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TNO report

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Dutch In-service Emissions Measurement and Monitoring Programme for Heavy-Duty Vehicles 2021

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Samenvatting

In het Nederlandse emissiemeet- en monitoringsprogramma voor zware bedrijfswagens wordt de schadelijke uitstoot bepaald van representatieve voertuigen uit de Nederlandse vloot. Het doel hiervan is om de ontwikkeling van de uitstoot te volgen en het niveau van de uitstoot van deze voertuigen vast te leggen.

Het meet- en monitoringprogramma in het algemeen
De gegevens die in de meet- en monitoringsprogramma's zijn verzameld, vormen de basis voor de vaststelling van de officiële getallen voor praktijkemissies – de zogenaamde emissiefactoren – die TNO jaarlijks oplevert. Emissiefactoren worden gebruikt op landelijk, regionaal en gemeentelijk niveau als input voor rekenmodellen voor voertuigemissies (VERSIT+) luchtkwaliteit, emissieverspreiding en stikstofdepositie (NSL-monitoring[1] en AERIUS[2]), en voor de beoordeling van huidig en voorgenomen beleid. Deze getallen vormen tevens de basis voor de nationale en internationale rapportages over de emissies (IIR en NIR rapportages[3] onder de Emissieregistratie rapportages en luchtkwaliteitskaarten GCN/GDN[4]). Daarnaast heeft de monitoring als doel om te bepalen of voertuigen onder druk van de strenger wordende Europese emissiewetgeving daadwerkelijk schoner worden en of zij in de praktijk ook schoon blijven over hun gehele levensduur. Het programma beoogt niet alleen representatieve gegevens te leveren over het niveau van de praktijkuitstoot maar signaleert ook eventuele problemen die kunnen leiden tot verhoging van deze uitstoot. De ontwikkelingen worden jaarlijks gerapporteerd.

Het meet- en monitoringprogramma in 2021
Momenteel zijn veel dieselvoertuigen uitgerust met een boordsysteem dat gegevens verzamelt zoals het brandstofverbruik en het AdBlue verbruik. Deze gegevens zijn real-time, op afstand in te zien door de vlootbeheerder. Deze functies worden vaak tegen betaling door de fabrikant ter beschikking gesteld. Een voertuig beschikt ook over sensoren die het mogelijk maken om de NO_x-emissies continu te monitoren, maar deze gegevens worden niet aan de gebruiker van het voertuig ter beschikking gesteld. Tot dusver worden de sensorgegevens alleen gebruikt voor de aansturing van het emissiebeheerssysteem. Deze gegevens kunnen echter ook voor controle van de emissies van het voertuig worden gebruikt. Specifiek doel van het meet- en monitoringsprogramma voor 2021 was om het potentieel te onderzoeken van continue emissiemonitoring in de toepassing van controle van de emissies. Het gaat hierbij dan in het bijzonder om de nauwkeurigheid en betrouwbaarheid van het monitoringssysteem voor met name NO_x, en de beschikbaarheid van gegevens. Een mogelijke controletoepassing is dat voertuigeigenaren door middel van continue NO_x-monitoring aantonen dat hun voertuig tijdens het gebruik in de praktijk aan specifieke NO_x-(praktijk)normen heeft voldaan. Dergelijk praktijk emissie-eisen zouden als onderdeel van duurzaam inkopen door de overheid bij aanbesteding van projecten of bij vergunningverlening met inzet van dieselauto's kunnen worden vereist.

[1] https://www.nsl-monitoring.nl/
[2] https://www.aerius.nl/nl
[3] http://www.emissieregistratie.nl/
[4] https://www.rivm.nl/gcn-gdn-kaarten

Monitoring als middel om de NO_x-uitstoot te controleren
Voor vrachtwagens worden nog regelmatig problemen geconstateerd met storingen, veroudering en manipulatie van de emissiebeheerssystemen.
Daarom zijn de mogelijkheden voor monitoring van de NO_x-emissies onderzocht. Er is vastgesteld dat vrijwel alle nieuwe vrachtwagens met een dieselmotor beschikken over een meetsysteem met sensoren dat de NO_x-uitstoot kan meten. Een enkele fabrikant in de EU monitort de NO_x-uitstoot al op afstand voor interne doeleinden. NO_x monitoring wordt al vereist in China. In 2022 wordt in California *NO_x tracking* verplicht waarbij informatie over de NO_x-uitstoot in de computer van de vrachtwagen wordt opgeslagen die daarna kan worden uitgelezen bij een inspectie of periodieke keuring. De standaardisatie van de meting, de nauwkeurigheid, de betrouwbaarheid, de beveiliging en de beoordeling van de emissieniveaus van individuele voertuigen zijn belangrijke aandachtspunten. Voor monitoring op afstand moet ook rekening worden gehouden met privacy. Monitoring van de NO_x-uitstoot van een voertuig vergt een regelmatige validatie van de NO_x-sensor. Die validatie kan bijvoorbeeld bij een periodieke keuring worden gedaan samen met een controle van de werking van het roetfilter. NO_x-monitoring via boordsignalen kan onder bepaalde voorwaarden worden gezien als een veelbelovende methode om de NO_x-emissieprestatie te beoordelen.

De nieuwste vrachtwagens stoten minder NO_x uit op de snelweg
Uit de metingen en analyses die in 2021 zijn gedaan kwam naar voren dat de nieuwste vrachtwagens, die sinds september 2019 moeten voldoen aan de aangescherpte Euro VI step-D norm, weer een beetje schoner zijn geworden ten opzichte van de voorgaande Euro VI normen voor wat betreft de NO_x-uitstoot op de snelweg. Het aantal metingen is nog wel laag (n=5). De trend dat vrachtwagens bij lage gemiddelde snelheden meer NO_x uitstoten dan op de snelweg blijft ook voor de nieuwste vrachtwagens met een Euro VI step-D motor duidelijk zichtbaar.

De NO_x-uitstoot op stedelijke wegen is nog onevenredig hoog
Omdat NO_x-beheerssystemen van Euro VI vrachtwagens suboptimaal kunnen presteren bij lage rijsnelheden, was de vraag hoe hoog de uitstoot van het schadelijke NO_x is wanneer voertuigen in stedelijke omgeving rijden.
De NO_x-emissies op stedelijke wegen zijn geëvalueerd en disproportioneel hoog bevonden ten opzichte van de limietwaarde.

Verdere verlaging van NO_x-uitstoot op stedelijk wegen vergt verbreding EU testeisen
De huidige EU standaard (EU VI Step A t/m D) en bijbehorende eisen dekken deze situatie dus nog steeds niet goed af. Behalve voor stadsbussen ontbreekt het aan afdoende controle van de emissies onder stadse rijomstandigheden, in de normale gebruiksconfiguratie van een voertuig. Ook is het in sommige gevallen moeilijk om een geldige conformiteitstest te rijden op de openbare weg, waardoor de test moet worden aangepast in overleg met de typegoedkeuringsinstantie. Normale rijomstandigheden worden daardoor uitgesloten en de aanpassing kan leiden tot een versoepeling van de testomstandigheden. Het is daarom wenselijk dat normale rijomstandigheden zoals rijden bij lage snelheden en stationair draaien, zoals in de stad gebruikelijk is, of rijden met gedeeltelijke belading niet worden uitgesloten maar expliciet worden meegenomen bij de evaluatie van een wegtest. Dit vereist aanpassingen van de testen voor zware bedrijfswagens voor de toekomstige, verwachte Euro VII norm.

Ammoniakuitstoot
Door de toepassing van SCR (Selectieve Katalytische Reductie)-systemen stoten dieselvrachtwagens ammoniak uit. Slecht werkende systemen kunnen een hoge uitstoot laten zien. Een analyse van indicatieve meetdata laat zien dat de spreiding groot is voor de eerste generatie Euro VI motoren (n=20). Voor de nieuwste motoren die getest zijn (n=5), ligt de spreiding en het gemiddelde lager maar de geteste voertuigen waren nieuwer tijdens de test, waardoor er minder storingen waren.

Roetfilters in orde
Vrachtwagens worden in het meetprogramma onderworpen aan een roetfiltertest zoals voor de periodieke keuring wordt vereist. Alle geteste roetfilters (n=9) laten lage meetwaardes zien ruimschoots beneden de limietwaarde voor de periodieke keuring, wat een indicatie is dat de roetfilters goed werken.

Dieselmotoren voor transportkoeling
De praktijk-NO_x-uitstoot is gemeten van een koelmachine op een lange-zware vrachtwagen-oplegger combinatie. De combinatie was voorzien van twee koelgeneratoren, één voor de vrachtauto en één voor de oplegger.
De koelgenerator van de vrachtauto is gemeten. De uitstoot was met 26 gram NO_x per uur de helft van de uitstoot van de vrachtwagen die over een zware Euro VI motor beschikt. De uitstoot van de koelmachine ligt op ongeveer hetzelfde niveau van een standaard vrachtwagen met een Euro VI motor. Evenals een eerder doorgemeten koelmachine (Vermeulen, 2021) blijkt dus dat de NO_x-uitstoot wat betreft ordegrootte vergelijkbaar is met de uitstoot van een moderne vrachtauto en de fijnstof uitstoot tenminste 10 keer zo hoog.

Zorgen over manipulatie, oudere vrachtwagens en ‘witte uitlaten’.
Euro VI vrachtwagens voorzien van effectieve emissiebeheerssystemen komen sinds 2013 voor in de vloot. Wanneer NO_x-emissiebeheersystemen goed functioneren wordt de schadelijke uitstoot van Euro VI dieselmotoren fors verlaagd. Bij slecht functioneren, door storingen, veroudering, of zelfs manipulatie van een systeem door de eigenaar, kan dit voordeel gedeeltelijk of geheel komen te vervallen. Veel voertuigen hebben al het einde van hun nuttige levensduur bereikt of hebben inmiddels veel kilometers op de teller staan. Onopgeloste storingen en veroudering kunnen leiden tot verhoogde uitstoot van NO_x en ammoniak. Witte uitslag aan de binnenkant van de uitlaten duidt op een slecht werkend SCR systeem en gaan waarschijnlijk gepaard met een hoge NO_x- en ammoniakuitstoot, waardoor het steeds belangrijker wordt om zeker te stellen dat de emissiebeheersystemen goed blijven werken. Er is tot dusver een zeer beperkt aantal oudere wagens doorgemeten. Er is dus weinig bekend over de frequentie van mogelijke problemen. Het wordt daarom aanbevolen oudere vrachtwagens te screenen en te onderzoeken of met een eenvoudige test problemen met een NO_x-emissiebeheersysteem kunnen worden vastgesteld.

Summary

The pollutant emissions of representative vehicles from the Dutch fleet are determined in the Dutch emission measurement and monitoring program for heavy commercial vehicles. The purpose of this is to follow trends of emissions and to determine the level of emissions from these vehicles.

The measurement and monitoring programme in general
The data collected in the measurement and monitoring programs form the basis for determining the official values for real-world emissions – the so-called emission factors – that TNO produces each year. Emission factors are used at national, regional and municipal level as input for calculation models for vehicle emissions (VERSIT+), air quality, emission dispersion and nitrogen deposition (NSL monitoring[5] and AERIUS[6]), and for the assessment of current and proposed policy. These numbers also form the basis for the national and international reports on emissions (IIR and NIR reports[7] under the Emission Registration Reports and Air Quality Maps GCN/GDN[8]). In addition, the purpose of the monitoring is to determine whether vehicles are also becoming cleaner under pressure from the stricter European emission legislation and whether these vehicles also remain clean over their lifespan in real world. The program aims not only to provide representative data with regard to the level of real world emissions, but also monitors whether there are problems that lead to an increase in these emissions. The developments are reported annually.

The measurement and monitoring programme in 2021
Currently, many diesel vehicles are equipped with an on-board system that collects data such as fuel consumption and, for example, AdBlue consumption. This data is real-time and can be viewed remotely by the fleet manager. These functions are often provided by the manufacturer for a fee. A vehicle also has sensors that make it possible to continuously monitor the NO_x emissions, but this data is not made available to the user of the vehicle. Until now, the sensor data has only been used to control the emission control system. However, this data can also be used to check the vehicle's emissions. The specific aim of the 2021 measurement and monitoring program is to explore the potential of continuous emissions monitoring in the application of emissions control. This concerns in particular the accuracy and reliability of the monitoring system for NO_x and the availability of data. A possible control application is for vehicle owners to demonstrate by means of continuous NO_x monitoring that their vehicle met specific NO_x (real world) standards while in use. Such real world emission requirements could be required as part of sustainable procurement by the government when tendering projects or when granting permits using diesel cars.

Monitoring as a means to control NO_x emissions
For trucks, problems are still regularly found with malfunctions, aging and manipulation of the emission control systems. That is why the options for monitoring NO_x emissions have been investigated.

[5] https://www.nsl-monitoring.nl/
[6] https://www.aerius.nl/nl
[7] http://www.emissieregistratie.nl/
[8] https://www.rivm.nl/gcn-gdn-kaarten

It has been established that almost all new trucks with a diesel engine have a measuring system with sensors that can measure the NO_x emissions. A single manufacturer in the EU already monitors NO_x emissions remotely for internal purposes. NO_x monitoring is already required in China. In 2022, NO_x tracking will be mandatory in California, with information about NO_x emissions being stored in the truck's computer, which can then be read during an inspection or periodic test. The standardization of measurement, accuracy, reliability, security and assessment of individual vehicle emission levels are key concerns. For remote monitoring, privacy must also be taken into account. Monitoring the NO_x emissions of a vehicle requires regular validation of the NO_x sensor. This validation can, for example, be done during a periodic inspection, together with a check of the particulate filter. NO_x monitoring via on-board signals can under certain conditions be seen as a promising method to assess NO_x emission performance.

The newest trucks emit less NO_x on the highway
The measurements and analyses carried out in 2021 showed that the latest trucks, which have been required to comply with the tightened Euro VI step-D standard since September 2019, have become a bit cleaner compared to the previous Euro VI standards for what concerns the NO_x emissions on the highway. The number of measurements is still low (n=5). The trend for trucks to emit more NOx at low average speeds is also clearly visible for the latest trucks with a Euro VI step-D engine.

NO_x emissions on urban roads are still disproportionately high
Because NO_x management systems of Euro VI trucks can perform sub-optimally at low driving speeds, the question was how high the emission of harmful NO_x emissions is when vehicles are driving in an urban environment. The NO_x emissions on urban roads have been evaluated and found to be disproportionately high compared to the limit value.

Further reduction of NO_x emissions on urban roads requires broadening EU test requirements
The current EU standard (EU VI Step A to D) and associated requirements therefore still do not cover low speed, low load driving situation well. Except for city buses, there is a lack of adequate monitoring of emissions under urban driving conditions, in the normal operating configuration of a vehicle. Also, in some cases it is difficult to drive a valid conformity test on public roads, so the test has to be adapted in consultation with the type approval authority. Normal driving conditions are thereby excluded and the adjustment may lead to a relaxation of the test conditions. It is therefore desirable that normal driving conditions such as driving at low speeds and idling, as is customary in the city, or driving partial load are not excluded but explicitly included in the evaluation of a road test. This requires adjustments of the tests for heavy commercial vehicles for the future, expected Euro VII standard.

Ammonia emissions
Due to the application of SCR (Selective Catalytic Reduction) systems, diesel trucks emit ammonia. Malfunctioning systems can show high ammonia emissions.
An analysis of indicative measurement data shows that the spread is large for the first generation Euro VI engines (n=20). For the newest engines tested (n=5), the spread and the mean are lower, but the vehicles tested were newer during the test, so failures are less.

Particulate filters are fine
In the measurement program, trucks are subjected to a particulate filter test as required for the periodic inspection. All tested particulate filters (n=9) show low test results, well below the current limit for the particulate filter test for periodic inspection, which is an indication that the particulate filters are working properly.

Diesel engines for transport refrigeration
Real world NO_x emissions have been measured from a transport refrigeration unit on a long-heavy truck-trailer combination. The combination was equipped with two cooling generators, one for the truck and one for the trailer. The truck's refrigeration unit has been measured. With 26 grams of NO_x per hour, the emissions were half of the emissions of the truck with a heavy Euro VI engine. The emissions from the refrigeration unit are about the same level as a standard truck with a Euro VI engine. Like a previously measured cooling machine (Vermeulen, 2021), it appears that the NO_x emissions are comparable in order of magnitude to the emissions of a modern truck and the particulate emissions are at least 10 times higher.

Concerns about manipulation, older trucks and 'white exhausts'.
Euro VI trucks equipped with effective emission control systems have been in the fleet since 2013. When NO_x emission control systems function properly, the pollutant emissions of Euro VI diesel engines are significantly reduced. In the event of malfunctioning, due to technical failures, ageing, or even manipulation of a system by the owner, this advantage may be partially or wholly lost. Many vehicles have already reached the end of their useful life or have many kilometres on the odometer. Unresolved malfunctions and aging can lead to increased emissions of NO_x and ammonia. White deposits on the inside of the exhausts indicate a malfunctioning SCR system and are likely to be associated with high NO_x and ammonia emissions, making it increasingly important to ensure that emission control systems continue to operate properly. So far, a very limited number of older cars have been measured. Little is therefore known about the frequency of possible problems. It is therefore recommended that older trucks are screened and examined to see if problems with a NO_x emission control system can be identified with a simple test.

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1 Introduction

1.1 Background

Reduction of pollutant emissions from vehicles is desirable from an air quality point of view and for the reduction of nitrogen deposition and eutrophication in nature reserve areas. Well-founded and first-hand knowledge of the real-world emissions of vehicles in normal use helps to follow trends, identify problems and establish representative data needed as input for emissions models, policy making and purchase decisions for cleaner vehicles. To serve these needs, the Dutch In-Service testing programme aims to measure and monitor on a regular basis the emissions of heavy-duty vehicles.

In the last two decades, the subsequent amendments of EU emissions regulation aimed mainly to reduce the NO_x emissions from vehicles. In the in-service emissions testing programme it was found that for heavy-duty vehicles with a diesel engine the regulation only managed to establish substantial reductions as of the introduction of Euro VI (Vermeulen et al., 2016) at the end of 2013. Studies (Vermeulen, van Gijlswijk, van Heessen, Buskermolen, & van Goethem, 2019) (Vermeulen, et al., 2021) (Mendoza Villafuerte, et al., 2021) and (Grigoratos, 2019) showed that despite the more stringent Euro VI requirements, the NO_x emissions may be higher than expected, especially at lower speeds as occur in urban driving. On motorways NO_x emissions levels were mostly on average comfortably below the level of the Euro VI emission limit.

The shortfall of the PEMS road test to control NO_x emissions at low speeds was recognized and addressed by changing the test requirements and the evaluation of the test for Euro VI certified engines. Changes in the requirements are marked as different ‘steps’. With step D, which was entered into force by September 2019, substantial improvements were introduced, aiming at a better control of NO_x emissions under low load, low speed driving conditions. The question is if these changed requirements were effective in terms of lower NO_x emissions mainly at low driving speeds as occurs on urban roads.

Since 2017, it has been known that there is large-scale manipulation of the SCR emission control systems by owners of trucks that work with the consumable reagent AdBlue. The result of the SCR manipulation is that trucks emit at least about a factor of ten more NO_x. Current truck engines are equipped with an on-board diagnostic system to monitor the operation of components of the emission control systems. However, this system can also be manipulated. There is not yet a good enforcement to prevent manipulation; During the mandatory periodic inspection, a vehicle is not examined for tampering, the frequency of roadside inspections and checks for tampering is limited and is a labour-intensive process, which means that per day only a few vehicles can actually be thoroughly checked. In addition to the manipulation, failures or deterioration of the emission control systems can occur, which can lead to an increase in emissions over time.
The malfunctions are sometimes also a reason to manipulate the systems (switch it off) so that the malfunction does not have to be repaired. This is to save the cost of the repair.

Because NO_x emission abatement systems using SCR are sensitive to manipulation, malfunctions and aging, it is desirable to investigate the possibilities of continuously monitoring of the NO_x emissions with sensors on board the vehicle.

1.2 Objectives

The general objectives of the Dutch in-service emissions testing programme are to:

- Provide the data needed for the determination of the Dutch emission factors for the Dutch fleet of heavy-duty vehicles.
- Determine trends over the different EU standards and steps: Are the vehicles getting sufficiently cleaner with each generation/step in the real world?
  - In 2021 the focus was on the determination of the level of NO_x emissions on urban roads and the latest trends of NO_x emissions for vehicles with Euro VI step D certified engines.
- Use the data and insights in discussions about the improvement of test procedures and EU standards.
  - For 2021 an additional objective of the measurements was to investigate the status quo of technical possibilities for NO_x emission monitoring of heavy-duty vehicles by means of on-board sensors.
- Screen the in-service conformity.
- Assess new/alternative technologies.
- Provide information to stakeholders, to help make purchase decisions for cleaner and more fuel efficient transport.

As indicated above the additional objective for 2021 was to investigate the potential of continuous emission monitoring in the application of emission control by means of on-board sensors. This concerns in particular the accuracy and reliability of the monitoring system for NO_x in particular, and the availability of data. A possible control application is for vehicle owners to demonstrate by means of continuous NO_x monitoring that their vehicle has complied with specific NO_x (practice) standards during real-world use. Such practical emission requirements could be required as part of sustainable procurement by the government when tendering for projects using diesel cars.

1.3 This report

This report documents the results of the measurements and data analyses that were conducted in 2021. In chapter 2 the methodology and test programme are described. In chapter 3 the results of the measurement and monitoring programme are presented. In chapter 4 emission trends as observed from the data are discussed and presented. In chapter 5 the current state of affairs of NO_x emissions monitoring is presented and discussed.

2 Methodology and test programme

For the general objectives of the programme the goal of the emissions measurement programme is to determine the real-world emission levels of representative heavy-duty vehicles of the Dutch fleet when the vehicles operate normally in their daily use.

For this year the programmes an additional objective of the measurements is to investigate the status quo of technical possibilities for NO_x emission monitoring of heavy-duty vehicles by means of on-board sensors. This concerns in particular the accuracy and reliability of the monitoring system for NO_x in particular, and the availability of data.

In the programme, both the Smart Emissions Measurement System (SEMS) and the Portable Emissions Measurement System (PEMS) are used. SEMS is used for measuring NO_x emissions during daily operation. PEMS is used for testing the in-service conformity according to formal requirements or to accurately determine emissions levels over defined on-road test trips.

2.1 SEMS, Smart Emissions Measurement System

SEMS is a sensor-based system developed by TNO [Heijne et al., TNO 2016a] and is used in the programme to measure and analyse the tail-pipe NO_x emissions during daily operation and a range of vehicle/engine parameters to be able to characterize the typical operation of the vehicles. In this way, for the group of vehicles, weeks up to months of data was collected per vehicle. The SEMS uses a calibrated automotive NO_x sensor, an ammonia sensor, GPS and a data-acquisition system to record the sensor data and data from the vehicle and engine at a sample rate of 1Hz. The system can operate autonomously and wakes up at ignition/key-on of the vehicle. The system can be stowed away so that normal operation is not hindered by the measurement. The recorded data is sent hourly to a central data server.

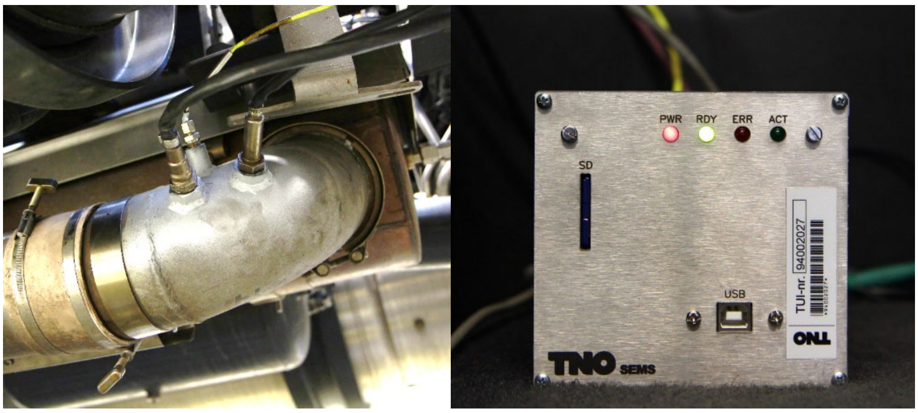

Figure 2-1: SEMS. *Left*: calibrated NO_x-O_2 sensor, NH_3 sensor and temperature sensor mounted in the tail-pipe. *Right*: autonomously running data recording unit with hourly data transmission to a central server via GPRS.

The raw data on the central server is post-processed automatically to filter and check the data. Sensor output is corrected using sensor specific calibration values. Mass-emissions and instantaneous engine power are calculated combining sensor data and engine and vehicle data such as manifold-air flow, fuel rate, engine torque, engine speed and sensor O_2 concentration where possible. For the vehicles for which no sufficient engine data were available to calculate the work specific emissions, an estimation of the average brake specific fuel consumption and CO_2 emission of the engine was used to estimate the vehicle's emissions in g/kWh.

2.2 On-board NO_x measurement

All recent heavy-duty diesel engines have an automotive NO_x sensor in the tail pipe that measures the NO_x and oxygen concentration of the exhaust gas.
The measured value is broadcasted together with other parameters from the engine and the vehicle on the vehicles internal communication network, the CAN bus and are available as digitally recordable values on the standardized OBD port.
The measured values and engine parameters together enable the calculation of the NO_x mass emissions from the tail pipe in grams per unit of time, work or distance.

2.3 PEMS, Portable Emissions measurement System

For more accurate technology assessment and in-service conformity checking a Portable Emissions Measurement System (PEMS) has been used to measure the NO_x emissions on the public road. A limitation is that the formal tests are bound to well-defined test routes and represent only a few hours of vehicle operation while a merit is the more accurate measurement and the fact that it is the formally prescribed instrument for off-cycle type-approval testing and in-service conformity testing[9] of Euro VI and Euro VI certified engines in heavy-duty vehicles. The PEMS used for the programme is a Horiba OBS-ONE. The formally prescribed pass-fail evaluation method is followed to evaluate the in-service conformity of the regulated gaseous emissions NO_x, THC and CO.

2.4 NPET, Nanoparticle Emission Tester

Stationary measurements of the tail pipe particle number concentrations have been introduced in the program in 2018. The results are used to obtain an indication of the diesel particle filters (DPF) filtration performance. The measurements are conducted during installation of SEMS on the vehicle. For the measurements, the particle number (PN) concentration in the tail pipe is measured at idle (500-600 rpm) and at a high engine speed (1500-2000 rpm). Additionally, the ambient PN concentration is measured before and after the exhaust measurements. The instrument used is an NPET model 3795 manufactured by TSI. The instrument is meant to measure the solid particle number concentration in post DPF diesel exhaust and uses a volatile particle remover to reduce semi-volatile and nucleation mode particles.

[9] EC regulation 582/2011

Table 1: Specifications of the Nanoparticle Emission Tester, NPET.

Instrument	**NPET**
Model	3795
Range	1,000-5,000,000 #/cm^3
Mode	Semi volatiles and nucleation mode particles are evaporated and oxidized and therefore not counted
Detection efficiency	23nm: <50% 41nm: >50% 80nm: 70-130% 200nm: <200% 30nm C40 droplets: <5%
Response time 10-90%-10% 0-90%	 <5s <10s

2.5 Test vehicles and tests

In 2021 extensive measurements were done on a construction vehicle using SEMS, PEMS and the on-board sensor signals. The vehicle was tested over formal PEMS trips as well as in normal use. A rigid-trailer combination with a transport cooling unit was measured with SEMS in normal use. The measurements are not finished in 2021, hence no results can be presented.

Table 2: Overview of test objects.

TNO Test Code photo	**Brand**	**Type**	**Use**	**Legislative category, Emissions standard**	**Power [kW] / engine # cilinders / displacement [cm3]**	**Mass running order, permissible maximum mass, maximum mass combination [t]**	**Tests**
VO_FM_######_EURVI 	Volvo	FM(X) 6x6 rigid	Construction: container crane loader	N3, VI - step D	285 / 6 / 10837	16,3 / 30 / n.a.	PEMS, SEMS PTI PN test Completed
SC_S5_######_EURVI 	Scania	S520 6x2 rigid + dolly semi-trailer	Cooled distribution/long haulage with TRU, Transport refrigeration Unit, see next row	N3, VI - step D	382 / 8 / 16353	14,9 / 28 / 50	SEMS test running (February 2022) PTI PN test on vehicle engine t.b.d.
MI_TU_R9615 	Mitsubishi TRU, Transport Refrigeration Unit, Yanmar engine	TRU: TU 100SAE , Engine: 3TNV76-XMR	Cooling cargo	Stage IIIA, category K	19.9 / 3 / 1115	n.a.	SEMS test running (February 2022)

3 Measurement programme: results 2021

3.1 Construction vehicle Volvo FMX 6x6 with Euro VI step D engine

The Volvo FMX 6x6 is a rental vehicle with a side loader, tipper container and a PTO propelled hydraulic crane, and it has all-wheel drive for off-road use and is generally used for construction material transport services, and operation on construction sites.

Table 3: Test vehicle specifications

TNO test code		VO_FM_######_EURVI
Brand	[-]	Volvo
Type	[-]	FMX VTN3R
Body	[-]	Rigid, crane, container, side loader, tipper
Vehicle Class	[-]	N3
Fuel	[-]	Trade Diesel EN590
Vehicle Identification Number	[-]	YV2X9R0E9KA850801
Swept Volume	[cm^3]	10837
Engine type		D11K380
Max. Power	[kW]	280
Euro standard	[-]	VI step D 595/2009*2018/932D
Masses: empty, running order, max permissible (from vehicle registration)	[kg]	16211, 16311, 28998
Registration Date	[dd-mm-yy]	11-10-2019
Vehicle data from board computer and OBD (Texa)		25-05-2021
Emission related diagnostic trouble codes		No
Odometer	[km]	64357
Average speed	[km/h]	24.2 km/h
Engine running hours	[h]	2655
Engine running at minimum	[h]	357 (13.4%)
PTO hours	[h]	950 (35.8%)
Avg. adblue consumption	[l/h]	0.82
Fuel consumption	[l], [l/100km]	29282, 45.4
Fuel consumption idle	[l]	769 (2.6%)
Fuel consumption PTO	[l]	3735 (12.8%)

Table 4: Overview of test trips performed, measuring tail pipe emissions with PEMS, SEMS and the on-board NO_x sensor.

Date	Test nr.	Trip	Payload [%], total vehicle mass [t]	Start condition
28 May	001	Commissioning trip EU6 N3	55, 23.2	Cold
31 May	002	EU6 N3	55, 23.2	Cold
01 June	003	EU6 N3	55, 23.2	Cold
01 June	004	Idling long	55, 23.2	
02 June	005	EU6 N3	100, 29.9	Cold
03 June	006	Trip to construction site	100, 29.9	Cold
03 June	006	Unload with crane, PTO	100-10	
03 June	006	Trip from construction site	10, 17.5	
03 June	007	Idling long	10, 17.5	
04 June	008	EU6 N3	10, 17.5	Cold
07 June	009	EU6 N3	10, 17.5	Cold

3.1.1 *Results PEMS: ISC trips*

Six PEMS trips were executed, including one commissioning trip to check route, equipment and requirements. Out of the six trips only one valid trip could be driven. For several reasons it was hard to drive a valid trip, see paragraph 3.1.6 for further discussion.

Table 5: Conformity factors and trip results of the in-service conformity trips that were driven.

Tripnr_triptype_payload%startcondition	CF NO_x 90-%	CF CO 90-%	CF THC 90-%	# (%) of valid windows	# (%) of valid urban windows	Urban/Rural /Motorway	# reference work	Test valid or invalid
Required	**<1.5**	**<1.5**	**<1.5**		**minimum of 1 urban window**	**30/25/45 +/- 5%**	**4-7 times WHTC reference work**	
001_E6N3_55C_ Comm	1.14	0.17	0.03	10231 (100%)	1191 (11.6%)	30/23/47	8.4	Reference work = invalid
002 E6N3_55C	~~3.89~~	0.04	0.02	8237 (100%)	631 (7.7%)	32/21/47	7.3	Drift check NO_x = invalid, NO_x measurement invalid (strike through), reference work = invalid
003 E6N3_55C	2.08	0.04	0.02	6547 (100%)	946 (14.4%)	36/20/44	5.9	Urban trip share invalid
005_E6N3_100C	**1.47**	**0.01**	**0.02**	**6757 (100%)**	**1193 (17.7%)**	**35/21/44**	**6.6**	**Valid trip**
008_E6N3_10C	1.17	0.09	0.07	5967 (95.6%)	0 (0%)	35/29/45	5.1	No valid urban windows = invalid
009_E6N3_10C	1.73	0.08	0.08	9695 (98.5%)	257 (2.6%)	28/21/51	7.6	Reference work = invalid, Motorway share = invalid

3.1.2 Results PEMS: averages

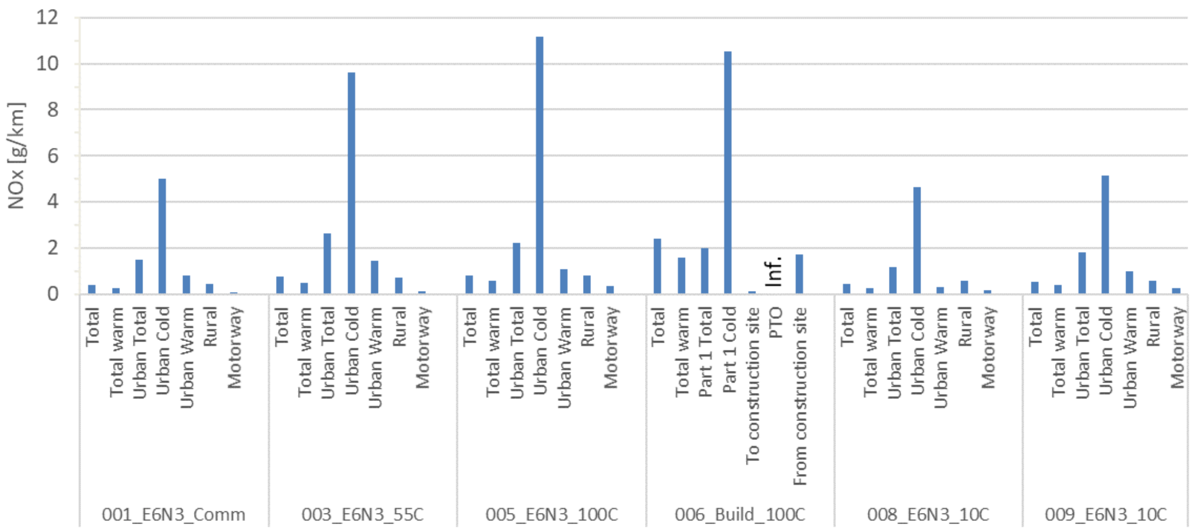

Figure 3-1: Average NO_x emissions in g/km for a total PEMS test trip and for each part of the test trip.

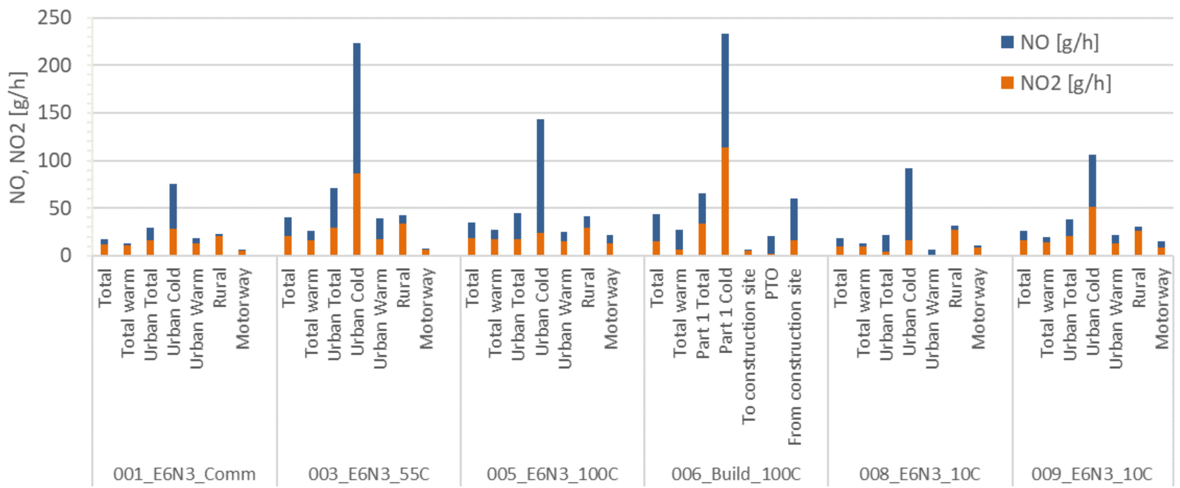

Figure 3-2: Average NO and NO_2 emissions in g/h for a total PEMS test trip and for each part of the test trip.

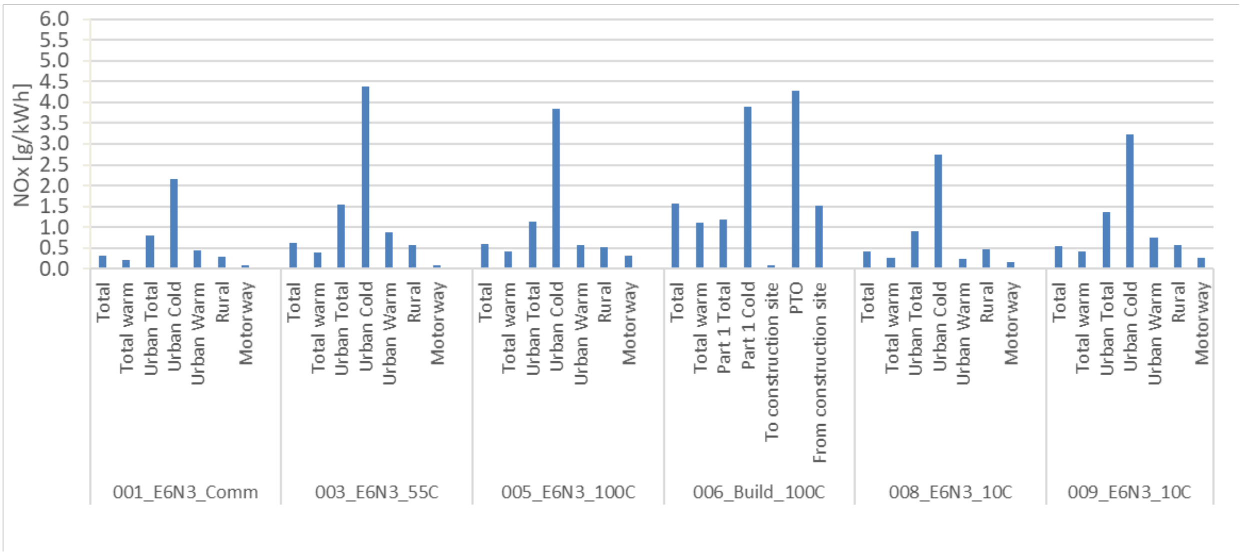

Figure 3-3: Average NO_x emissions in g/kWh for a total PEMS test trip and for each part of the test trip

3.1.3 *Results PEMS: crane usage*

During the PEMS test programme one test sequence was attributed to measuring emissions while using the PTO propelled hydraulic crane to unload Legio blocks from the vehicle, from 100% payload to 10%

Figure 3-4: Using the PTO propelled hydraulic crane to unload concrete blocks from the vehicle.

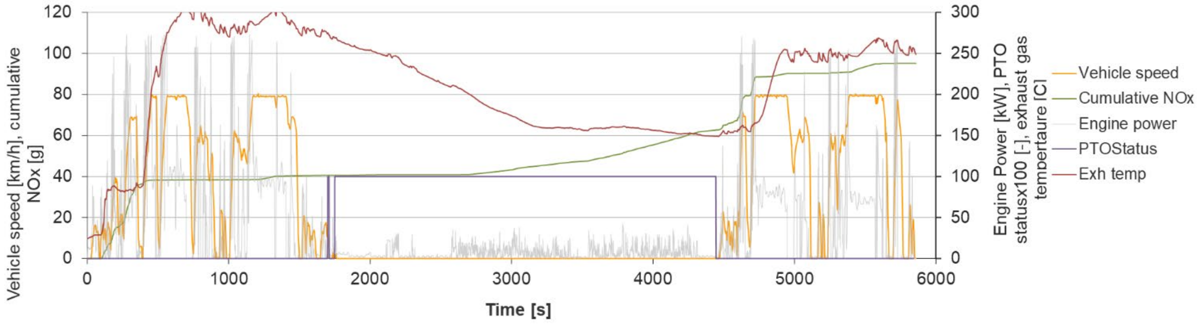

Figure 3-5: The graph above shows that during crane usage, exhaust gas temperatures post SCR decrease and eventually the NO_x emissions start to increase after about 800s. When the vehicle starts driving after the unloading, the NO_x emissions are high until the SCR has warmed up again.

The engine power during crane use is low compared to the maximal engine power. The NO_x emissions rate during crane operations are about 25 g/hr which is at a comparable level of the NO_x emissions when driving.

3.1.4 Particle number idle and high idle test

The Volvo (indicated VO185 in the chart below) was tested with the NPET particle counter at low idle (550 rpm) and high idle (1500 rpm) and a warm engine. At these conditions the particle number concentration is very low and lower than the ambient PN concentrations.

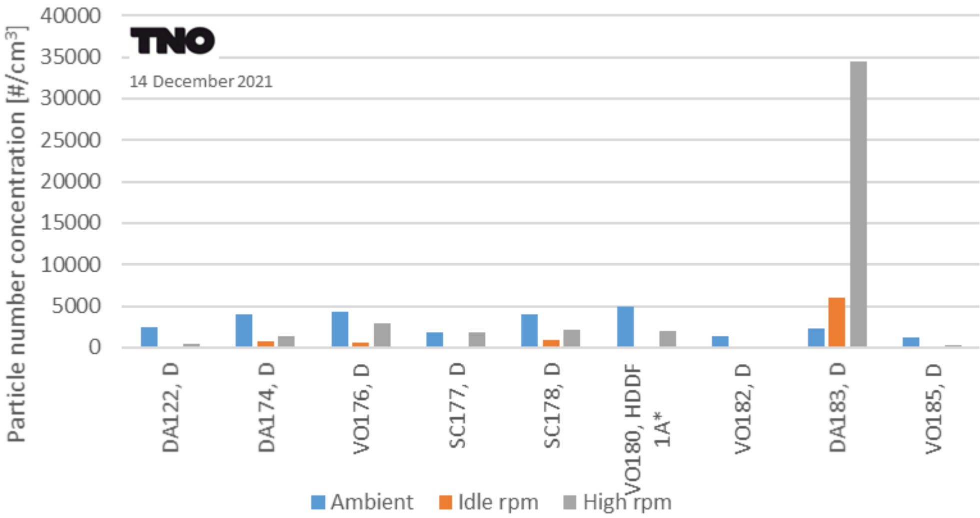

Figure 3-6: ambient and tail-pipe particle number concentrations measured with the NPET at low and high idle of the truck engine.

3.1.5 *Results SEMS: Real world usage*

Real world measurements were done during normal usage in a period from about two months.

- SEMS test period: normal operation from 8 June to 17 August 2021
- SEMS total test time: 229 h
- Average speed: 22.7 km/h
- Distance: 5383 km
- v<0.5 km/h, engine running (engine idle + PTO) usage: 49.8% of the total engine running time
- Average SEMS Sensor NO_x: 0.89 g/kWh
- Average SEMS Sensor NOx: 30.7 g/h
- Average Urban, road and motorway NO_x emissions: 3.7, 0.75, 0,11 [g/km] at average speeds of 10.8, 40.9 and 76.6 respectively.
- Average SEMS NH_3 sensor concentration: <1 ppm, with no windows lasting 30 minutes where the average NH_3 sensor concentration was higher than 10ppm (as is formally only requirement for a 30 minute WHTC test on an engine test bed).
- CO_2: 25 kg/h
- Fuel consumption: 12.7 l/h
- Fuel consumption: 57 l/100km

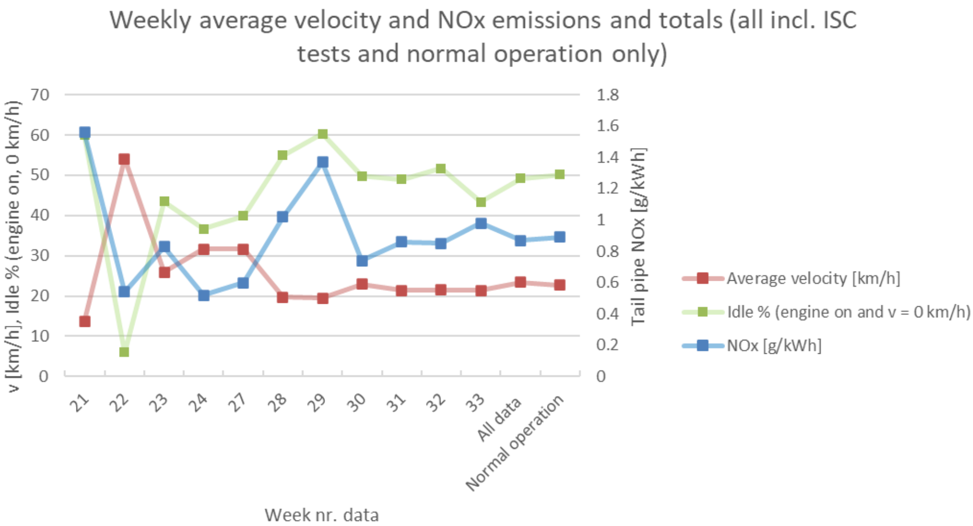

Figure 3-7: Weekly averages of NO_x emissions, vehicle speed and fraction v=0 km/h. Week 21 the PEMS was built on the vehicle and in 22 the PEMS were performed. Weeks 23 to 33 are from normal use. During the PEMS tests in week 22 the average velocity is higher and the idle fraction is lower than can be observed for normal usage for this vehicle in the weeks after. Due to driving with higher speeds and less idling, which is more optimal for SCR performance, the NO_x emissions are on the lower side, whereas in normal use the NO_x emission tend to be higher, probably this is due to the lower speeds and higher fractions of idling.

3.1.6 *Conclusions*

Based on the results of the test programme, the following conclusions are drawn:

- The Conformity Factor for NO_x over a single valid N3 trip is 1.47 and thus below the limit of 1.5. Generally, for in-service conformity testing, more than one vehicle should be tested to determine whether the vehicle type is compliant with the in-service conformity requirements. In this programme only one vehicle was tested and therefore the results are indicative only.
- It is difficult to drive a valid trip with this vehicle within the constraints of the PEMS testing and evaluation rules. See paragraph 3.1.7 for a more detailed evaluation. The trip needed to be adapted several times to be able to drive a valid trip and it only succeeded once when the payload was 100%. For other invalid trips the Conformity Factor for NO_x varied with results lower and higher than the limit of 1.5.
- The conformity factors for CO and HC emission are well below the factor 1.5 for the single valid trip and all invalid trips.
- The particle number test for periodic inspection showed very low PN concentrations indicating that the DPF is in good condition.
- In real world daily use, the level of the NO_x emissions measured with SEMS with a NO_x sensor is on average about 0.9 g/kWh which is higher than the formal test cycle limit and in-service conformity limit. It needs to be remarked that the real world conditions with a low average speed, a high share of idling and low load crane usage are demanding regarding NO_x reduction. Such conditions are however normal for such a vehicle, but formal tests do not include this kind of usage.

3.1.7 *In-service conformity testing issues*

PEMS tests performed on a 6x6 construction vehicle have shown that it can be difficult to drive a valid legal in-service conformity trip. The test facility has ample experience with driving PEMS test trips, but mainly with main stream HDVs such as tractor semi-trailers. Out of six trips, only one trip was valid. For three trips, the reference work was too high. For two trips, the share of a sub trip did not meet the requirements and for another trip there was no valid urban window. For the 6x6 construction vehicle trips needed to be adjusted to meet all the requirements. Trips with normal operation are rendered invalid and artificial changes needed to be made to drive one valid trip. A PEMS test trip needs to meet requirements regarding the shares of urban, rural and motorway driving, the amount of total work, a valid urban window after applying the 90-% rule and excluding data of cold engine operation ($T_{coolant}$ <70 ºC). Therefore, trips need to be adjusted to meet all requirements and this results in the fact that a natural, normal trip can be rendered invalid and trips need to be artificially changed to meet the requirements. It is the combination of requirements that cause this problem. For instance, after exclusion of 10-percentile of the MAW (Moving Averaging Window) a valid urban MAW should remain. At low payload and low engine power, urban MAW's are very long and thus decreases the amount of MAWs in urban driving and increase the chance that no valid urban MAW remain after applying the 90-% rule. To solve this, the urban part needs to be increased and as a result the trip work increases, because the trip shares need to be respected at the same time, while also the trip work is maximized. Examples are also known for other vehicle types, where driving needs to be adapted to meet the requirements: e.g. vehicles with a high engine power and with a low payload.

In this case, it is hard to achieve MAW with an average power higher than 10% in urban driving. To resolve this, the vehicle has to drive fast and brake hard to keep the power above the threshold.

When new procedures are designed, it should be ensured that trips are performed with normal driving for all common vehicle types, that test with normal driving are not rendered invalid, and that requirements do not lead to the necessity to make artificial changes to an otherwise normal trip to drive a valid trip.

3.2 Long haulage rigid-dolly-semi-trailer Scania S520 6x2 with Euro VI step D engine

The Scania S520 is a company owned vehicle and is generally used for national in the Netherlands and international distribution services construction services, hauling plants and flowers into Germany. The vehicle is 6X2 rigid vehicle which tows a dolly-semi-trailer. The truck has a Mitsubishi underbody mounted transport refrigeration unit to cool the rigid box interior, see paragraph 3.3. The semi-trailer has a front mounted Thermoking SLXi transport refrigeration unit to cool the trailers interior.

Table 6: Test vehicle specifications

TNO test code		SC_S5_######_EURVI
Brand	[-]	Scania
Type	[-]	S520
Body	[-]	Rigid
Vehicle Class	[-]	N3
Fuel	[-]	Trade Diesel EN590
Vehicle Identification Number	[-]	YS2S6X20005580795
Swept Volume	[cm^3]	16363
Engine type		V8
Max. Power	[kW]	382
Euro standard	[-]	VI step D 595/2009*2018/932D
Masses: empty, running order, max permissible (from vehicle registration)	[kg]	14975, 14985, 28000
Registration Date	[dd-mm-yy]	19-06-2020
Emission related diagnostic trouble codes		No (Dashboard)
Odometer (total, trip)	[km]	239313, 37919
Average speed (total, trip)	[km/h]	#, 57 km/h
Engine running hours (total, trip)	[h]	#, 663
Engine running at minimum (trip)	[h], [% of total]	153, 23
Avg. Adblue consumption (total, trip)	[l/h]	n.a.
Fuel consumption (trip)	[l], [l/h], [l/100km]	10843, 16.3, 28.6
Fuel consumption idle (trip)	[l]	402

3.2.1 Results SEMS: Real world usage

Real world measurements were done during normal usage using SEMS in a period from of three months. Note that the vehicle idles 25% of the time. The average speed is low compared to other long haulage vehicles. Partly, this is caused by the high fraction idling. Partly, this is probably caused by the fact that the vehicle is a long vehicle which cannot drive as fast as a regular vehicle on urban and rural roads. The low average speeds on urban (6.1 km/h) and rural (27.6 km/h) confirm this.

SEMS test period: normal operation from 1-11-2021 to 4-2-2022
- SEMS total test time: 214 h
- Distance: 11187 km
- Average speed: 52.4 km/h
- Idle (v<0.5 km/h, engine running idle): 25.3 %
- Average SEMS Sensor NO_x: 0.79 [g/kWh]
- Average SEMS Sensor NO_x: 56 [g/h]
- Average Urban, road and motorway NO_x emissions: 11.9, 2.9, 0.4 [g/km] at average speeds of 6.1, 27.6 and 78.9 km/h respectively.
- Average SEMS NH_3 sensor concentration: <1 ppm, with no windows lasting 30 minutes where the average NH_3 sensor concentration was higher than 10 ppm (as is formally only requirement for a 30 minute WHTC test on an engine test bed).
- CO_2: 45 kg/h
- Fuel consumption: 17 l/h
- Fuel consumption: 32.7 l/100km

3.3 Mitsubishi transport refrigeration unit

The cooling unit is a Mitsubishi underbody mounted transport refrigeration unit to cool the rigid box interior. The units internal power source is a Stage K, Stage IIIA D, 1.1 litre Yanmar diesel engine without emission abatement system. Stage III A ($19 \leq P < 37$ kW, category K) means a combined NO_x +HC limit of 7.5 g/kWh and a PM limit of 600 mg/kWh.

The NO_x emission is 26 g/h, which is about of the average NO_x emission of the Euro VI truck it is mounted on.

Based on the assumption that the unit would emit particulate matter (PM) around the Stage II limit value (0.6 g/kWh) and using emission factors for tractors for PM it can be estimated that the PM emission of this cooling unit would at least be 10 times higher than of a 300 - 400 kW Euro VI truck engine.

When active, the cooling unit ran on average for about 5.6 hours a day.
For this engine the actual engine power could not be calculated from CAN bus signals because this bus was not present. The power was modelled from the CO_2 emissions which were fitted to the max. output as provided in the engine specifications and to the minimum output without any load. Still a certain amount of uncertainty remains as the zero load point could not be determined exactly. During the tests the engine runs most in a low speed, low power.

TNO test code	**MI_TU_#####**
Brand, type	Mitsubishi TU100SAE-CNE Engine: Yanmar, 3TNV76-XMR
Configuration	Cooling unit under body
Engine power [kW], displacement [l]	19.9 kW, 1.115
Emission class	Stage IIIA (K)
Emission abatement system	-
TA number	Not found on engine/cooling unit.

Total test period [days], days active [days]	**81, 41**
Total activity [hours], [hours/day]	229, 5.6
Average power [%]	21%
Stand-by [minutes/hour]	
NO_x [g/h], [g/kWh]	26, 6.4
Total NO_x [kg]	6.1
CO_2 [kg/h]	3.3
Total CO_2 [t]	0.75
Fuel consumption [l/h]	1.21

4 Emissions trends

The data obtained from the measurements can be used to conduct additional investigations into specific topics that are important to reveal trends and for the determination of the emissions factors. The additional investigations all focus on NO_x emissions:

- NO_x emissions on urban roads and directions for a real driving emissions test.
- NO_x emissions levels of heavy-duty vehicles with a Euro VI Step D certified engine.
- Impact of (cold) starts on NO_x emissions.
- NH_3 emissions

4.1 High NO_x emissions of heavy-duty vehicles driving in urban areas and directions for a real driving emissions test.

4.1.1 NO_x problem at low driving speeds

Road transport is an important source of air pollutants and contributes significantly to emissions of harmful nitrogen oxides and particulate matter. Air pollution by road vehicles is particularly important if the emissions occur in areas with a high density of the population, where people live and work (European Environment Agency, Emissions of air pollutants from transport, 2021), (European Environment Agency, Exceedance-of-air-quality-standards in Europe, 2021). To reduce air pollution, EU emissions standards for road vehicles gradually became more stringent. Vehicle manufacturers managed to comply with the standards by introducing advanced emissions control technologies. This has led to a substantial decrease of the emissions over the last decades Several studies (Grigoratos, 2019) (Vermeulen, van Gijlswijk, van Heessen, Buskermolen, & van Goethem, 2019), however, reported a lagging decrease of the pollutant emissions under specific driving conditions of heavy-duty vehicles (HDVs) because the selective catalytic converter for the reduction of NO_x (SCR) still do not always work optimally. For heavy-duty vehicles various sources reported that the tail pipe emissions levels of NO_x are skewed towards driving at lower speeds, which means that higher levels of NO_x are observed when heavy-duty vehicles drive at these low speeds. Given the importance of air-pollution caused by road transport in populated areas, it is necessary to investigate if the high emissions of NO_x occur when driving on urban roads, in urban areas and what the level of the NO_x emissions is in this situation. Therefore, a database with emissions data of heavy-duty vehicles obtained under normal use in the Netherlands has been analysed to determine the activity and the level of NO_x emissions of HDVs driving in urban environment.

4.1.2 Database with years of data for evaluation

In the in-use testing programme for heavy-duty vehicles TNO measures and monitors the exhaust gas emissions of heavy-duty vehicles on a regular basis to investigate how much the vehicles emit in real world usage. Amongst others, this data is used to model the so-called official national emissions factors which are to represent typical real world emissions of road vehicles in-use. A database with emissions data of 37 vehicles with Euro VI certified engines, operating for weeks to months in normal use in the Netherlands and abroad, is available for analyses.

The database contains in total 4.6 years and 1.9×10^6 km of data (average speed is 47 km/h) of various types of HDVs, such as long haulage vehicles, distribution trucks, refuse collection vehicles, buses and construction vehicles as operated in their daily duty. The database includes, next to emissions data, GPS and data from the vehicle that allows the attribution of the emissions to road type. For the exercise the road types *urban, rural and motorway* were distinguished for all vehicles. This distinction was made by coupling GPS location to Open Street Maps to determine the speed limit for each relevant road, and thereby which road types should be assigned to the data. Remark is that speed limits for driving on private roads or terrains, driving in tunnels and data without GPS signal due to signal loss, could not be assigned. Remark is that data of driving on private roads or terrains, driving in tunnels and data without GPS signal due to signal loss, could not be assigned. Overall usage was categorized as *refuse collection, city and regional bus operation, local, national and international distribution (long haulage), construction and other use*. For the various types of heavy-duty vehicles in the database the shares of driving and the NO_x emissions were determined over the three road types and for roads that couldn't be categorized for all vehicles.

4.1.3 Heavy-duty vehicles usage

City buses obviously drive most on urban roads, followed by refuse collection vehicles. These vehicles operate in urban areas, but some refuse collection vehicles and regional buses also service small towns and villages due to which the share of rural and motorway driving can be higher. Long haulage trucks drive the lowest fraction on urban roads. For local and national distribution, fractions of urban driving are higher than for long haulage and shows more variation. These vehicles service for instance companies, distribution centres and shops that often happen to be located in urban regions. Construction vehicles also service urban areas, the amount of time depending on the location of the constructions site. For all vehicles, a varying part of the driving cannot be attributed to a registered road type, but it is observed from the GPS locations that most of this driving is at private yards such as distribution centres, depots or construction yards. Additionally, as small share represents data with GPS signal loss for which no location could be defined.

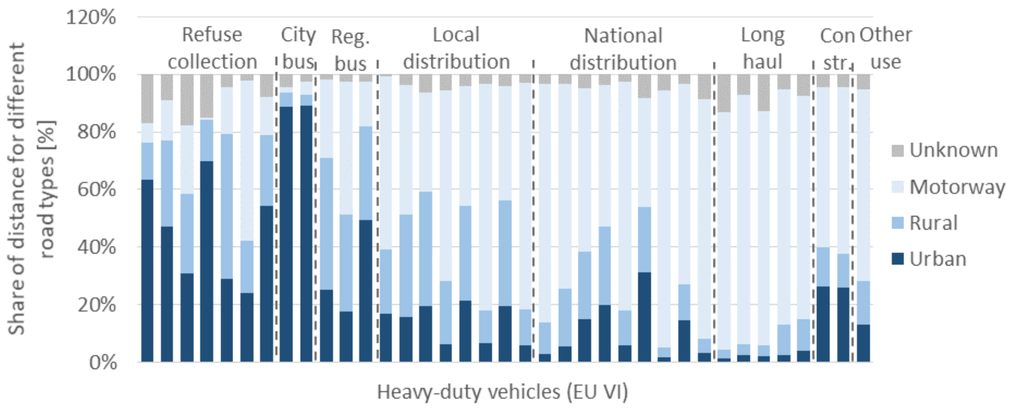

Figure 4-1: Share of the total distance driven for different road types urban, rural and motorway and vehicle usage categories. A share of the data can't be assigned to a road type, most of this data probably concerns private yards or roads.

Looking at trip distance of heavy-duty vehicles it appears that for the whole database, almost 50% of the trips (key-on to key off) are shorter than 10 km.

Analyses showed that for a lot of the vehicles these trips are for instance for manoeuvring around a depot, shunting trailers and short trips for servicing the vehicle.

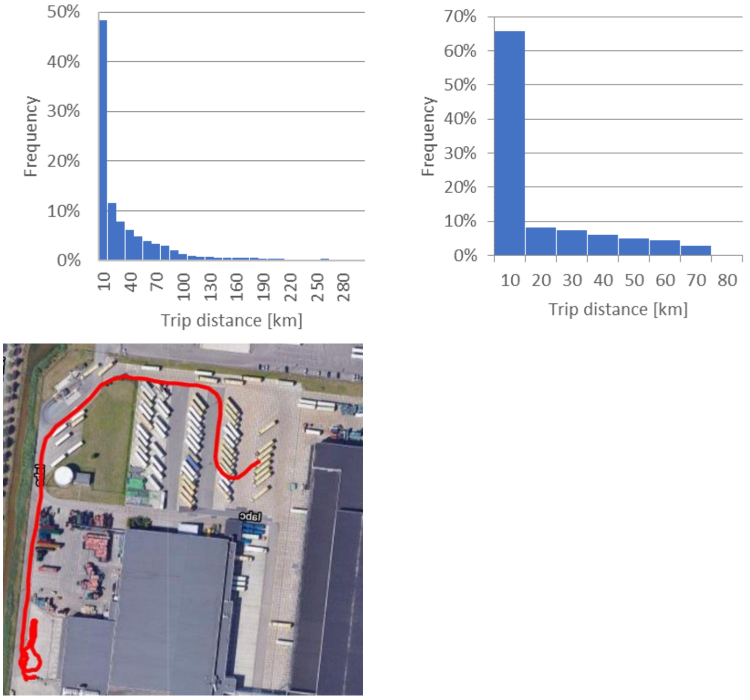

Figure 4-2: Above left: frequency distribution of trip distance of the entire database. About half of the trips are shorter than 10km. Above right: example of the frequency distribution of trip distance of a tractor semi-trailer used for supermarket distribution.
Below: example of typical short trip of a tractor semi-trailer, manoeuvring on a distribution yard.

4.1.4 *NO_x emissions on urban roads*

When NO_x emissions levels of driving on urban roads are analysed, it can be observed that on urban roads almost all vehicles emit more NO_x than the type-approval limit value of 460 mg/kWh for a Euro VI engine, and that in most cases these emissions are substantially higher than on motorways. This clearly shows the skewedness of the emissions, not only towards lower speeds and loads as observed in earlier investigations, but also towards driving on urban roads in densely populated areas.

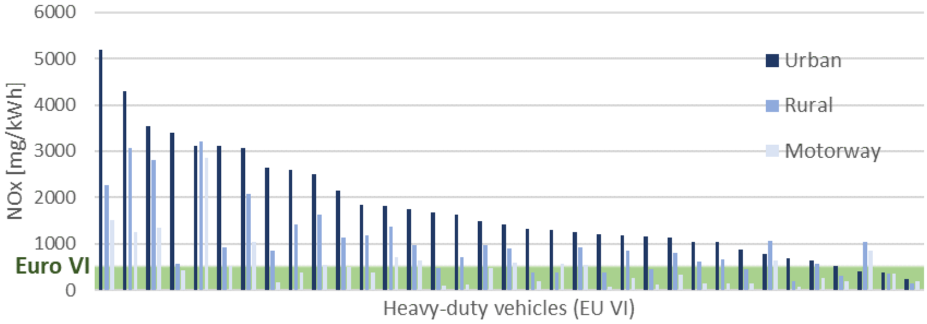

Figure 4-3: Average work specific NO_x emissions for a number of HDVs, when vehicles drive on urban roads, rural roads and motorways.

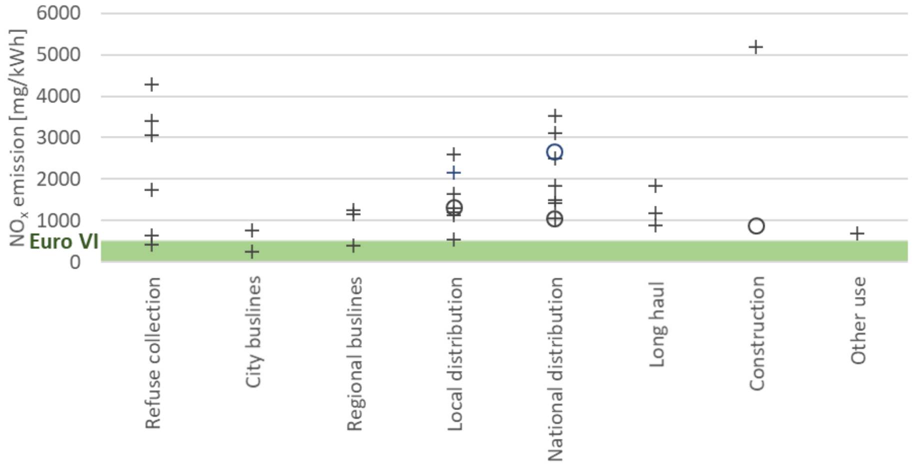

Figure 4-4: Average work specific NO_x emissions when vehicles drive on urban roads. In real-world urban use, the NOx emissions levels clearly exceed the limit that is set for type approval of a Euro VI certified engine (upper edge of green area). Vehicles with Step-D certified engines are marked with a circle.

The fact that NO_x emissions levels are higher on urban roads lead to the situation that a substantial share of the NO_x emissions of HDVs takes place in an urban environment. For city buses and refuse collection vehicles this is obvious, about 60% to 90% of the total NO_x emission are emitted on urban roads. For vehicles for the transportation of goods operating in local, regional and national distribution services (from 12 ton rigid trucks to 44 ton tractor semi-trailers) the NO_x emission is also substantial and ranges from 22% to 40%. For regional buses in the dataset this is 40%. For construction vehicles the share of NO_x emitted on urban roads is 60%. A significant share of NO_x is emitted on uncategorized roads, such as at depots and yards.

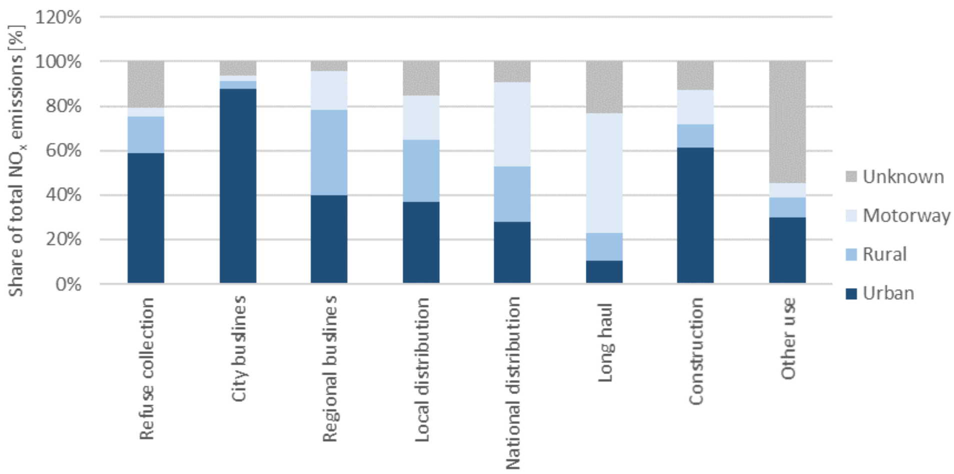

Figure 4-5: Share of total NO_x emissions per road type for different types of usage of heavy-duty vehicles.

The GPS data reveals the actual ranges of operation of heavy-duty vehicles, which can be rather scattered and varying from vehicle to vehicle.

From the evaluation of real world emissions data of HDVs with Euro VI certified engines it became very clear that the standard and requirements have led to a skewed emissions behaviour for NO_x due to which the emissions are still high in urban driving conditions.

The reason is that ‘urban driving conditions’ are a mix of all kinds of normal driving which currently are not explicitly controlled by regulation. These conditions include short trips, manoeuvring, cold or semi-cold starts, low load operations, idling, start – stop, use of auxiliaries, which are all dynamic and varying operations currently not part of tests. In addition, the regulation controls averaged emissions instead of spatial relevant emissions and the procedure targets mainly optimal conditions and exclude the more challenging conditions that often happen to be ‘urban driving conditions’. To address the problem of high NO_x emissions of driving on urban roads in areas with a high density of the population, regulation of NO_x emissions of heavy-duty vehicles should explicitly include these normal driving conditions as at present this is not the case (Vermeulen & Ligterink , 2018), (Mendoza Villafuerte, et al., 2021) and (Rodriquez & Huzeifa, 2021).

To improve the situation some obvious options are at hand:

- No exclusion of data or complicated evaluation rules that invalidate tests done with normal use
- Test vehicle types on their normal usage profiles.
- Explicitly control low load urban driving, cold start and idle emissions

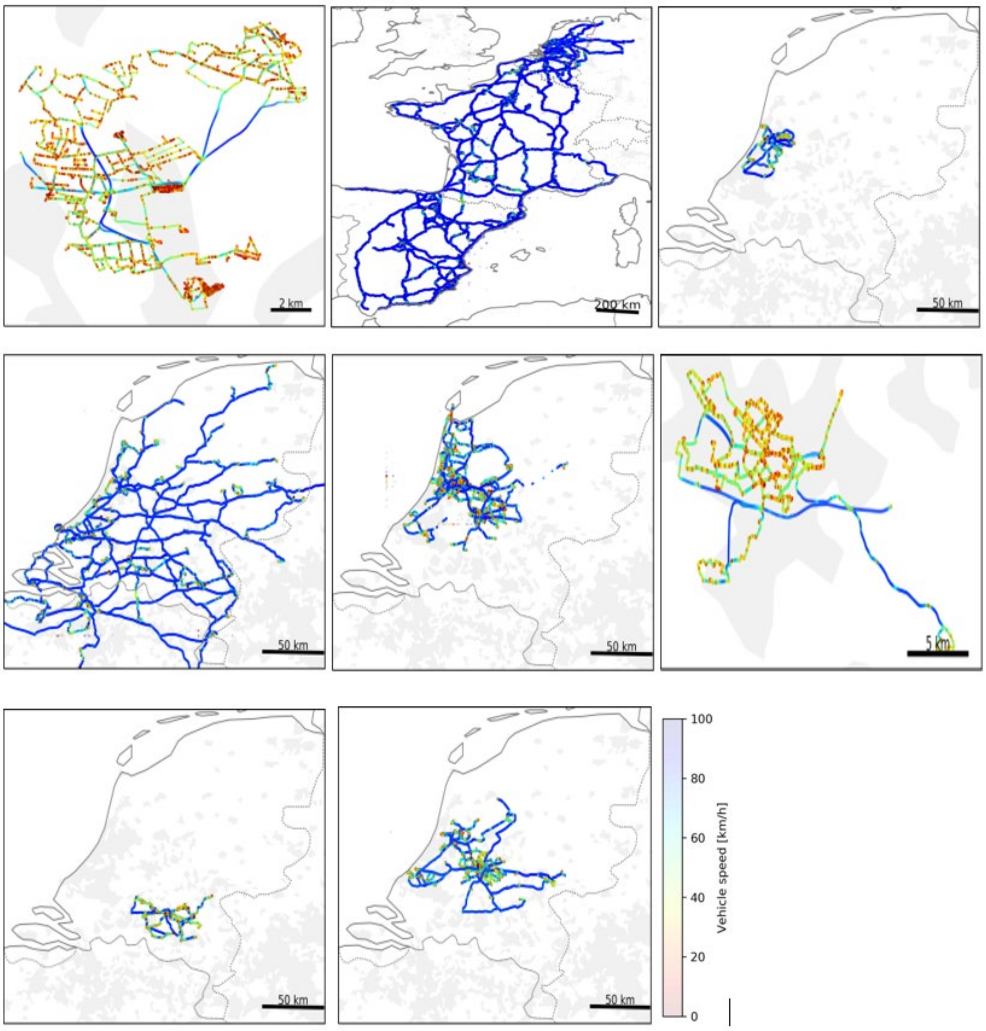

Figure 4-6: Typical examples of GPS-based position and speed of heavy-duty vehicles for different kinds of usage. Top left: refuse collection in a city, top middle: long haulage, top right: local distribution, middle row left: national distribution, centre: regional distribution, middle row right: city bus, below left: regional bus, below middle: construction.

4.1.5 *Conclusions*

Despite the progress made in controlling NO_x emissions from heavy-duty diesel vehicles, a large fraction of the fleet has much higher NO_x emissions in daily operation due to insufficient SCR performance, particularly when operating in urban environment. Especially low operation temperature of the SCR is a problem that may occur when heavy-duty diesel vehicles drive at low speeds such as in urban traffic. Evaluation of a large dataset showed that indeed NO_x emissions are highest on urban roads and substantially exceed official test cycle limits whereas on motorways the NO_x emissions are generally much lower.This skewedness means that for most trucks a substantial share of the NO_x emissions take place in an urban environment. The current EU emissions regulation fails to control this. The NO_x emissions are still high on urban roads, where the emissions rather should be low because of the high density of the population.

Dedicated tests can address specific issues with high emissions like low engine load, idling, short trips and operating auxiliary equipment from the main vehicle engine, e.g., loading with a crane of a tail lift. Currently, such vehicle operations are largely excluded from testing due to the limited power demand. Or, the testing is prohibitively long and complex due to the work-based evaluation approach. The In-Service Conformity testing should encompass all normal use, rather than be based on some specific use of the vehicle. Only with wide range of testing conditions emission the control systems will be robust for the different operations in the urban environment. Moreover, shorter, simpler, and dedicated tests will bring more to the front the specific issues with high emissions, as observed in normal vehicle usage.

4.2 NO_x emissions levels of heavy-duty vehicles with a Euro VI step D certified engine.

In the EU, heavy-duty emissions regulation became more stringent from step-C to step-D with a change of the standard where the power threshold for the PEMS test changed from 20 to 10% and due to changes in the requirements for the PEMS test. These new requirements aimed at ensuring that test data of urban driving is included in the evaluation of the test.

In 2020 and 2021 five vehicles with a step D certified engine were tested. The NO_x emissions are plotted in the graph below. For motorway driving 4 out of 5 ’step-D’ vehicle have NO_x emissions which are at the low end compared to the former Euro-VI step A to C vehicles. One vehicle has somewhat higher emissions but this is a long heavy- vehicle with a large engine. For rural driving, one vehicle is at the average NO_x level of the former Euro-VI step A to C vehicles, three others are below the average. The long vehicle has clearly higher NO_x emissions but the average speed is quite low for rural driving, probably because of the length of the vehicle. For urban driving two out of the four have lower NO_x emissions than the average of step A to C. One rigid truck was tested during the Corona pandemic in mainly free flow traffic conditions and has a high average speed in urban driving which is favourable for low NO_x emissions. Three others, a construction vehicle (green), the tractor semi-trailer (blue) and the long 6x2 rigid dolly-semi-trailer have higher NO_x emissions but are clearly operated under more demanding conditions when SCR efficiency is considered. For the three vehicles the average speed is low to very low (6-11 km/h). The construction vehicle isn’t driving for 50% of the time and often only its hydraulic crane is used. The tractor tanker trailer operates at very low average speed and frequently at low engine temperatures, which is probably caused by frequent cold starts. About a third of the NO_x emissions of this vehicle are produced at engine coolant temperatures below 70 ºC. Given the low number of vehicles tested (n=5) and the big differences in driving conditions, no firm conclusion can be drawn about urban emissions levels. At the motorway the NO_x emissions seem to be lower for the vehicles with step-D certified engines. The trend that NO_x emissions increase when vehicles are operated at low speeds, such as at urban driving, remains.

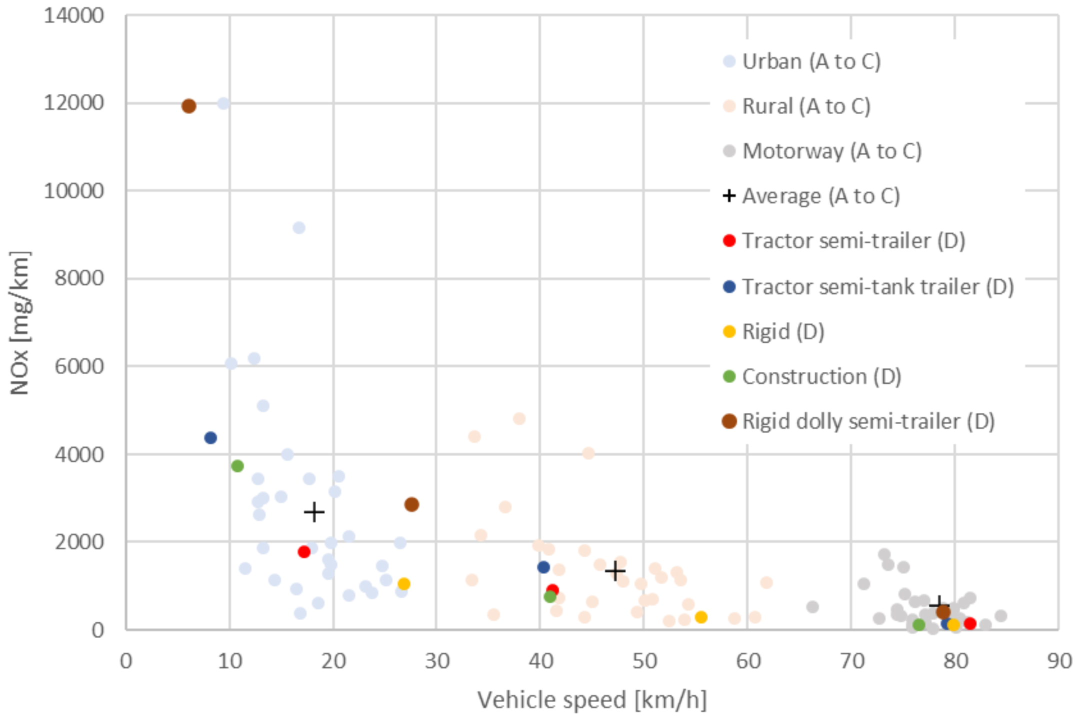

Figure 4-7: NO_x emissions for vehicles with Euro VI certified engine over urban, rural and motorways. The saturated dots represent vehicles with step-D certified engines.

4.3 Impact of (cold) starts on NO_x emissions

4.3.1 Background

Selective Catalytic Reduction (SCR) is used in most new HD engines to meet the legal emission limits for NO_x. In the SCR, NO_x is reduced with a reductant, usually ammonia (NH_3), to nitrogen (N_2) and water (H_2O).

An SCR system needs to be warm to operate. This means that at lower temperatures NO_x is not reduced and thus increased NO_x emissions can be expected when the catalyst and the exhaust gas are cold. This can happen after a cold start or even after a warm start if the catalyst was not warmed up sufficiently or already cooled down to below the light off temperature. The temperature of an SCR catalyst at a start of the engine depends on the soak temperature, soak time and the catalyst temperature when the engine was stopped. Aside of the temperature the use of the vehicle after a start and resulting engine loads and speeds will determine the levels of emissions when the catalyst is not yet warm and will also affect warm up speed. EGR also impacts cold start NO_x emissions behaviour. The amount of EGR applied depends on the start temperature and the engine load. To understand the impact of cold start on total NO_x emissions one needs to know the level of the NO_x emissions after a cold start and the dependencies.

4.3.2 Objectives

TNO aims to use the large amount of logged and measured data that it has available for the real world usage of heavy-duty vehicles to assess the influence of cold starts and operation with cold engine/exhaust system in general.

Based on the findings, a better understanding of the contribution of cold starts to the total NO_x emissions and differences between test bench results and real world emissions is sought. It could also provide understanding of the advantages of additional measures to ensure proper SCR operation at low coolant and exhaust gas temperatures (SCR pre-heating, EGR).

4.3.3 *Status of work and findings*

As an illustrative example of the work done so far, data of a semitrailer tractor with an empty mass of 8740 kg and a gross-combined mass of 50,000 kg will be discussed here. The truck is equipped with a 320 kW rated engine and certified according to Euro 6. Between July 2019 and February 2020, more than 900 hours of logged data has been collected.

The distributions of the total masses of NO_x and NH_3 emitted during real-life operation are depicted in Figure 4-8 and Figure 4-9. Referring to Figure 4-8 it can be seen that the majority of NO_x and NH_3 is emitted at engine coolant temperatures between 80°C and 100°C, which is the normal operation temperature of engine coolant. Below these temperatures, the thermostat of the engine cooling circuit is closed to increase the fluid temperature.
This distribution is, however, not conclusive without additional information. The reason is that it is depending on the vehicle's operation. Urban delivery will probably yield different time shares of engine temperature intervals – and therefore different share of pollutant mass – than long haul operation. Therefore, the distribution of engine work as a measure of vehicle operation spent in a certain temperature range is added to the plot. This seems justified since emission limits for HD are usually given in g/kWh.

Most of the engine work is done in the range between 80°C and 100°C. However, the NO_x/NH_3 peak at 85°C–90° is due to the fact that the engine had to deliver a lot of work in this range. Furthermore, the shares of work are higher at high temperatures, whilst the shares of emitted pollutant mass are lower. This is an indication that cold engine temperatures may lead to higher specific emissions.

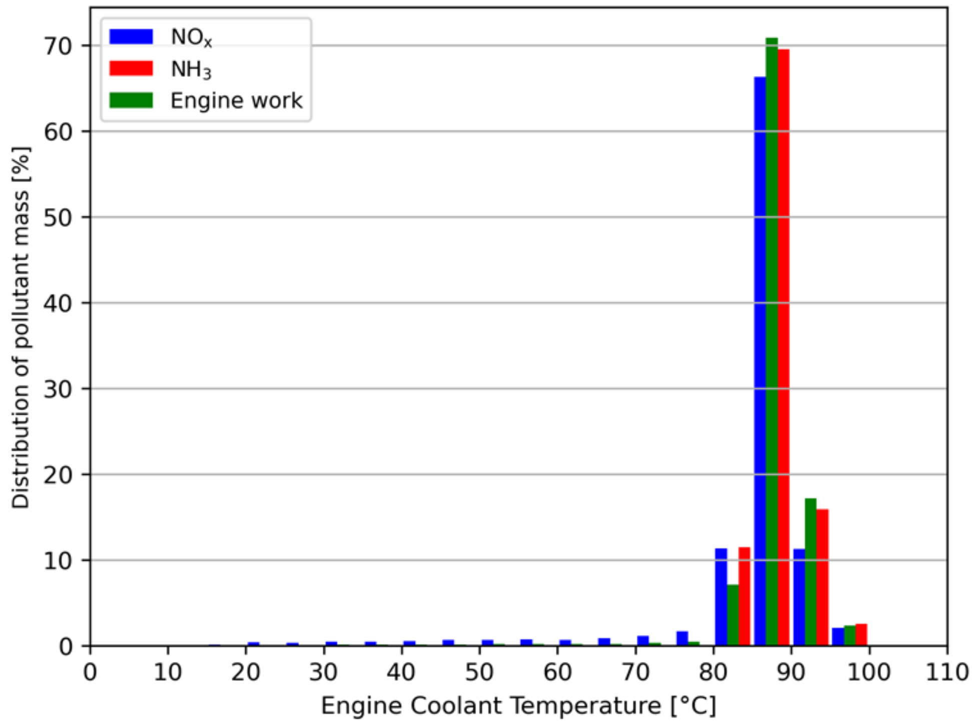

Figure 4-8: Distribution of total emitted pollutants over intervals of engine coolant temperature.

In Figure 4-9, the same approach is taken with respect to the exhaust gas temperature. The distribution of emitted mass of NO_x show a significant negative skew, i.e., an asymmetry to the left side – this means to lower exhaust gas temperatures. The peak around 450°C is believed to origin from regeneration of the particulate filter.

NH_3 mass emissions are almost symmetrically distributed around ≈250°C. in the range of the peak, significant amounts of NO_x are emitted although a sufficient amount of ammonia is available. At lower temperatures, less NH_3 was measured. This is most probably due to the electronic aftertreatment control which limits urea flow at low SCR temperatures. Above 300°C both, NO_x and NH_3 shares go down because this is the temperature range with optimum operation of the SCR.
Again, vehicle operation has to be taken into account by discussing the distribution of engine work. The distribution of engine work has its peak between 250° and 300°C with a negative skew. Between 240°C and 330°C the share of work is equal or higher than the share of NO_x. At lower temperatures, the operation of the SCR seems to yield less good results. The unfavourable NO_x to engine work ratio at higher exhaust gas temperatures is probably caused by regeneration of the DPF.

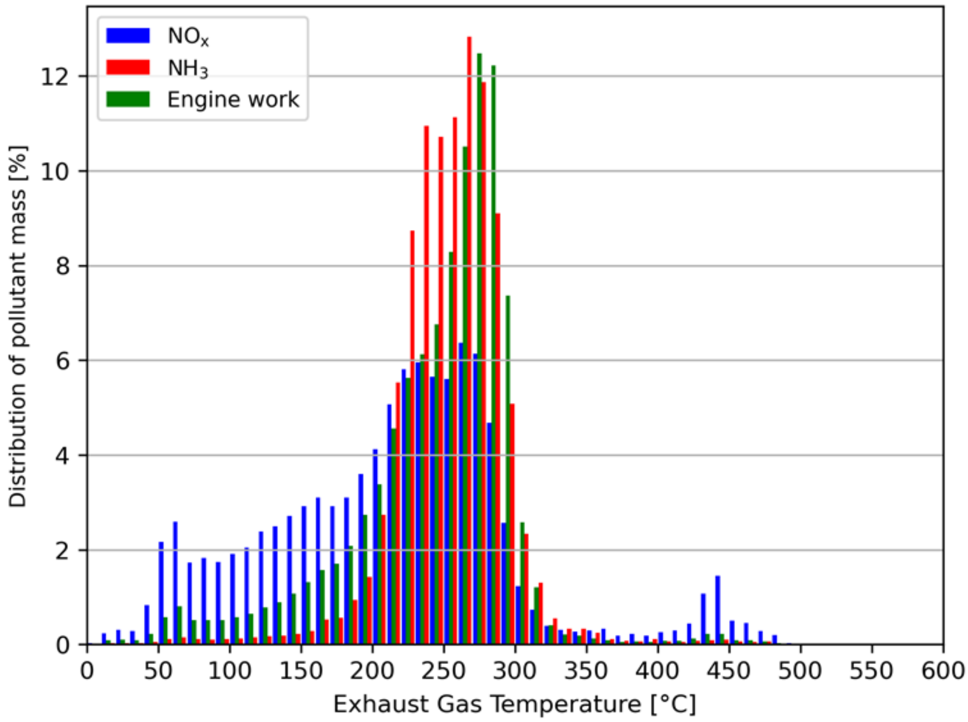

Figure 4-9: Distribution of total emitted pollutants over intervals of exhaust gas temperature.

4.3.4 *Further research*

Although a lot of analysis has already been done, there are still open questions that need to be studied, e.g.,

- the influence of DPF regeneration on NO_x emissions;
- the effect of cold starts on emission of unburnt hydrocarbons; or
- the influence of vehicle usage on real world emissions.

4.4 NH_3 emissions

The use of SCR for NO_x abatement of diesel vehicles requires the reagent ammonia for the catalytic reduction of NO_x produced by a diesel engine over a catalyst. AdBlue is a solution of water and urea which is injected upstream of the SCR catalyst. Exhaust heat should decompose the AdBlue to ammonia. Under certain conditions the ammonia can leave the catalyst unused. Also deposits formed by not fully decomposed urea can sublimate at higher temperatures and lead to temporarily high ammonia emissions from the tail-pipe. The test programme therefore measures the ammonia concentrations with a sensor in the tail-pipe to obtain an indication of the level of NH_3 emissions and possible problems with excessive NH_3 slip. The sensor used is not very accurate but gives a fast indication of the tail-pipe concentrations. The ammonia emissions of the vehicles with Euro VI step A to C certified engines show a spread from very low to almost 400 mg/km for a single vehicle. This higher value is less accurate due to the lower accuracy of the sensor used at measured concentrations higher than 100ppm.

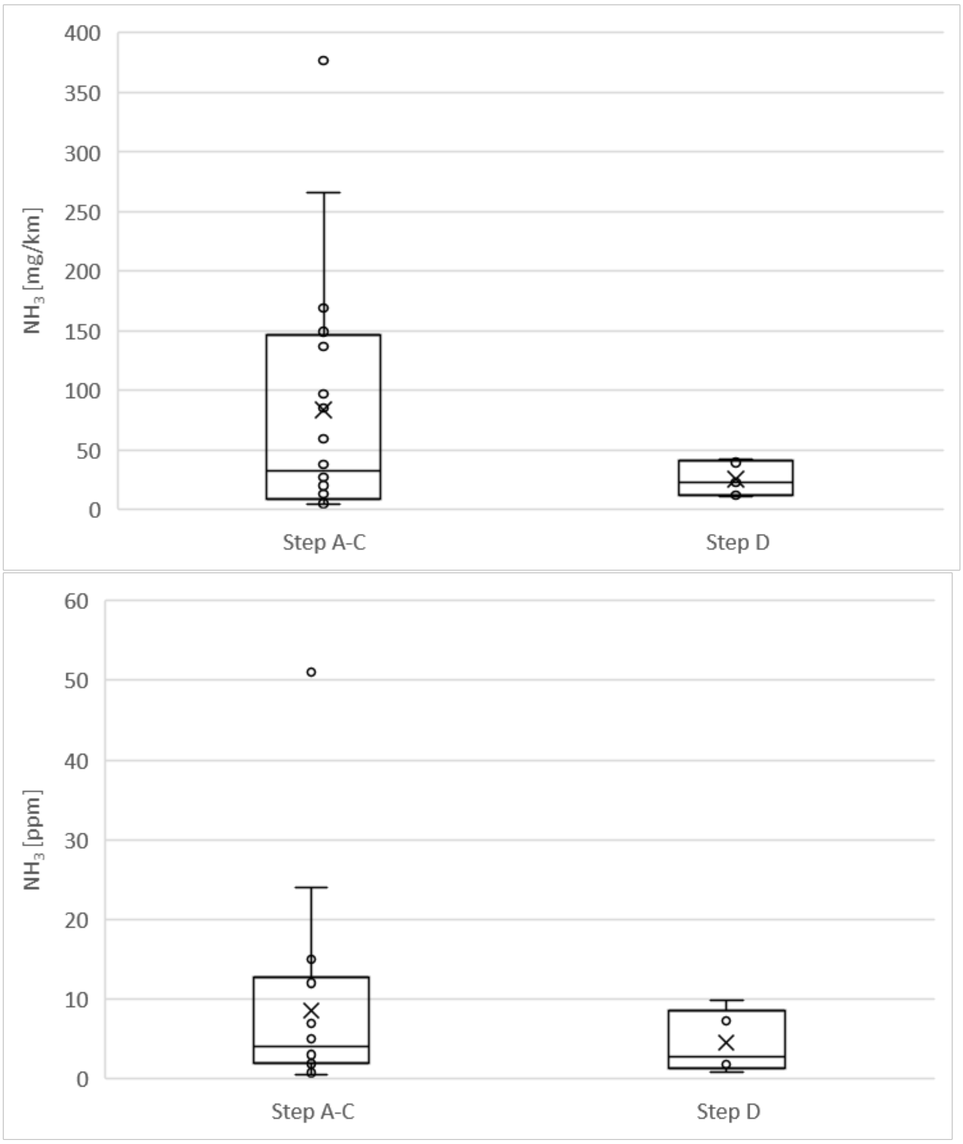

Figure 4-10 and Figure 4-11: Exhaust ammonia concentrations (upper graph) and ammonia emissions per kilometre (lower graph) of Euro VI step A to C certified engines (n=20) and Euro VI step D certified engines (n=5).

5 NO_x monitoring for heavy-duty vehicles: status quo

Current diesel engines mainly use SCR to reduce the high NO_x emissions of these engines. Problems with this type of NO_x control system are reported such as a lagging performance at low vehicle speeds, ageing, fouling, ammonia slip and tampering of the system by vehicle owners. Efficient SCR operation fully depends on the dosage of a reagent, a consumable called AdBlue or DEF (Diesel Exhaust Fluid) which is a reason some owners do shut off the dosing of this reagent to save costs.

Monitoring of NO_x emissions on a fleet level is seen as an effective means to detect these problems. The hypothesis is that heavy-duty vehicles have a NO_x measurement system on-board and are connected to the cloud (over-the-air transmission of 'data' is possible), hereby enabling fleet-wide remote emissions monitoring and/or enabling N(P)TI. This hypothesis is tested in an investigation which focusses on the technical aspects of the measurement, the definition of the status quo by looking at the presence of components for NO_x measurement on board of HDVs and by summarizing the current developments in other regions of the world, such as in China where NO_x monitoring became mandatory for China 6b and California where NO_x tracking becomes mandatory for my 2022 vehicles.

5.1 European Union

In the EU, on-board monitoring (OBM) or remote monitoring of activity data or emissions data is not required. On-board monitoring (OBM) is however a topic in the working group discussions about renewal of the Euro 6/VI regulation and OBM is seen as a possible means to control emissions on a fleet level because other measures so far have shown to be inefficient to a certain extend: ISC testing with PEMS is burdensome and its reach is limited to a few vehicles which are to be tested in good running order. On-board diagnostics (OBD) effectiveness is also limited and can be manipulated. Also, durability requirements do not regulate lifetime emissions. OBM could address these issues by fleet-wide monitoring.

5.1.1 Case construction vehicle with Euro VI-D certified engine

Measurements on the construction vehicle, see paragraph 3.1, with simultaneous measurement of the NO_x concentrations with a reference instrument (PEMS, chemiluminescence) SEMS (calibrated NO_x sensor) and the on-board NO_x sensor enables the comparison of the NO_x data.

The instruments show good correlation, with exception of some excursions observed for the on-board NO_x sensor which in a few instance shows a somewhat higher concentration than the two other instruments. The excursions could not be explained from the data, e.g. looking at the measured NH_3 and the NO and NO_2 concentrations.

The on-board NO_x sensor broadcasted a high constant numerical value of 65535 until 10 minutes after the engine was started. It is known that to increase lifetime expectancy NO_x sensors need to actively be heated to avoid condensation of water on the sensor that could lead to a sensor break down.

The SEMS NO_x sensor is reaches operating temperatures generally within a minute however. A NO_x sensor can thus start to measure quite fast after a cold start but the OEM chose to not broadcast or activate the sensor measurement until only 10 minutes after the start of the engine.

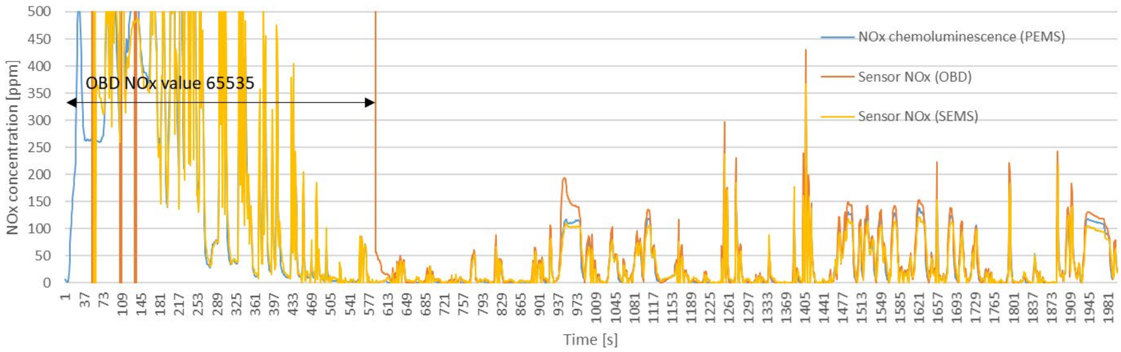

Figure 5-1: NO_x concentrations as measured with a reference instrument (PEMS, chemiluminescence) SEMS (calibrated NO_x sensor) and the on-board NO_x sensor. The instruments show good correlation, with exception of some excursions observed for the on-board NO_x sensor which in a few instance shows a somewhat higher concentration than the two other instruments. The on-board NO_x sensor broadcasted a high constant value of 65535 until 10 minutes after the engine was started.

5.1.2 *Overview OEMS*

Interviews were held with four OEMS. One vehicle was extensively tested to determine technical possibilities for NO_x monitoring.

The common conclusions for monitoring from the interviews are:

- Main reasons for over-the-air monitoring of data are: predictive maintenance, driving style, fuel consumption.
- Three out of four OEMS do not monitor NO_x data over the air of vehicles in the EU fleet but mention that vehicles need to broadcast onboard data for mandatory NO_x monitoring under the China emissions regulation. OEMS that are active on the V.S. market mention the California Air Resources Board (CARB) REAL regulation with NO_x tracking which requires to store actual and recent averaged and binned NO_x data on-board.
- Data transfer, data requirements and accuracy are not defined or standardized in the EU.
- All recent diesel trucks in the EU have two NO_x sensors. (Upstream and downstream of the SCR).
- The NO_x sensor is only broadcasting NO_x concentration values after about 10 minutes after a cold start. This seems the case for most vehicles.
- Introduction of modems for the transfer of information to a back office started 8 to 10 years ago. Currently, most vehicles have a modem which can be used for various service subscriptions.
- Privacy of data is mentioned as an important topic. A customer needs to sign for sending vehicle data to a back office. Does environmental law take precedence over privacy law (GDPR)? This has not been tested in court yet.

Experience from one OEM with monitoring:

- Most current vehicles are standard equipped with a system using NO_x sensors and a modem for data-communication which allows broadcasting the levels of NO_x emissions and other information over the air to a backend.
- When monitoring NO_x of a fleet, outliers are seen. This may be attributed to aged NO_x sensors or sensors that are already out of the accuracy specification when new (+/-10ppm). This can be detected if one of two sensors deviates but is harder when both are offset. A health check or plausibility check would be needed to assure correct operation of the sensors. It is the question if this can be done online or offline in a workshop.
- Detection of manipulation is possible in some cases but probably not always, for instance when false signals are emulated very accurately.
- High resolution data leads to more possibilities for accurate analyses but the challenge is how to deal with the large amount of data, see the China regulation. High resolution on-board processes would save data transfer and large amounts of off line data storage at the cost of ECU power and memory. Software would need to be secure and certified.

5.2 China

In the China VI-b emission standard, remote monitoring has been introduced for regulating in-use emissions of heavy-duty diesel vehicles (HDDVs). The standard requires the collection and transmission of real-time data regarding engine and aftertreatment operating conditions and tailpipe nitrogen oxides (NO_x) DPF and other emission-related data through the electronic control unit and the NO_x sensors present on-board of the vehicles. The data needs to be transmitted to environmental authorities. Additionally, Beijing developed OBM systems for China V HDDVs since 2018 and Beijing is investigating retrofitting OBM systems since 2017. (Zhang, et al., 2020) reports a technical and policy assessment of the recent OBM programs in China and Beijing. In 2018, China finalized China VI standards that will apply to new heavy-duty diesel vehicles nationwide in two stages. The first stage, China VI-a, is largely equivalent to Euro VI and applied to gas engines in July 2019, urban HDVs in July 2020, and all new HDVs in July 2021. The second stage, China VI-b, adds requirements such as anti-tampering monitoring and remote on-board diagnostics data reporting that are expected to enhance real-world emissions compliance. China VI-b will apply to gas engines nationwide starting in January 2021 and all new HDVs in July 2023.

Investigation in China (Yi Tan, 2019) reports the following:

"…*Both OEM-performed and retrofitted OBM data were collected from a fleet of OBM-instrumented vehicles. First, our assessment shows high data integrity and quality of OEM-performed OBM systems. In contrast, a considerable fraction of HDDVs equipped with retrofitted OBM systems did not completely report* NO_x *concentrations, intake mass air flow and other parameters. Next, eight OBM-instrumented HDDVs were tested on road by portable emissions measurement systems (PEMSs) to examine the reliability of sensor-based* NO_x *concentrations. The majority (6 of 8) shows a good agreement between OBM and PEMS results with an average relative error of approximately -15%.*

Furthermore, calculation of NOx mass emissions, inter-trip variability, and alternative methods of enforcing in-use emissions management (e.g., to develop concentration metric-based emission limits) are discussed…" and "…*This early-stage assessment suggests the OBM approach has the potential to play a central role in in-use emission inspections for HDDVs in China. The regulatory agency should focus more attention to the data integrity and the reliability of NO_x sensors by developing effective verification processes…*".

5.3 California/CARB

In California under the CARB Real Emissions Assessment Logging (REAL), Medium Duty and Heavy-Duty vehicles are required to record (track) and report NO_x and GHG emissions as of 2022 with a phase in for GHG emissions for LD and MD from 2019 to 2021. REAL relies on existing technology and hardware to estimate and track NO_x emissions and is a quick real world screening tool for flagging issues, emissions inventory development and new tool for evolution of future regulatory development. REAL requires engines to log NO_x and GHG emissions and engine activity data and store recent and lifetime data separately The input data needs to be measured on board at a frequency of 1Hz but is aggregated in arrays (lifetime, 100hr) and bins (speed, %-rated power). The required accuracy for the NO_x work specific mass emissions is +/- 20% or +/- 0.1 g/bhp.h. Data has to be readable for instance for transmission to be done at periodic inspection with a data reader. The NO_x and GHG tracking is found cheap with 46 dollars per vehicle. CARB: "…*Currently, to get a snapshot of how vehicles are performing in terms of emissions, CARB either brings them to laboratories for testing or equips a handful of vehicles with Portable Emissions Measurement Systems (PEMS) equipment to find high emitters on the road*..". The NO_x tracking would make makes spotting problems more effective and efficient.

Parameter	Active 100 Hour Array	Stored 100 Hour Array	Lifetime Array	Lifetime Engine Activity Array
NOx mass – engine out (g)	x	x	x	n/a
NOx mass – tailpipe (g)	x	x	x	n/a
Engine output energy (kWh)	x	x	x	x
Distance traveled (km)	x	x	x	x
Engine run time (hours)	x	x	x	x
Vehicle fuel consumption (liters)	x	x	x	x

Figure 5-2: On-board data to be stored at different time scales. Source CARB presentation Diesel On-Board Diagnostics Section, March 14, 2019

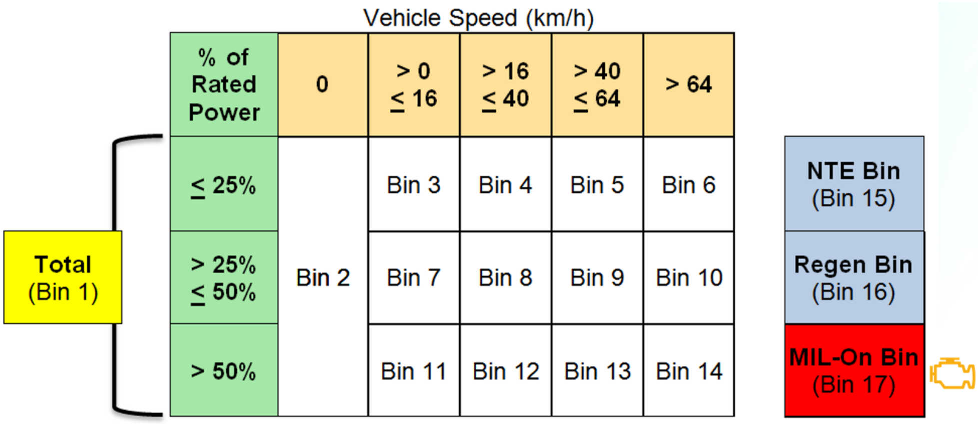

Figure 5-3: On-board data needs to be stored in power and speed bins. Source CARB presentation Diesel On-Board Diagnostics Section, March 14, 2019

6 Conclusions

In the Dutch in-service testing programme real-world emissions of representative heavy-duty vehicles are measured on a continuous basis to collect the data necessary to: determine emissions factors, to follow emissions trends to determine if vehicles are getting cleaner under the pressure of emissions regulations and to monitor for possible problems. In the last years the focus was primarily on the development of NO_x emissions. Although NO_x emissions decreased substantially on average the test programme in recent years showed high variance and high emissions levels when vehicles drive at low speeds. Also malfunctions, manipulation and ageing of vehicles has shown to increase the emissions levels substantially. Therefore, the programme focused on investigating the possibility of NO_x monitoring using the onboard sensors of heavy-duty vehicles because this could be a future tool to control the NO_x emissions in a more effective way. From the work performed in 2021 the following can be concluded:

The measurements and analyses carried out in 2021 showed that the newest trucks, which have been required to comply with the tightened Euro VI step-D standard since September 2019, are emitting less NO_x on the motorway compared to the previous Euro VI generations (step A to C). This trend is not clear for rural and urban driving. The number of measurements is still low (n=5) to determine a significant difference between Step D and earlier generations of vehicles. The previously observed trend that trucks can emit more NO_x at low average speeds, such as with urban driving, continues for the latest trucks with a Euro VI step-D engine as NO_x emissions levels increase towards slower driving speeds. Also the ammonia emissions were evaluated and seem to have decreased for step-D certified engines. Engines were generally newer though than the ones tested for Euro VI step A to C)

The NO_x emissions of heavy-duty vehicles with a Euro VI step A to D certified engine have been evaluated specifically on urban roads and were found to be disproportionately high compared to the limit value. The current EU standard (EU VI A to D) and associated requirements still do not cover this situation well. Except for city buses, there is a lack of adequate testing of emissions under urban driving conditions, in the normal operating configuration of a vehicle.

In some cases it is difficult to drive a valid in-service conformity test on public roads which means that in discussion with the type-approval authority the test has to be adapted to fit within the criteria. Normal driving conditions are thereby excluded from in-service conformity testing and the adjustment may lead to a relaxation of the test conditions.

The shortfall of the current testing regime to control NO_x emissions on urban roads and other normal driving conditions would requires adjustments to the tests for heavy commercial vehicles for the Euro VII standard.

To improve the situation some obvious options are at hand:

- No exclusion of data or complicated evaluation rules that invalidate tests done with normal use.
- Test vehicle types on their normal usage profiles.
- Explicitly control low load urban driving, cold start and idle emissions.

A small transport refrigeration unit (driven by a small diesel engine) that was measured during normal use had on average 26 g/h NOx, which is about half the NO_x emission of the big truck (6x2 rigid-dolly-semi-trailer) it is mounted on. The level is on par with the NO_x emissions of regular diesel trucks with a Euro VI diesel engine. For an earlier measurement of NO_x on another refrigeration unit (Vermeulen, 2021) a two times higher NOx emission was found (52 g/h) but that unit has a bigger engine (2.1 l vs. 1.1 l) and probably the cooling demand was higher. It is estimated that the transport cooling unit emits more than 10 times as much particulate matter than the Euro-VI truck it is mounted in.

The options for on-board, remote and fleet-wide monitoring of NO_x emissions have been investigated. It has been established that almost all new trucks with a diesel engine have a measuring system with sensors that can monitor the NO_x emissions. A single manufacturer in the EU already monitors NO_x emissions remotely for internal purposes. NO_x monitoring is already required in China.

In 2022, in California NO_x tracking will be mandatory, using information about NO_x emissions stored in the truck's computer that can be read during an inspection or periodic test.

- The standardization of measurement, accuracy, reliability, security and assessment of individual vehicle emission levels are key concerns. For fleet-wide monitoring, the privacy and responsibilities of the parties involved are also important points of attention.
- Monitoring the NO_x emissions of a vehicle requires regular checks of the NO_x sensor. This check can, for example, be done during an inspection together with a check of the operation of the NO_x emission control system.

One heavy-duty vehicle with a step D certified engine was tested over on in-service conformity test using PEMS. It was difficult to perform a valid test with this vehicle. This is caused by the applicable formal EU PEMS test rules for in-service conformity testing that can render a normal trip on the public road invalid.
The conformity factor for NO_x was just below 1.5 for the single valid test out of the seven test that were performed. The vehicle passed the Dutch test for periodical inspection of DPF-equipped vehicles and showed low ammonia emissions.

Little is known about the frequency of possible problems with NO_x abatement systems of older vehicles. It is therefore recommended to screen older trucks and see if problems can be identified with a simple test.

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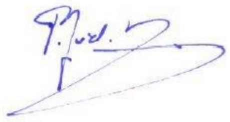
8 Signature

The Hague, 28 February 2022



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