Deutsche Umwelthilfe

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

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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 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.

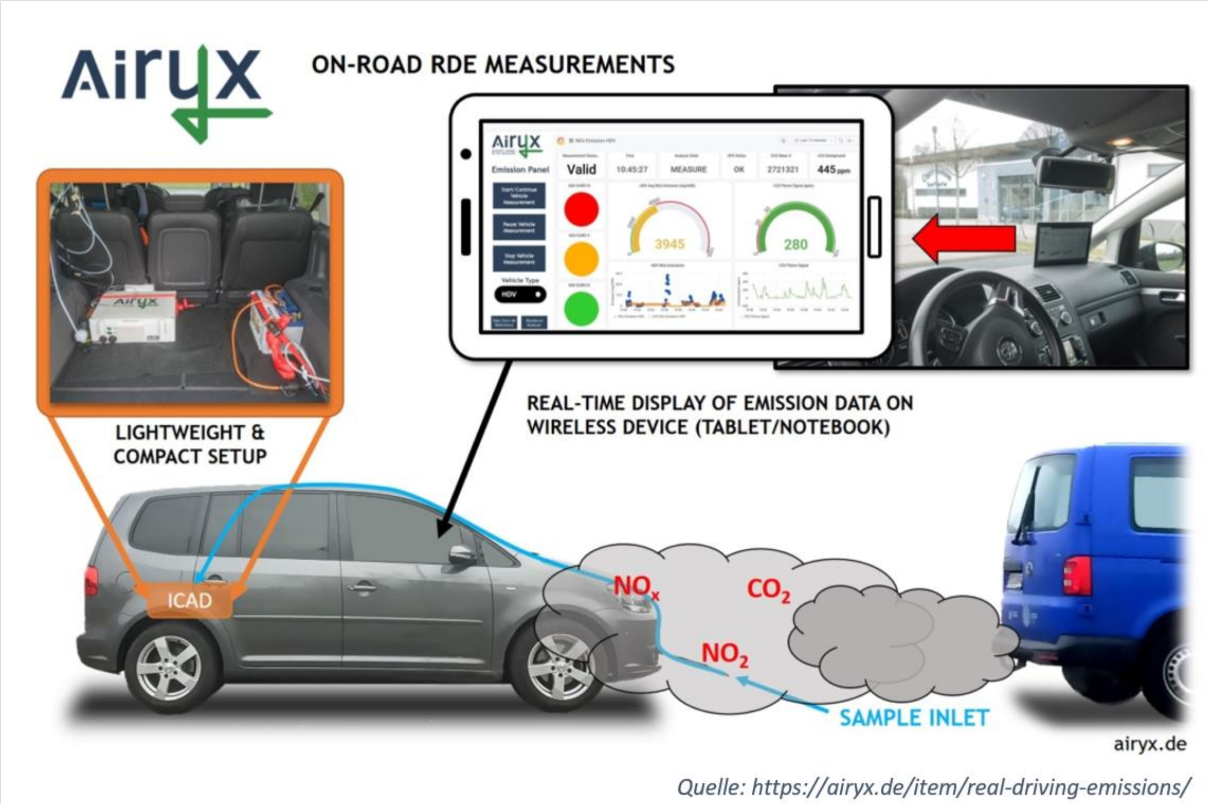

Figure 2 Plume Chasing Procedure

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 notebook, 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 assignment 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 concentration 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 sampled part of the exhaust plume. This ratio remains largely stable at different degrees of dilution 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 measurement. 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.

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

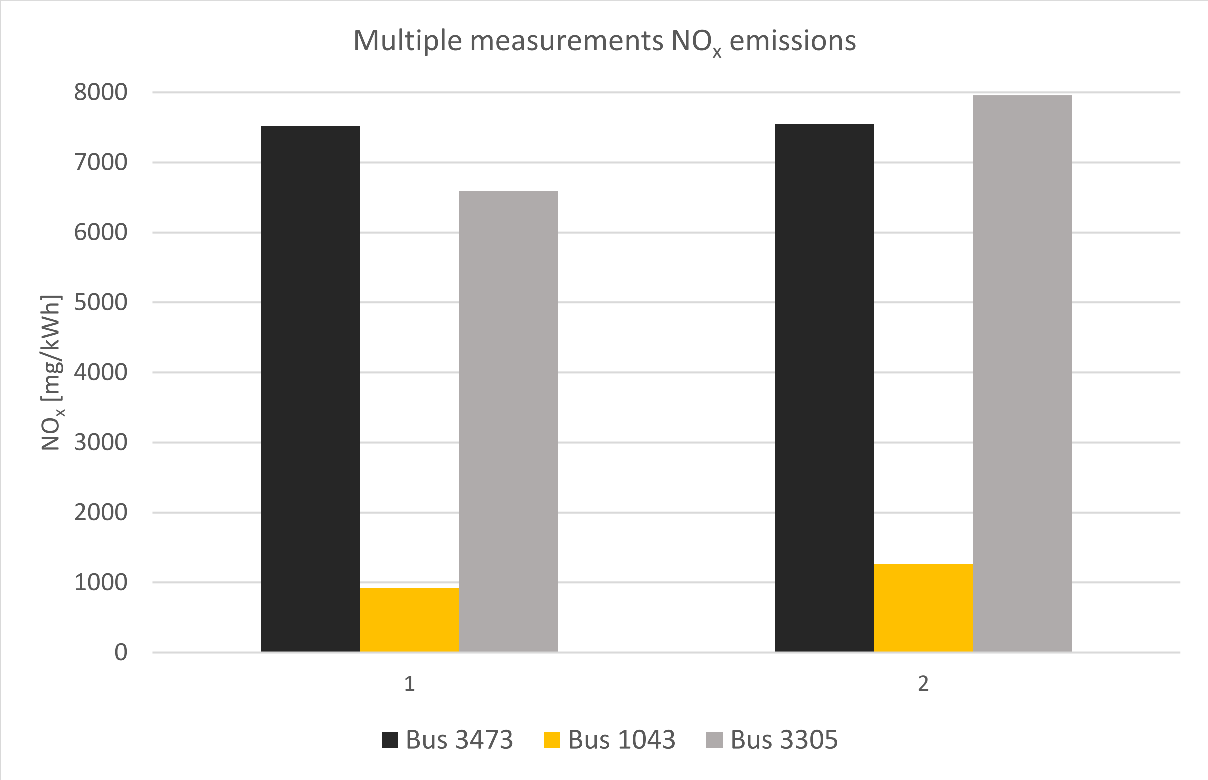

Figure 3 Reproducibility of the measurement

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).

We analyzed public diesel busses in urban areas of Berlin simultaneously with TÜV Nord to compare two different measurement methods. Our DUH EKI used the "Plume Chasing" method operating with an ICAD NOx and CO2 analyzer from AirYX GmbH whereas the TÜV Nord used the PEMS method operating with a system from SENSORS INC. The aim was to show the feasibility of future measurements with plume chasing, instead of PEMS, as there are numerous advantages. PEMS systems are quite complex to install, it needs a heating phase and a calibration run with reference gases. The results are in indeed more accurate, but the effort is quite high, compared to the fast installed plume chase system. The only challenge using plume chasing is to get valid data in heavy traffic of city centres, as external impacts are numerous and the system requires rarefied emissions.

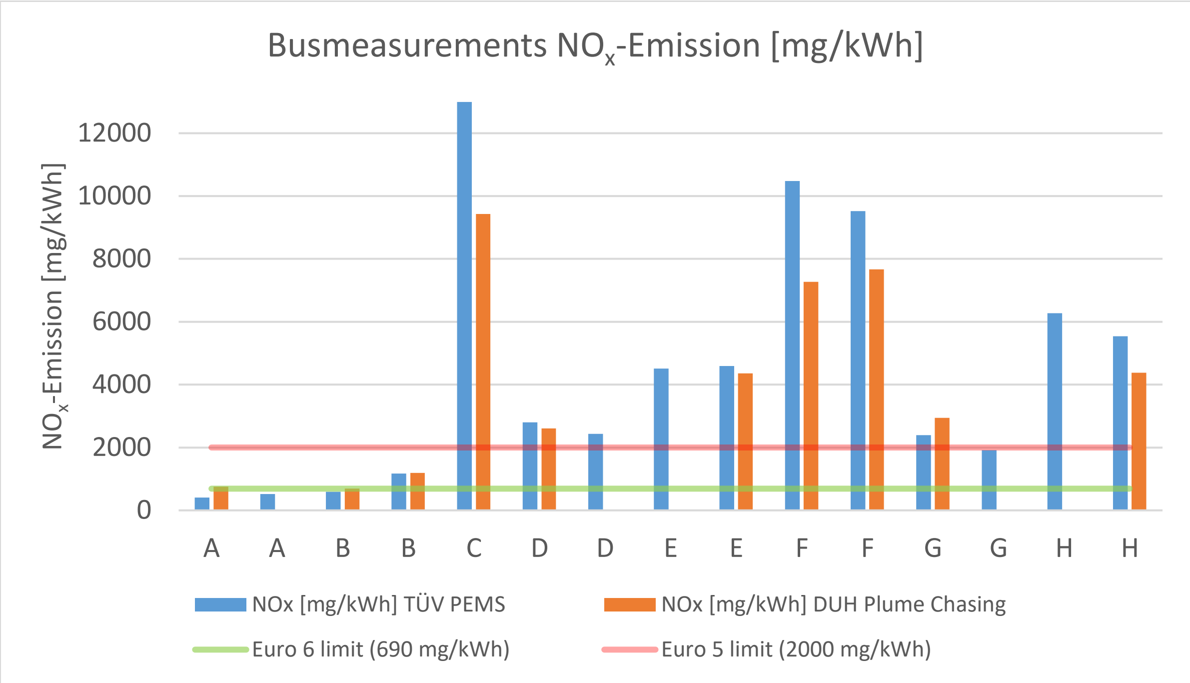

Figure 4 Comparison between PEMS and plume chasing method

The graph shows the congruence of both methods detecting high emitting, as well as low emitting vehicles, which works properly in both cases. The deviation seen for the high polluters indicates the limitation of the plume chasing method.

Nevertheless, the outcome is this method would be appropriate for future measurements to detect high emitting busses or HDVs at all. Subsequently these vehicles could be ruled for further tests or even fined.

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.

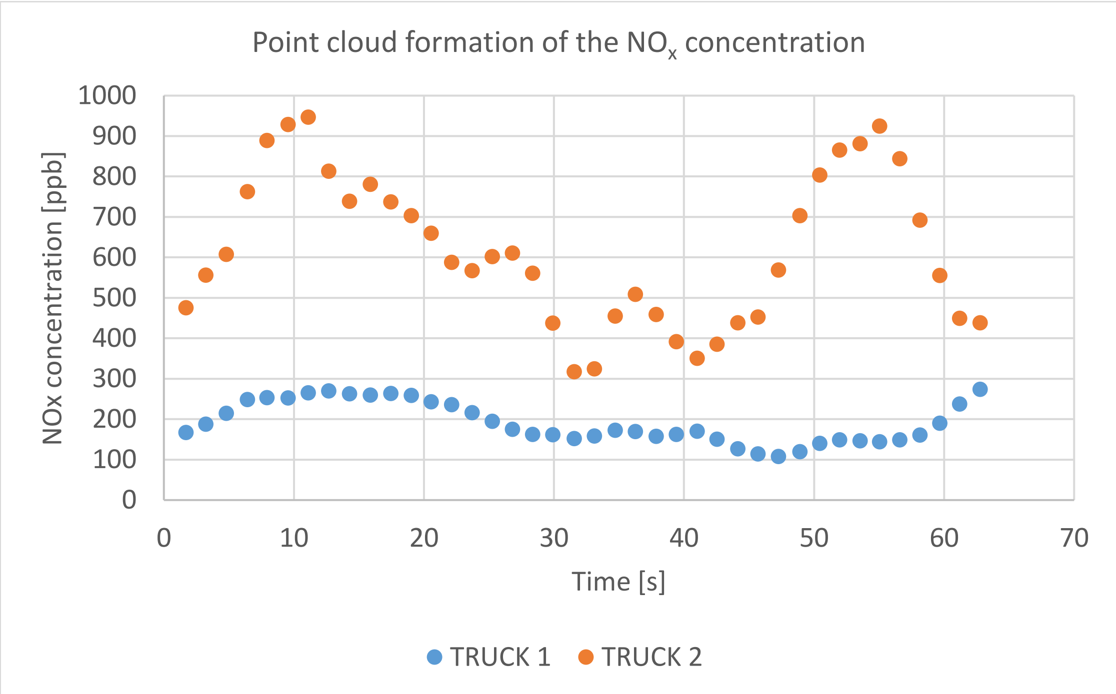

Figure 5 Point cloud formation of NOx concentration

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 of these, 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.

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