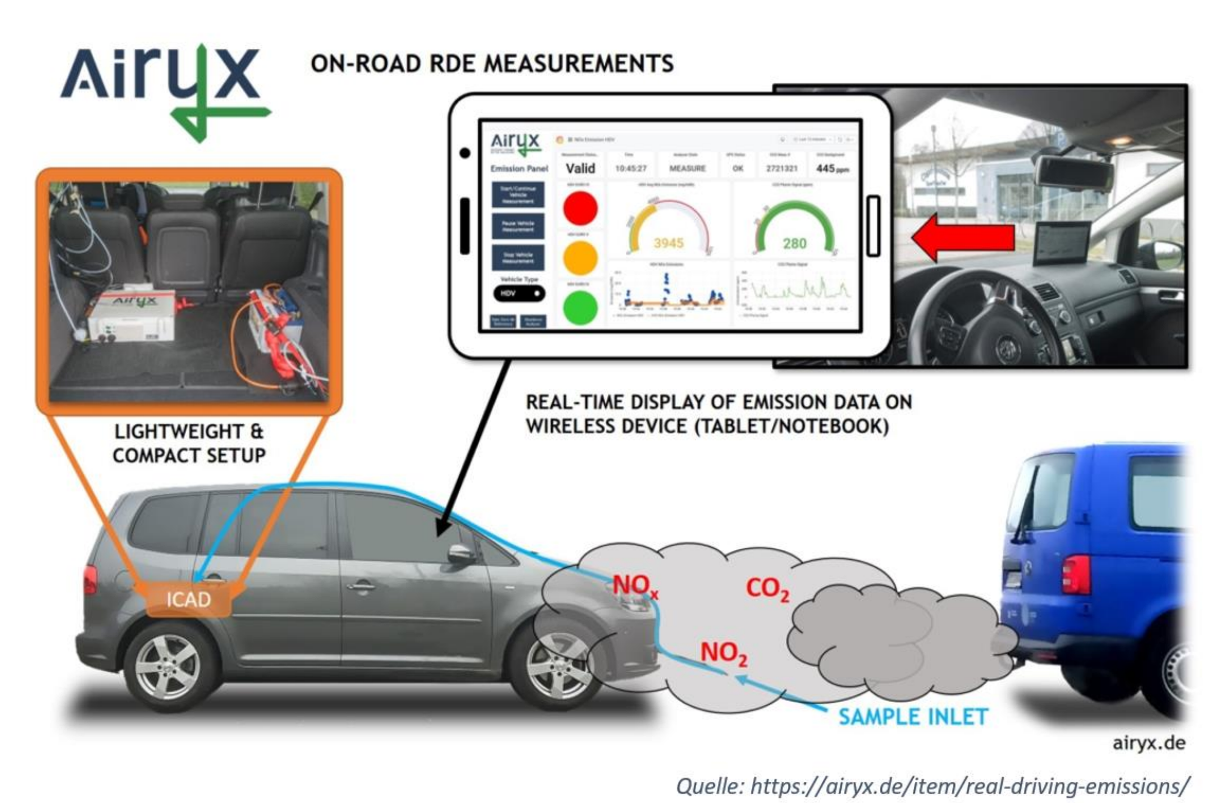

Figure 2 Plume Chasing Procedure

The mobile ICAD-NO_x-200DM (Iterative Cavity Enhanced Differential Optical Absorption Spectroscopy) measuring instrument is ready for use after a few minutes warm-up phase and without complex calibration. The user interface is a standard tablet computer or note-book, which can be connected to the instrument via LAN or WLAN. The measurement data is displayed in real time and started and stopped both continuously and manually, segmented for each individual HDV, captured and recorded. The latter facilitates the subsequent assign-ment of the measurement data.

The measuring system continuously determines the current local background CO_2 immission. In order to ensure that the measuring sensor is located in the exhaust plume of the vehicle in front, measuring points are only recorded as valid as soon as the measured CO_2 concen-tration is at least 30 parts per million (ppm) above the local CO_2 background immission. NO_x emissions are determined by the concentration ratio of the gases CO_2 and NO_x in the sam-pled part of the exhaust plume. This ratio remains largely stable at different degrees of dilu-tion of the exhaust plume with the ambient air. This concentration ratio can be used to draw very precise conclusions about the total NO_x emissions of the HDV in front during the meas-urement. For the output of the measured values in mg/kWh, an efficiency of the HDV drive of 40 percent is assumed, which corresponds to the usual operation of HDVs in the optimum operating range. This offers the advantage that valid values can be recorded even in the event of fluctuations in the operating range, such as slight uphill or downhill travel. However, full-load driving, e.g. on motorway slip roads, or complete shutdown of thrust when coasting are not taken into account in the measurements.

Depending on the ambient conditions, the measurement of an HDV is complete and valid after two to ten minutes, which means that at least 45 valid individual measurement points have been recorded over the measurement period. Subsequently, the measurement of the next HDV can be initiated. Times between measurements, i.e. outside the exhaust plume of a vehicle in front, are used by the measuring device to determine the local CO_2 background immission again.

It was taken care ensuring that any falsification by third party road users was excluded as far as possible. To this end, only the vehicle in front was measured during convoy driving and the entire measurement journey was documented by video in order to be able to verify the data during the subsequent evaluation in the event of any anomalies. The video recordings have also proved helpful for the identification of the manufacturer, country of origin, registration number or exhaust emission standard, if this has not already been done during the measurement.

Comparative measurements with the sensors PEMS devices from EKI of DUH in past years have shown that this method provides realistic and comparable data (DUH, 2019).

Extensive measurements with this system were carried out in Denmark, on behalf of the Danish Road Administration. Together with the Danish police, 480 HDVs were measured, of which 30 HDVs subsequently withdrawn from service and inspected by the police due to suspiciously high NO_x emission values. For all HDVs withdrawn from service, a defect or manipulation of the exhaust gas purification system was detected in the further inspection[2].

Furthermore, measurements carried out by the EKI in the past, also using the plume chasing method, clarified that the emission values can be reproduced with repeated measurements. Thus, in the context of measurements on city buses, three of the buses examined were measured a second time on a further section of the route to ensure that the measurement results are reproducible. The following figure illustrates this (see Fig. 3).

[2] https://fstyr.dk/da/-/media/FSTYR-lister/Publikationer/ReportDenmark2020v101.pdf

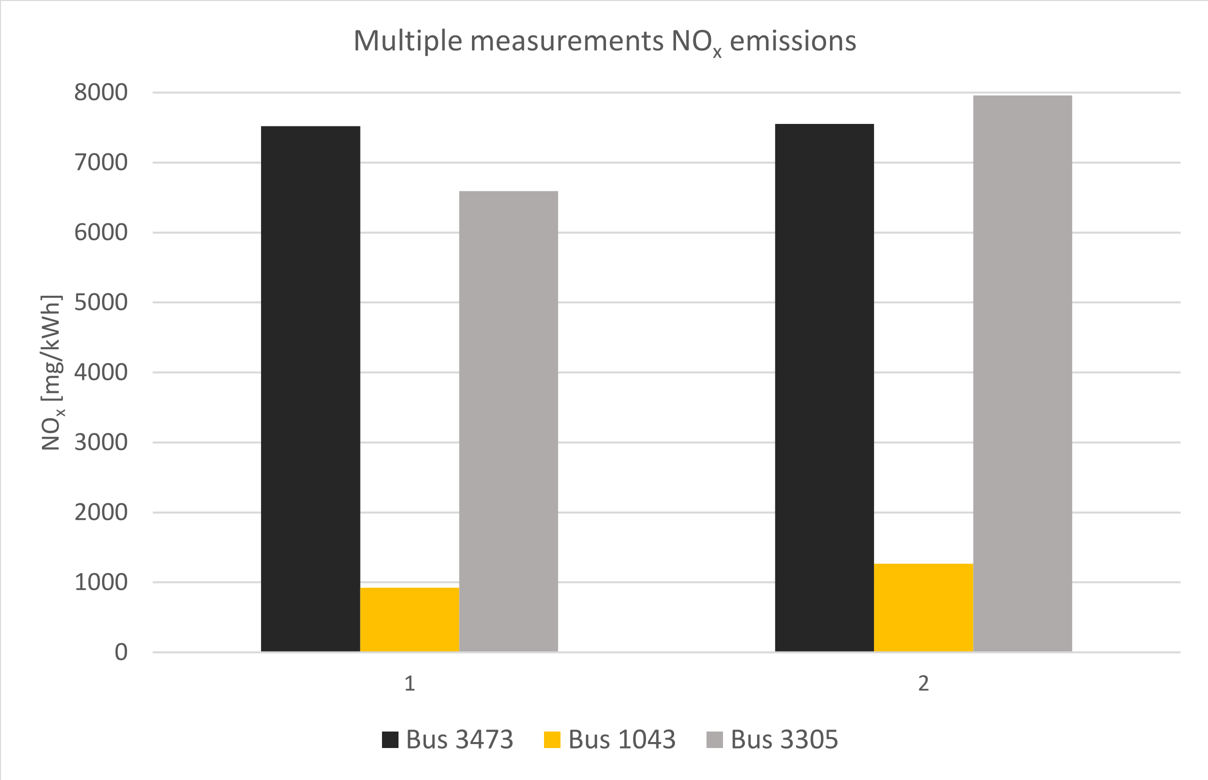

Figure 3 Reproducibility of the measurement

4. Data collection

The measurements were carried out on German and inner-European motorways and trunk roads between January 2020 and September 2021. From around 800 individual tracking runs, 700 data sets could be generated, from which 545 emerged as valid.

The selection of the measured HDV was made according to the existing traffic situation. The measurement vehicle pulls in behind the HDV selected for measurement and the measurement recording is started. As soon as the exhaust plume of the HDV in front is detected, the measuring sensor continues to be located in the exhaust plume and the CO_2 threshold value of 30 ppm above the background immission is exceeded, the data points for the respective individual HDV are assigned to a data set. Typically, a point cloud of NO_x concentration is now formed from which the NO_x emissions for the particular vehicle are calculated. The following figure illustrates how point clouds are formed from the individual measurement points of the NOx concentrations of two trucks.

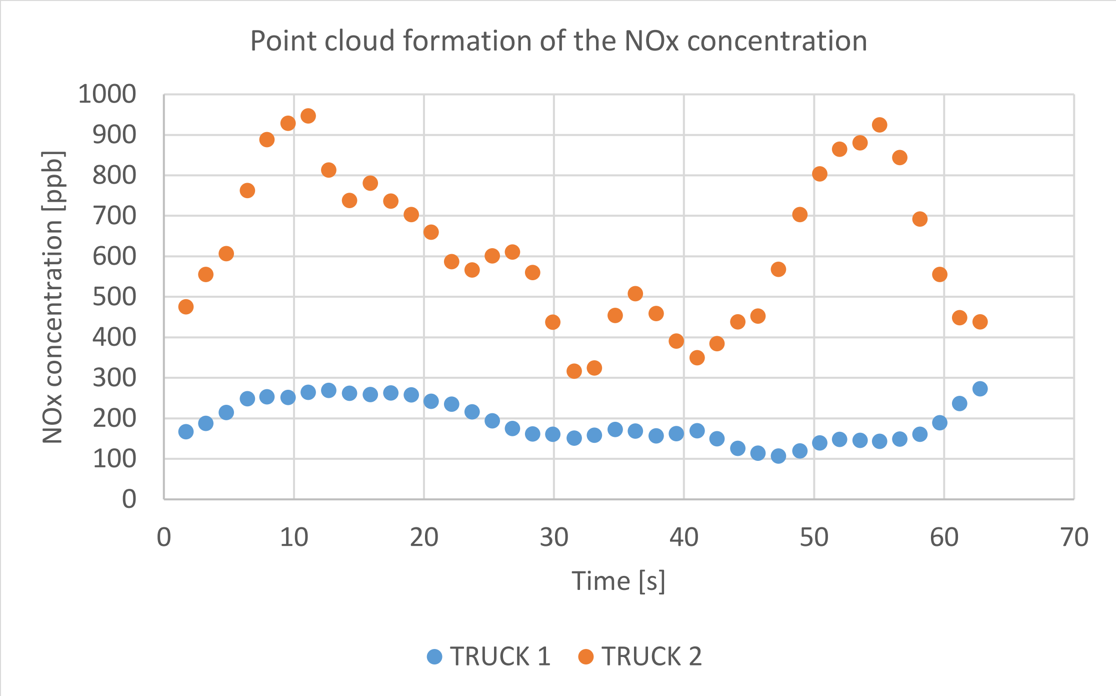

Figure 4 Point cloud formation of NOx concentration

The course is visualized by a graph and a measuring point cloud with a variably adjustable time interval on the user interface of the measuring system. As soon as the 45 data points required for a valid measurement have been collected, the measurement can be terminated and the individual data segment is closed then. If necessary, e.g. if a high volatility of the collected data is observed, the measurement can be continued for the collection of further measurement points in the segment. Subsequently, all relevant data such as time, manufacturer, model, emission standard, country of origin of the measured vehicle are documented and additionally, for a later review, the overtaking process of the HDV is recorded by a dashcam. In particular, the documentation and determination of the exhaust emission standards are especially relevant here in order to decide whether the limit values have actually been exceeded in post-processing.

For the HDVs examined here, the NO_x limits for Euro V of 2,000 mg NO_x/kWh according to the European Transient Cycle (ETC) and for Euro VI of 460 mg NO_x/kWh according to the Worldwide Harmonized Transient Cycle (WHTC) apply. Since the engines are measured on the test bench, the legislator has added a "conformity factor" of 1.5 to the NOx limit value for testing Euro VI vehicles on the road, so that they are permitted to emit 690 mgNO_x/kWh on the road.[3] In addition, an error factor of 1.4 was added to the respective NO_x limit values when evaluating the data collected here. This results from measurement inaccuracy and other influences that could be determined as a maximum in repeat measurements. This results in a NO_x threshold value of 2,800 mg/kWh for Euro V trucks and, rounded up, a NO_x

[3] https://dieselnet.com/standards/eu/hd.php

threshold value of 1,000 mg/kWh for Euro VI trucks above which the trucks are classified as suspect.

5. Results

In total, data sets from 545 HDV measurements were successfully evaluated over the study period. These measurements took place on motorways in Germany, France, Austria, Poland and Slovakia. Measurements were increasingly taken on transit routes for international HDV.

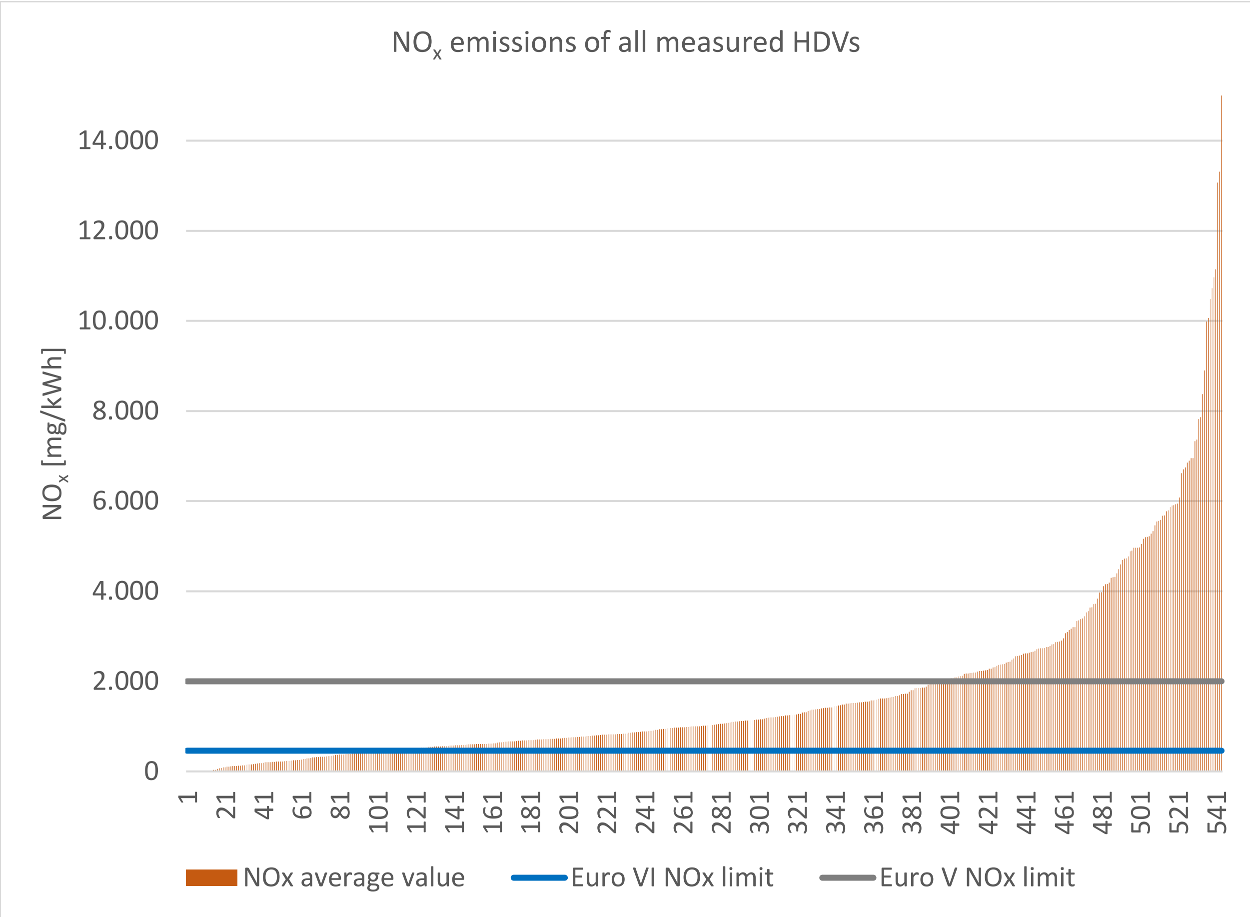

Figure 5 NO_x emissions from measured HDVs

187 of the examined HDVs are registered in Poland and 95 in Germany. The remaining 263 trucks were registered in other EU countries, Belarus, Bosnia and Herzegovina, Kazakhstan, Iran, Macedonia, Russia, Serbia and Ukraine.

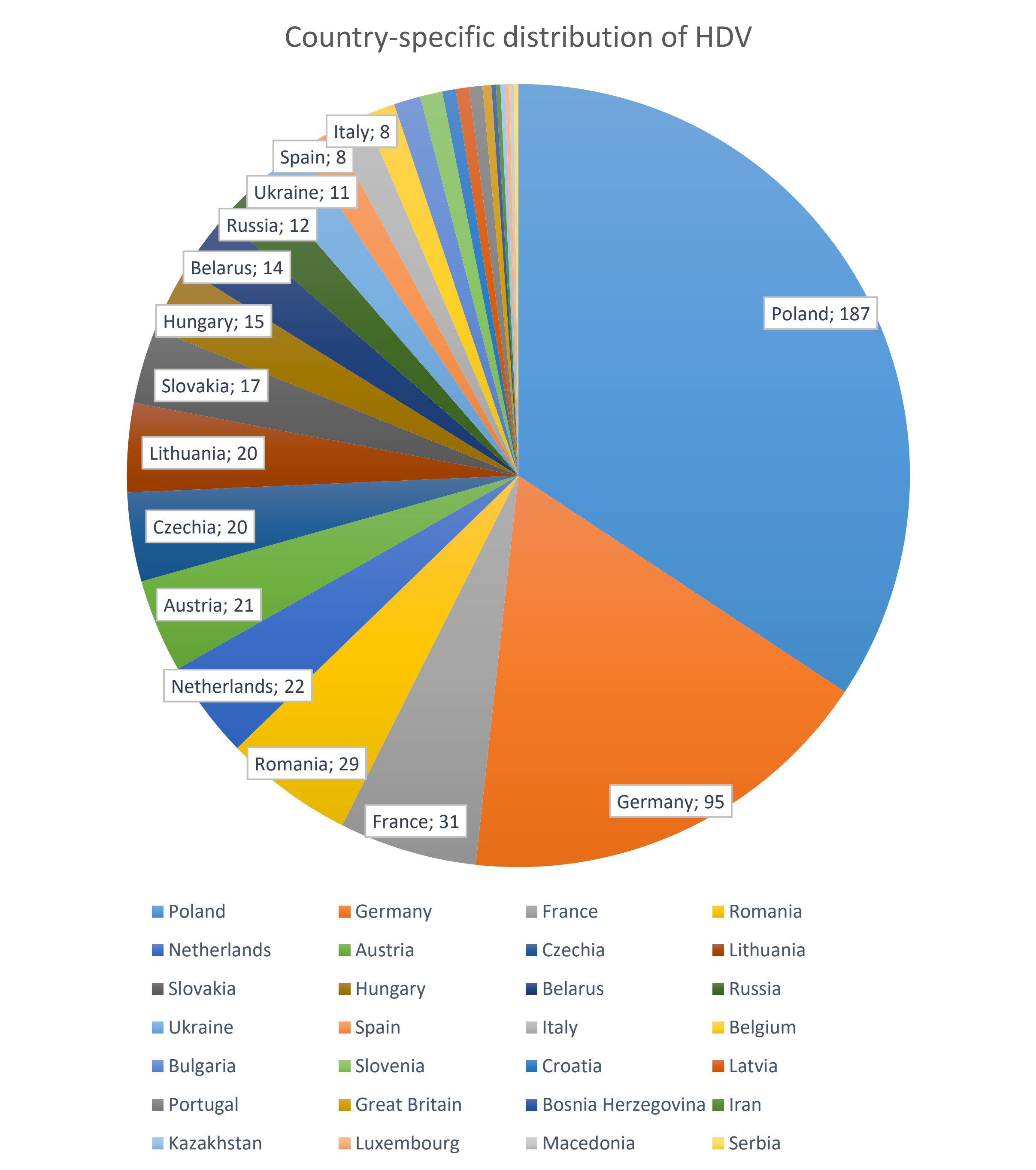

Figure 6 Country-specific distribution of HDV

Country of origin	Number	Percent
Poland	187	34,3%
Germany	95	17,4%
France	31	5,7%
Romania	29	5,3%
Netherlands	22	4,0%
Austria	21	3,9%
Czechia	20	3,7%
Lithuania	20	3,7%
Slovakia	17	3,1%
Hungary	15	2,8%
Belarus	14	2,6%
Russia	12	2,2%
Ukraine	11	2,0%
Spain	8	1,5%
Italy	8	1,5%
Belgium	7	1,3%
Bulgaria	6	1,1%
Slovenia	5	0,9%
Croatia	3	0,6%
Latvia	3	0,6%
Portugal	3	0,6%
United Kingdom	2	0,4%
Bosnia and Herzegovina	1	0,2%
Iran	1	0,2%
Kazakhstan	1	0,2%
Luxembourg	1	0,2%
Macedonia	1	0,2%
Serbia	1	0,2%
Total	**545**	

Table 1 Country of origin of the measured HDV

Of the 545 HDVs, 158 HDVs could be assigned to Euro V, 368 HDVs to Euro VI and one HDV each to Euro III and Euro IV emission standards. The remaining 17 HDVs could not be assigned to any exhaust emission standard and, like the Euro III and Euro IV HDVs, are not included in the following calculations.

Exhaust emission standard	Number	Percent
Euro V	158	30,0%
Euro VI	368	70,0%

Table 2 Distribution of measured HDV by exhaust emission standard

Averaged across all Euro V HDVs, NO_x emissions were 3,338 mg NO_x/kWh. Only 37 percent complied with the NO_x limit of 2,000 mg/kWh and only 56 percent of the vehicles complied with the NO_x threshold of 2,800 mg/kWh.

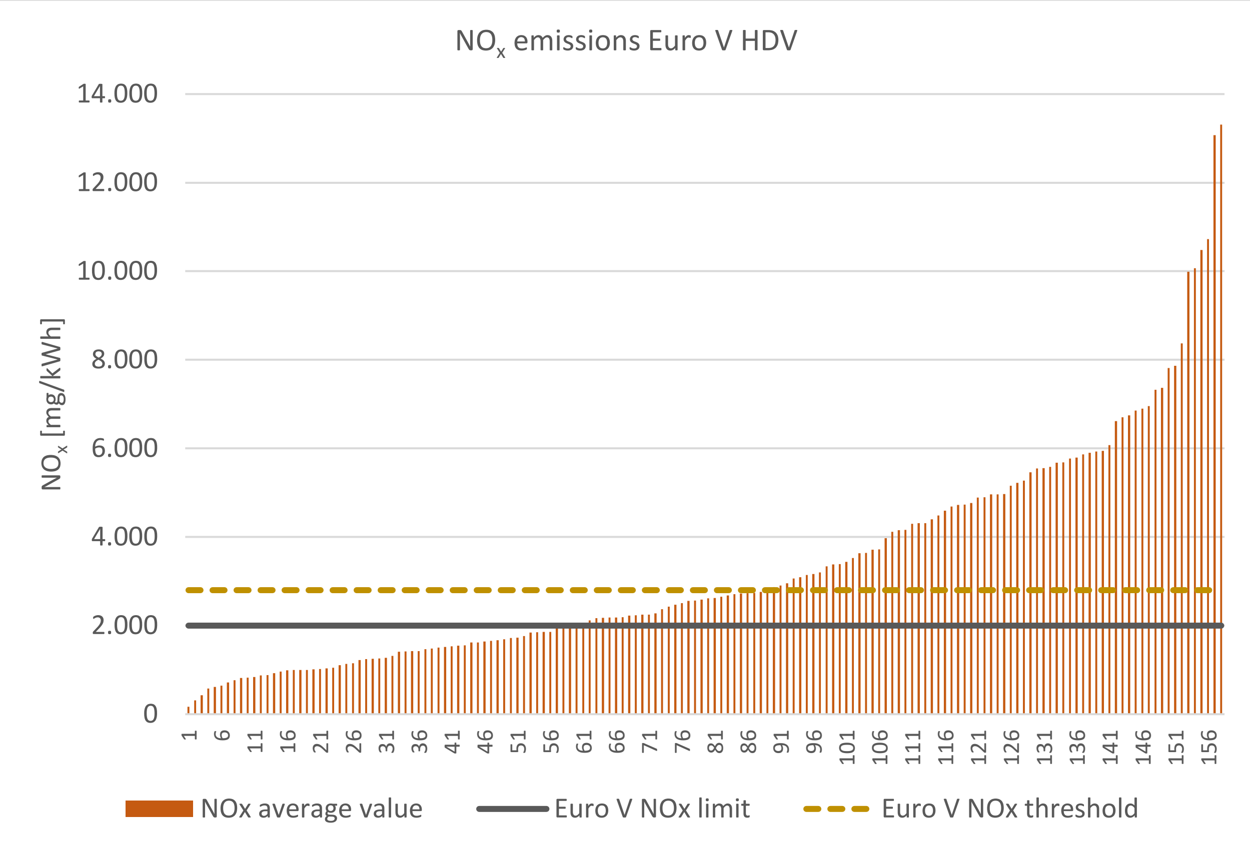

Figure 7 Overview NO_x emissions Euro V HDV

For the Euro VI HDVs studied, NO_x emissions averaged 1,067 mg/kWh. Only 46 percent of the vehicles complied with the on-road NOx limit of 690 mg/kWh (including compliance factor of 1.5). The NO_x threshold of 1,000 mg/kWh was met by 66 percent of the vehicles. For better clarity of the Euro VI HDV emission values, the NO_x scale of the graph was limited to 10,000 mg/kWh, see Figure 8.

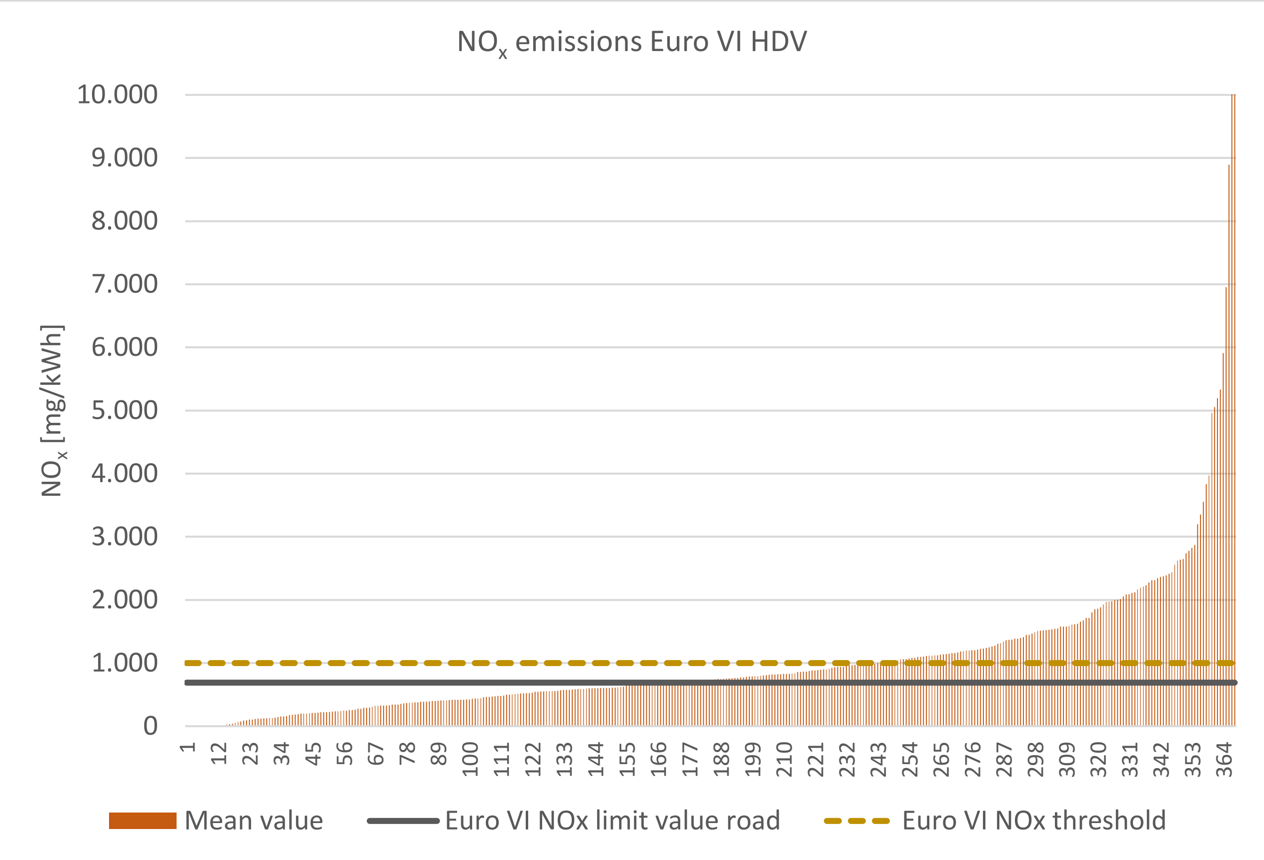

Figure 8 Overview of NOx emissions Euro VI HDV

In the further investigations it was noticed that there were always conspicuous vehicles with very high emissions (high emitters), which showed extreme NO_x emissions up to an average of 14,000 mg NO_x/kWh, in one case even over 18,000 mg NO_x/kWh, and short-term peak values (within the data segment) far above this.

For a closer look, the median of the total emissions of the measured HDV fleet was determined. This is 3,065 mg NO_x/kWh and divides the fleet into two groups, each emitting the same amount of nitrogen oxides. There are 447 HDVs below the median and 79 HDVs above. This means that 15 percent of the HDVs are responsible for half of the total emissions.

The top 5 percent emit a quarter of the total emissions and 1.1 percent, the top emitters, namely the most problematic vehicles within the measurements, cause about one twelfth (about 8 percent) of all NO_x emissions.

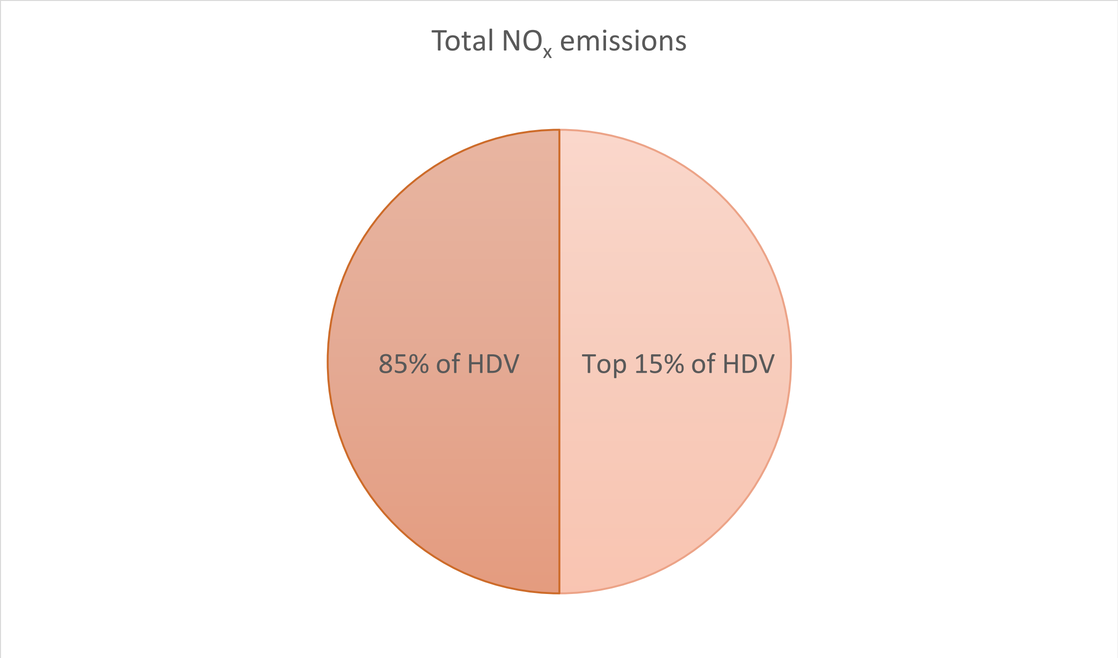

Figure 9 Distribution of total NO_x emissions

If the Euro V and Euro VI HDV are considered separately, a similar picture emerges.

The median for Euro V HDVs is 4,771 mg NOx/kWh. Of the 158 vehicles, 120 (76 percent) are below and 38 (24 percent) are above the median, each causing half of the total emissions.

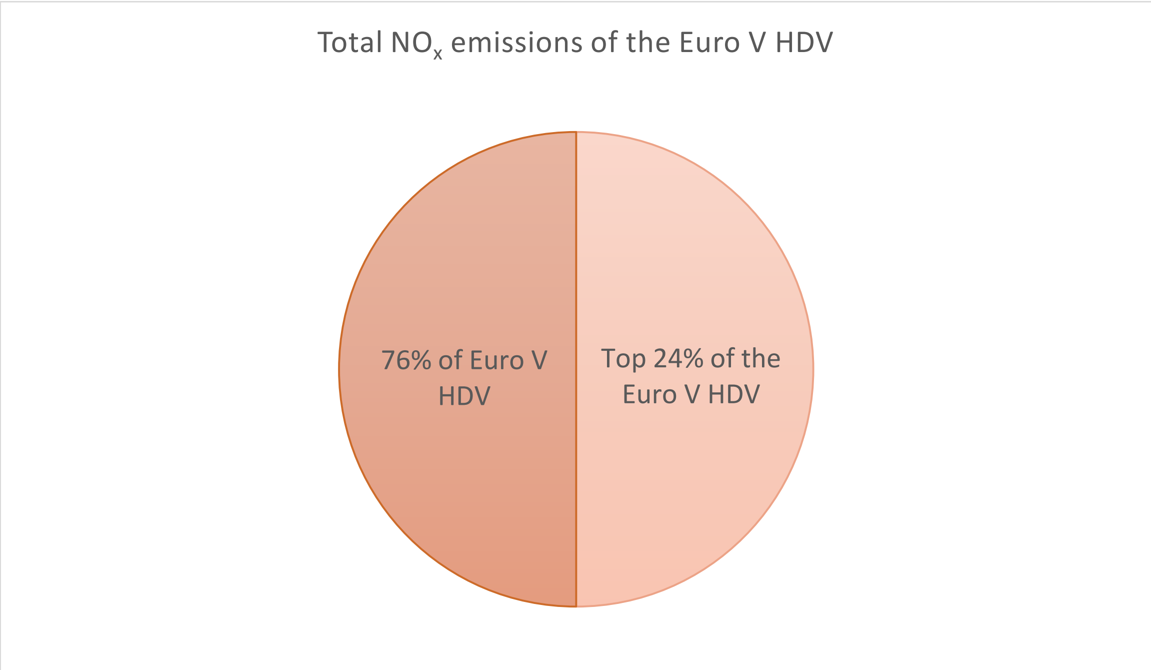

Figure 10 Distribution of total NO_x emissions Euro V HDV

For Euro VI HDVs, the median is 1,529 mg NO_x/kWh. Of the 368 vehicles, 303 (82 percent) are below the median and 65 (18 percent) are above the median, each causing half of the total emissions. The top 5 percent of Euro VI HDVs cause more than a quarter of total Euro VI HDV NO_x emissions.

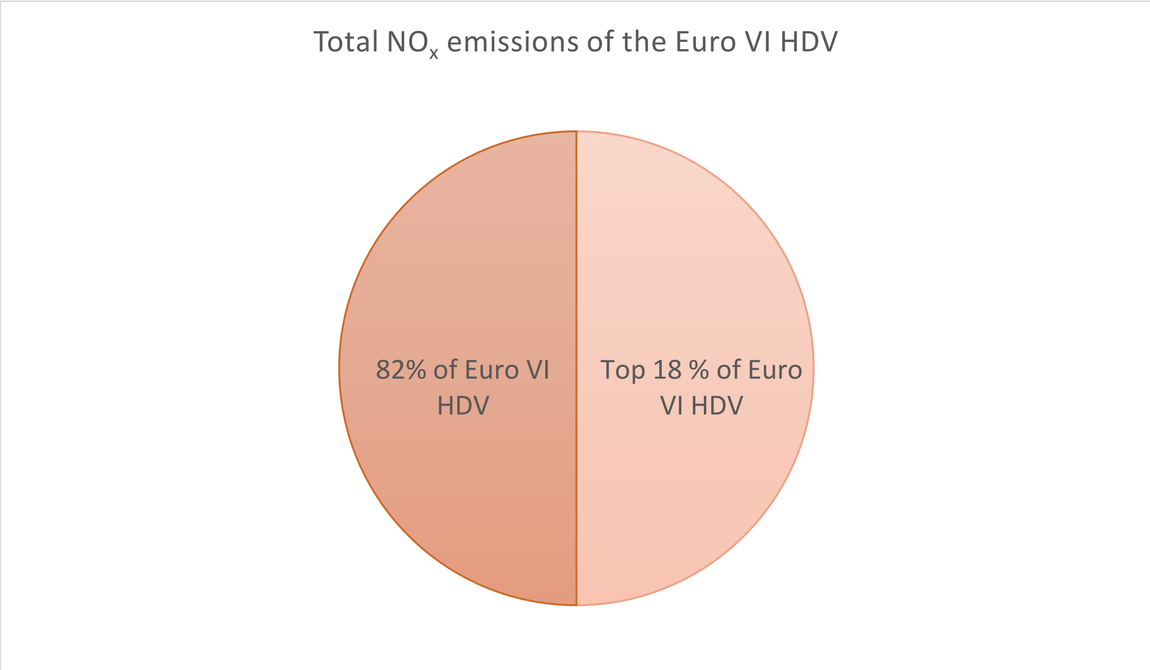

Figure 11 Distribution of total NO_x emissions Euro VI HDV

Due to indications of stricter controls and corresponding sanctions by Polish authorities regarding illegally used AdBlue emulators, separately considered measurements were carried out on HDVs on both Polish and European motorways. A comparison of the average NO_x emissions of Polish HDVs on Polish and European motorways clearly shows the impact of the random checks. The average NO_x emissions of Polish HDVs in Poland are 38 percent lower than the level of Polish HDVs on European motorways.

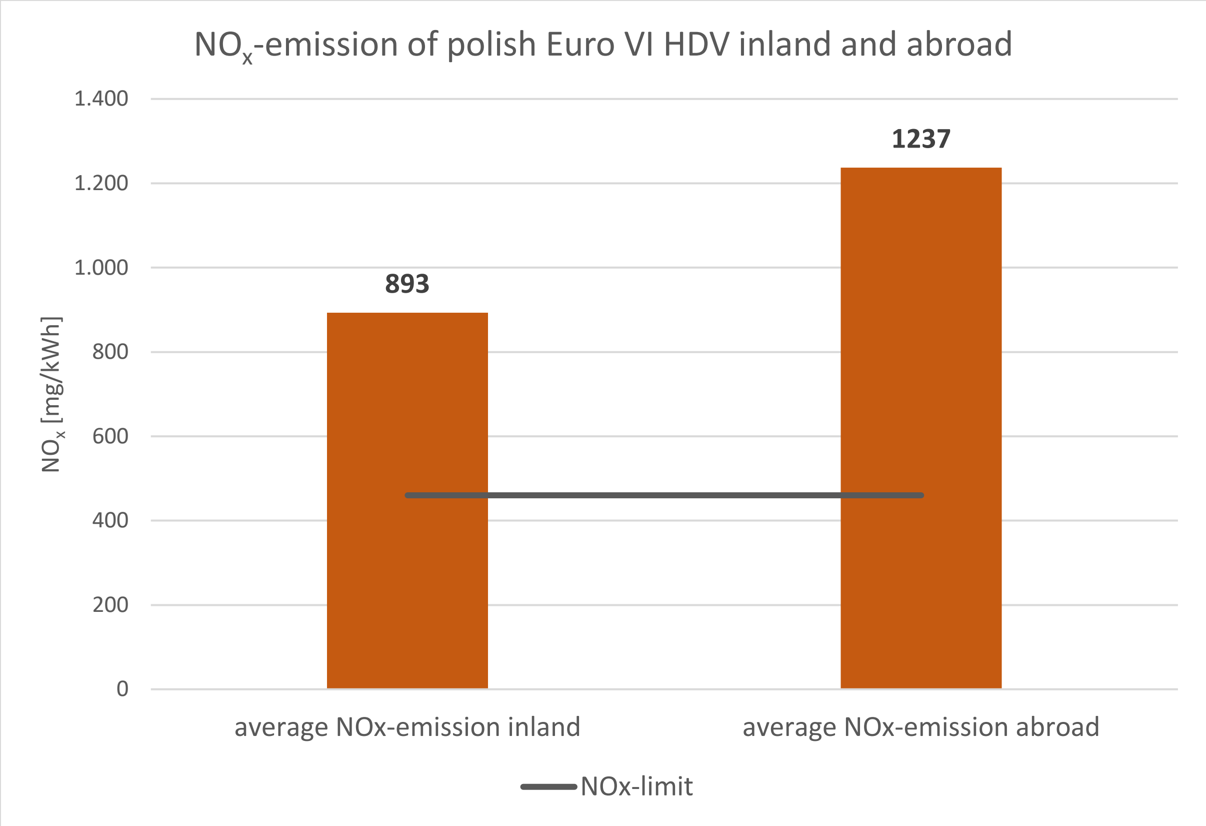

Figure 12 NO_x emissions from Polish HDVs, domestic and foreign

6. Conclusion

The NOx emissions of the HDV measured in this study show that the limit value specifications are missed by far in many cases in real road operation.

Despite the addition of a "conformity factor" and a generous error factor to compensate for measurement inaccuracy and other influences, only around half of the Euro V HDVs and around two thirds of the Euro VI HDVs were below the respective NO_x threshold. A closer look reveals that only a small proportion of the HDVs double the total emissions of the fleet. In case of Euro V HDVs 24 percent and in case of Euro VI HDVs only 18 percent are responsible for the doubling of NO_x emissions.

Based on our measurements on identical HDVs with moderate emission values, it can be concluded that the suspected high emitters have negligent or intentional technical defects or manipulations, especially in exhaust gas aftertreatment. Past publications suggest that there is a non-negligible proportion of vehicles whose exhaust gas aftertreatment or even engine control is deliberately manipulated in order to give the haulage company an unjustified competitive advantage. In this case, the urea consumption is decreased or reduced to zero by changes in the exhaust system, in the vehicle software or by the installation of a so-called AdBlue emulator. This cost saving has dramatic consequences: without the necessary urea for exhaust gas aftertreatment, NO_x emissions increase drastically, as can be seen here.

In the case of inspections by competent authorities using the procedure applied here, NO_x emission reductions could be effectively achieved with manageable effort by identifying these HDVs and subjecting them to a technical inspection and, if necessary, sanctioning and decommissioning them. The reliable identification of defective or manipulated exhaust systems using the plume chasing method is shown, for example, by the measurements on the Danish motorways.[4]

The extremely high NO_x emissions of individual HDVs not only lead to significantly higher air pollution, but also to toll fraud, since defective and manipulated exhaust systems do not comply with the specified exhaust emission standards according to which the truck toll is calculated.

The present report shows impressively that investigations and control by the relevant authorities, at least in Germany, are by far not sufficient to detect and santion the frequent exceeding of limit values and to exert sufficient pressure on the haulage companies to put an end to this misconduct.

[4] https://fstyr.dk/da/-/media/FSTYR-lister/Publikationer/ReportDenmark2020v101.pdf

Deutsche Umwelthilfe

Deutsche Umwelthilfe e.V.
Bundesgeschäftsstelle Berlin
Hackescher Markt 4
10178 Berlin
Tel.: 030 2400867-0

Projekt Emissions-Kontroll-Institut
Deutsche Umwelthilfe e.V.
Simon Annen
Projektmanager Verkehr & Luftreinhaltung
Hackescher Markt 4
10178 Berlin

Projektleiter
Dr. Axel Friedrich
Telefon: +49 152 29483857
E-Mail: axel.friedrich.berlin@gmail.com

Ansprechpartnerin
Dorothee Saar
Leiterin Verkehr & Luftreinhaltung
Hackescher Markt 4
10178 Berlin
Telefon: +49 30 2400867-72
E-Mail: saar@duh.de

Datum und Ort der Messung: 2020 bis 2021, internationale Autobahnen

Titelfoto: DUH