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TNO report

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The Netherlands In-Service Testing Programme for Heavy Duty Vehicle Emissions 2011

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Samenvatting

In opdracht van het Ministerie van Infrastructuur en Milieu voert TNO Sustainable Transport and Logistics regelmatig metingen uit aan vrachtwagens om de prestaties en duurzaamheid op het gebied van schadelijke emissies te bepalen voor representatieve praktijksituaties.

De gegevens uit het meetprogramma worden voornamelijk gebruikt voor:
1. het vaststellen van trends ten aanzien van de praktijkemissies,
2. emissiemodellering en
3. het vaststellen van de conformiteit van in gebruik zijnde zware bedrijfsvoertuigen.

De metingen zijn uitgevoerd met een mobiel emissiemeetinstrument (PEMS, Portable Emission Measurement System). Daarnaast zijn ook metingen gedaan met een instrument dat de emissie vanaf enige afstand langs de weg kan meten in de uitlaatgasstroom van elk passerend voertuig (RES, Remote Emission Sensing).

Het meetprogramma van 2011 voorziet in nieuwe inzichten over de emissieprestatie van de aankomende Euro VI technologie die verplicht wordt vanaf 31 December 2013 voor zware bedrijfsvoertuigen. Samen met resultaten van eerdere meetprogramma's kunnen tevens conclusies worden getrokken over de emissies van de huidige generatie zware bedrijfsvoertuigen (Euro V, EEV).

De resultaten van testen met twee Euro VI vrachtwagens, een prototype en een productievoertuig, zijn een eerste indicatie dat de Euro VI technologie de potentie heeft om de schadelijke uitstoot significant te verminderen in vergelijking met de huidige Euro V vrachtwagens.
Hoewel de eerste resultaten veelbelovend zijn, beperkt deze eerste indicatie zich tot de geteste vrachtwagens en de gegeven technologie die de fabrikanten hebben gekozen voor de motorenfamilie geplaatst in hun range zware vrachtwagens. De emissieprestaties van nog niet verkrijgbare Euro VI distributievrachtwagens, bussen en vrachtwagens van andere fabrikanten zijn nog niet bekend. Ook de effecten van veroudering zijn onbekend. Voorts is de EU emissiewetgeving nog in ontwikkeling en zijn er nog aanpassingen nodig om lage emissies te garanderen onder alle relevante gebruikscondities. Het wordt daarom aanbevolen om de emissies en de veroudering te blijven monitoren en om de sterke kennispositie die Nederland heeft ten aanzien van de ontwikkeling van emissiewetgeving te handhaven.

Van de huidige generatie zware bedrijfsvoertuigen (Euro V en EEV) is een flink aantal uitvoerig getest. Uit de resultaten kan geconcludeerd worden dat de emissies een gespreid beeld laten zien. Gemiddeld genomen, lijken de NO_x emissies van vrachtwagens van de tweede generatie Euro V bij lage snelheden wat te zijn gedaald ten opzichte van de eerste generatie. Het verschil tussen de generaties is de toepassing van OBD II en maatregelen als koppelreductie bij overschrijding van de OBD limietwaarden voor NO_x. Echter blijft ook voor de tweede generatie gelden dat het EEV en Euro V keurmerk bij dieselvoertuigen geen garantie geven voor lage emissies, omdat de resultaten per voertuig sterk kunnen verschillen en sommige voertuigen en voertuigentypes problemen hebben om in de praktijk een lage uitstoot te halen.

Hierdoor ontstaat een behoefte aan een aanvullende methode om de praktijkemissies te beoordelen, los van de bestaande Euro V en EEV emissiewetgeving. Dit kan bijvoorbeeld vlooteigenaren ondersteunen bij een milieubewuste keuze voor de aanschaf van nieuwe voertuigen. TNO werkt op dit moment aan een dergelijke methode die eenvoudig en goedkoop inzicht zal geven in de praktijkemissies van voertuigen.

De praktijk emissiemetingen met PEMS zijn ook gedaan volgens de EU methode voor het bepalen van de conformiteit van in gebruik zijnde voertuigen. Volgens deze methode haalden 3 van de 6 voertuigen de benodigde conformiteitsfactor niet voor de NO_x uitstoot. Eén voertuig overschreed de grenswaarde van 1,5 slechts marginaal terwijl de twee andere voertuigen de grenswaarde ruimschoots passeerden. Voor de overige gereguleerde emissies CO en HC werd de conformiteitsfactor door alle 6 de voertuigen ruimschoots gehaald.

Het werk wordt in 2012 en 2013 voortgezet met onder meer praktijkemissiemetingen aan nieuwe Euro VI voertuigen die op de markt komen.

Summary

Commissioned by the Ministry of Infrastructure and Environment of the Netherlands, TNO Sustainable Transport and Logistics regularly performs measurements to determine the in-service performance and durability of the pollutant emissions of heavy-duty vehicles under representative conditions.

De data from the measurement programme is mainly used for:
1. the determination of trends of real world emissions,
2. emission modelling and
3. checking the in-service conformity.

To obtain these data measurements were performed with a portable emission measurement system (PEMS) and by means of Road Side Remote Emission Sensing (RES).

The 2011 measurement programme yields new insights regarding the emission performance of the upcoming Euro VI technology for heavy-duty vehicles, mandatory as of 31 December 2013 and, together with the results from earlier performed programmes, leads to conclusions on the emission performance of past and present generations of heavy-duty vehicles (Euro V, EEV).

The test results of measurements performed with a portable emission measurement system on two heavy-duty vehicles with Euro VI technology, one prototype and one production vehicle, are a first indication that this Euro VI emission stage has a large potential to reduce pollutant emissions significantly compared to the current generation of Euro V heavy-duty vehicles.
This first indication is limited to vehicles of two manufacturers who have chosen a certain technology path for their mainstream engines mounted in long-haulage vehicles. The emission performance of other vehicles and of other brands and types of the Euro VI stage is still uncertain as they have not been tested yet. Also the durability has not been investigated.
Furthermore, the EU emission legislation still needs further refinement to guarantee low pollutant emissions under all relevant circumstances. It is therefore recommended to continue monitoring the emission performance and durability of representative vehicles in-service and to continue the knowledge position that supports the strong Netherlands role in the development of robust European emission legislation.

After having tested a large number of Euro V and EEV vehicles extensively with PEMS it can be concluded that the emission performance of these vehicles is mixed. On average the NO_x emissions of the last generation of Euro V seem to have improved somewhat at low driving speeds, compared to the first generation Euro V. Still Euro V and also EEV does not guarantee low emissions for diesel vehicles because the results are scattered. Some individual vehicles and types of vehicles still proved to have problems to perform well under real-world driving conditions. Because of this a need exists for an additional method to judge the emission performance apart from the existing Euro V and EEV emission legislation. This could for instance assist fleet-owners with the choice for a clean vehicle. At the moment TNO develops a simple and cheap method to fulfill this need.

Besides the assessment of the trends of the real world emissions the tests performed with PEMS are also used to check in-service conformity.
According this check 3 out of 6 Euro V heavy-duty vehicles were not able to obtain a Conformity Factor of 1,5 for NO_x. One vehicle just exceeded the 1,5 marginally, the two others clearly exceeded 1,5. One of these two vehicles was a light medium duty truck (N2, 3,5 – 5,0t) and one a long haulage truck (N3, 20-50t). For the other regulated emissions the conformity factor was well below 1,5 for all tested vehicles.

The work will be followed up in 2012 and 2013 with further emission tests, checking the In-Service conformity and real driving emissions of new Euro VI heavy-duty vehicles arriving on the market.

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1 Introduction

1.1 Background

Road Transport is of great economic importance for the Netherlands. With large ports on the North Sea and a dense network of roads, rail-, water- and airways the Netherlands logistic infrastructure serves as a gateway for the transport of goods and people from all over the world to the inner lands of Europe and vice versa. These activities and all local activities, all increased by economic growth, come with an environmental burden to the region, mainly for air quality. Already in the previous century the Ministry of the Environment recognized this situation and introduced, amongst others, national policies with the aim to effectively reduce pollutant emissions at the source.

In 1994 the Ministry started the SELA programme (Schone En Lawaai Arme voertuigen) to stimulate the introduction of clean and low-noise heavy-duty vehicles on the market. This programme required vehicles to comply with certain stringent national emission and noise requirements, which were checked by TNO with dedicated test procedures.

In the meantime the EU emission type approval legislation [70/156/EC] developed its procedures and requirements, supported by insights of the national programmes. As a result, EU emission limits have become more stringent over time and the type approval test procedure recently improved by moving from an engine-based laboratory procedure to a procedure also including more real-world oriented requirements [2007/46/EC, 2011/595/EC]. All this resulted in enormous technological improvements, made by the manufacturers to reduce the pollutant emissions and at the same time also improving the efficiency of the powertrain.

Today, the EU emission legislation for heavy-duty vehicles is still under development and although it has advanced substantially over time, results of the in-service testing programme performed with the current generation of vehicles (Euro V) showed that the EU emission legislation still requires some further refinement to guarantee the so needed low-pollutant emissions at the source.

1.2 Aim and approach

The general aim of the Netherlands in-service testing programme for heavy-duty vehicles is to gain insight into trends in real-world emissions of generations of heavy-duty vehicles, under the usage conditions relevant for the Dutch situation.

More specifically the aims of the programme are:

- to assess the real-world emission performance with a focus on the NO_x and NO_2 emissions. In the view of air quality problems in Dutch city centres, in particular urban or low speed driving conditions are considered.
- to check the conformity of vehicles in-service against the applicable requirements as laid down in the EU emission legislation [582/2011/EC].
- to collect information to establish emission factors for the (inter)national models which calculate pollutant emissions.to evaluate the in-service conformity

procedure for the type of truck using latest Euro V and Euro VI emission technologies, and
- to extend the knowledge needed for the development of methods to effectively regulate real-world emissions in the EU.

For this investigation, TNO used a Portable Emission Measurement System (PEMS) for determination of the real-world truck emissions. PEMS is introduced in the Euro V and Euro VI heavy-duty emission legislation for determination of 'in-service conformity' [582/2011/EC] and as such is a widely accepted method to measure real-world emissions and determine the in-service emission performance.

PEMS measures the exhaust gas components NO_x, NO_2, CO_2, CO and HC. The measurements can take place driving the truck on the road in normal traffic. As such, PEMS yields estimates for real-world emissions performance of the investigated vehicle. PEMS does not yet include a validated method to measure PM (particulate matter).
For determining realistic emission factors, detailed insight in the composition and typical distributions of the emissions of the Dutch fleet is necessary. Amongst others, knowing how many vehicles fall into the high emitter category is essential. For this purpose, TNO investigated the possibilities for gaining insights in the emission behavior of representative samples of the fleet using Remote Emission Sensing (RES).

1.3 Structure of the report

Chapter 2 describes the results of the basic activities;

- Checking of the in-service conformity of HDV based on the latest requirements as laid down in 582/2011/EC and amendments.
- Evaluation of Real World Driving Emissions presenting trends over the generations of HD vehicles up to Euro VI and a direct comparison between two of the stages of Euro V (B2G versus B2D) to determine whether implementation of improved requirements from one stage to the other has led to the expected improvements.
- Evaluation of the effectiveness of current legislative procedures, especially with regard to the in-service conformity procedure using PEMS and the development of effective Off-Cycle provisions.
- Gathering data for the purpose of emission modelling

The programme allows to perform additional or ad-hoc research on request. The activities performed are discussed in **chapter 3**. In 2011 the following work was performed next to the regular PEMS test programme:

- Investigation into a method to check tail pipe emissions in a simplified manner using sensors. The application of such a method could be to check emissions under conditions which currently aren't directly under the control of EU legislation but which are found relevant for the Dutch situation, like urban driving at low speeds.
- Tests for the support of the EU project on the development of procedures to determine the CO_2 emission of HDV. Particular tests were performed on the powertrain test bed on a medium duty truck to determine its driveline losses.

- Remote Emission Sensing. Using RES a measurement session was performed at the flower auction in Aalsmeer aimed specifically at heavy-duty vehicles. These measurements were used to determine whether the RES instrument is sensitive enough to identify high emitters amongst heavy duty vehicles.

2 In-service testing of emissions with PEMS

2.1 In-service conformity

This paragraph presents the results of on road testing with PEMS (Portable Emission Measurement System) applying the ISC rules for testing and the pass-fail method to determine the Conformity Factor.

2.1.1 *Vehicles tested*

The vehicle selection was based on multiple goals:

- to select vehicles of the latest generation Euro V and EEV vehicles, the so-called Euro V B2G and EEV C(K) with OBD II and NO_x measures (5 vehicles).
- to select the newest generation Euro VI HDV available on the market (1 vehicle).
- to select a N2 vehicle in the 2,5 to 5t GVM range (1 vehicle).

Table 1: overview of the vehicles tested and some specifications

Vehicle	**Legislative category**	**Vehicle category**	**Vehicle type**	**Model year**	**Emission reduction technology**	**Power range [kW]**	**Odometer [km]**
Vehicle N	V B2(G)	CI, N3	Tractor Semi-trailer	2010	SCR	350-400	4747
Vehicle P	V B2(G)	CI, N3	Tractor Semi-trailer	2009	SCR	300-350	206121
Vehicle Q	EEV C(K)	CI, N3	Tractor Semi-trailer	2011	SCR	300-350	87255
Vehicle R	EEV C(K)	CI, N2	Rigid	2010	EGR, DPF	100-150	144566
Vehicle S	V B2(G)	CI, N3	Tractor Semi-trailer	2011	SCR	300-350	45562
Vehicle T	V B2(G)	CI, N3	Tractor Semi-trailer	2010	SCR	300-350	169436
Vehicle U	VI	CI, N3	Tractor Semi-trailer	2011	EGR, DPF, SCR	300-350	10980

2.1.2 *Procedure for checking the conformity of engines and vehicles in-service*

European type approval for emissions of Euro V truck engines is obtained from tests performed on prescribed engine cycles on an engine test bed under laboratory conditions. For the determination of real world emissions of in-use vehicles, execution of engine tests on an engine test bed may not be representative. With the introduction of PEMS, or Portable Emission Measurement System, it has become possible to monitor real-world emissions of vehicles in normal traffic situations. In 2011 the EU Directive Relevant European Regulations and Directives:

[582/2011/EC] was introduced which describes on-road emission tests using PEMS for checking the conformity of vehicles in-service for Euro V and Euro VI (Annex II and Annex XII).

PEMS is a system to measure exhaust gas emissions of a vehicle. The measurements can take place on the road in normal traffic. PEMS yields estimates for real-world emissions performance of the investigated vehicle. The system is introduced in the EURO V and Euro VI Heavy-Duty engine emission legislation for determination of 'in-service conformity'. 'in-service conformity' in this matter can be explained as: does the vehicle In-Service comply with the emission standards if its engine would be tested on an engine test bed. The 'in-service conformity' method is designed to check if vehicles In-Service and on-road are in conformity with their original type approval over the engine test. For Euro VI the check of 'in-service conformity' using PEMS is mandatory. For Euro V it is allowed to use PEMS as an alternative test method for the regular engine test bed method for checking 'In-Service-Conformity'.

For this investigation, TNO used a PEMS for determination of the real-world truck emissions. The measured exhaust gas components are NO_x, NO_2, CO_2, CO and HC. The fuel consumption can be calculated from the emissions using the carbon balance method.

Using the PEMS, all vehicles were tested by driving a set of specified trips.

Aim of the specified trips was to meet the following requirements:

- represent typical Dutch urban, rural and motorway conditions;
- yield results that are comparable with the results that were obtained during the previous PEMS measurement programmes;
- assess the effectiveness and robustness of the procedures currently being used for in-service conformity legislation and being developed for the future Off-Cycle Emission legislation;
- and assess the relation of in-service conformity legislation and future Off-Cycle Emission legislation with real-world emissions for typical Dutch driving conditions.

Table 2: overview of trip requirements according to the in-service conformity legislation [582/2001/EC]

Vehicle category	**Trip duration percentage (± 5%)**		
	Urban	**Rural**	**Motorway**
M1 and N1	45	25	30
N2	**45**	**25**	**30**
N3	**20**	**25**	**55**
M2 / M3	45	25	30
M2 / M3 M3 of Class I, II or Class A	70	30	0

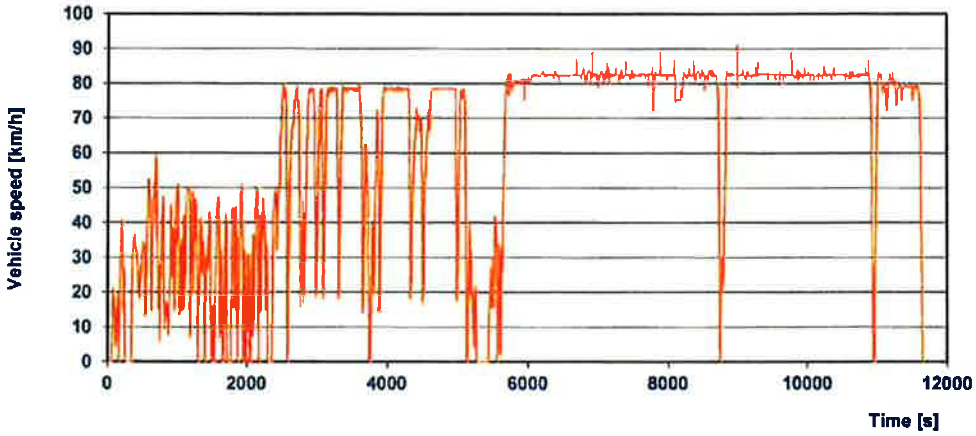

Figure 1: example of a speed trace of the N3 trip according Euro VI specifications

2.1.3 *Pass fail method for in-service conformity*

The pass-fail evaluation method has been applied, using the EMROAD tool (version 5.1 build 8). This tool can upload emission data from PEMS and CAN data from the vehicle in an Excel workbook to calculate the conformity factors (CF) according to the in-service conformity rules. A Conformity Factor (CF) is the fraction of the calculated emission value according to the given data-evaluation method, of the WHTC limit value. A CF of 1.5 for NO_x means that an equivalent of 1.5 times 2.0 g/kWh = 3.0 g/kWh is calculated by the tool for the given regulated emission component. Vehicles are not allowed to emit more than 1.5 times the emission limit value under the for the ISC procedure prescribed conditions and data-evaluation rules. Generally for ISC checking, more than one vehicle should be analysed to determine whether the vehicle type is compliant with the in-service conformity requirements. In this programme only one vehicle per type was tested and therefore the results are indicative only.

The next table shows the settings as used for the pass-fail data evaluation with EMROAD. The CO_2 averaging window method was used for the data-evaluation. This method calculates the average emissions over windows as large as the CO_2 mass that would have been emitted during an ETC test (Euro V) or WHTC test (Euro VI). Criteria are defined to exclude windows from the dataset, see the table below.

Cold engine operation and high altitudes are excluded from the pass-fail analysis. Furthermore, windows with a very long duration are excluded. This is an alternative for the power threshold as used for the work window method; a power threshold excludes windows where the average power in a window is below a certain percentage of the rated power. A maximum for the window duration also excludes windows with a very low average power because at a low average power it takes a long time before the CO_2 reference mass is reached.

What remains after exclusion of data is a set of ‘valid windows’ of which the single window with the largest value of 90 percentile of the data is taken to calculate the CF for each emission component.

Table 3: EMROAD data evaluation settings for the calculation of the Conformity Factor according to the proposed pass fail method

EMROAD version	5.1 build 8
Reference quantity	Work or CO_2
Reference torque	As provided by the manufacturer or ECU
Torque calculation method	Method 3 (using % torque, reference torque and friction torque)
Reference cycle	ETC (Euro V) or WHTC (Euro VI)
CO_2 estimation	CO_2 and work provided by OEM or work or CO_2 estimated from brake specific fuel consumption (EMROAD): 200g/kWh used
Data exclusion	Engine coolant temperature < 70 °C, Altitudes > 1500 m, 10th percentile of the maximum values of the valid windows
Time-alignment	On
Fuel density	0.84 kg/litre, (EN590 market fuel)
Vehicle speed	GPS vehicle speed
Conformity Factor	1.5

2.1.4 *ISC Results*

The figures below show the Conformity Factors for the regulated pollutant emissions. For NO_x vehicle Q and R, both EEV vehicles, clearly exceed the limit for the Conformity Factor (1,5). Vehicle P just exceeds the limit. The other Euro V vehicles N, S and T are well below the limit. Vehicle U, a Euro VI vehicle, has a very low CF. Three out of six Euro V and EEV vehicles with OBD II and NO_x measures exceeded the maximum CF for NO_x.

The results for every individual vehicle are discussed in a summary report per vehicle. The results of the vehicles have been discussed with the manufacturer's representatives. In the case of one vehicle the OEM still investigates the possible cause of the high NO_x emission. In the case of another vehicle the OEM explained that for their Euro V medium duty segment no PEMS tests have been performed for ISC. For this segment the ETC engine test is still performed without additional PEMS tests, which is formally allowed for Euro V vehicles. According to the OEM the reason for the high NO_x emissions could be the difference between the engine load and speed on the type approval test cycle as performed on the engine test bed and the engine load and speed as occurring in the real world.

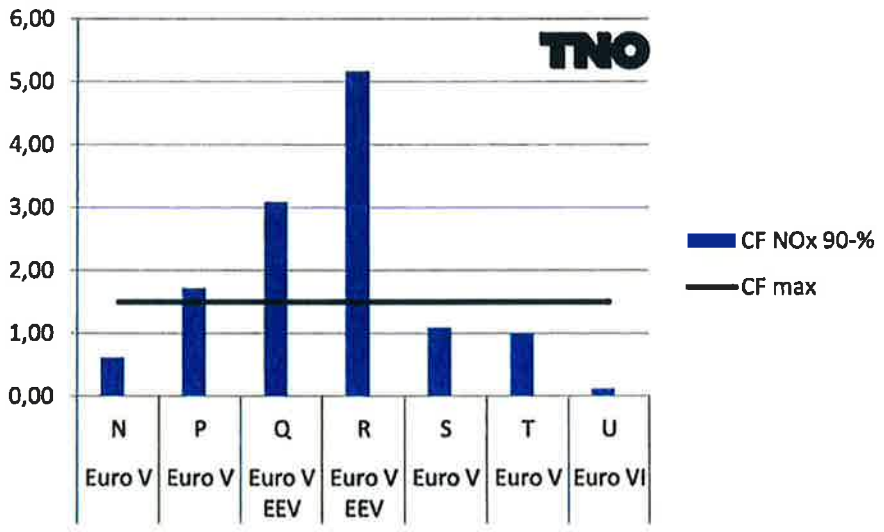

Figure 2: NO_x Conformity Factors

For CO all vehicles are well below the limit.

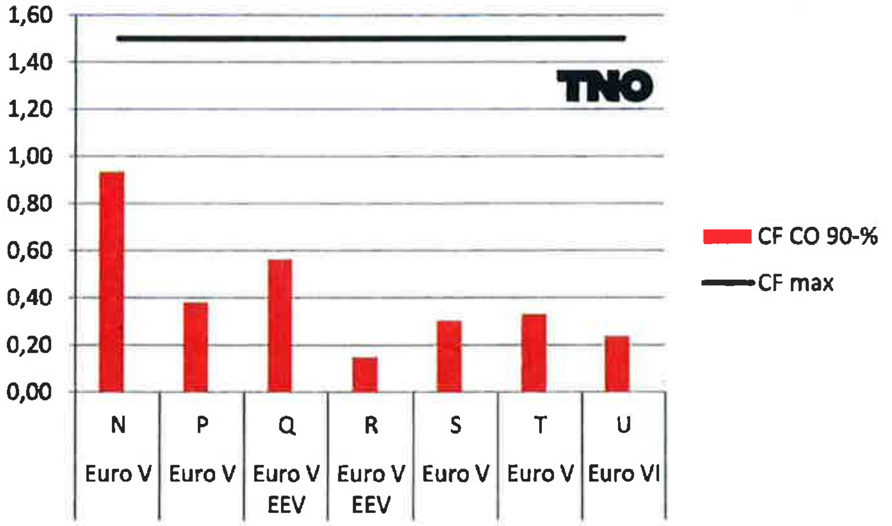

Figure 3: CO conformity factors

For HC all vehicles are well below the limit.

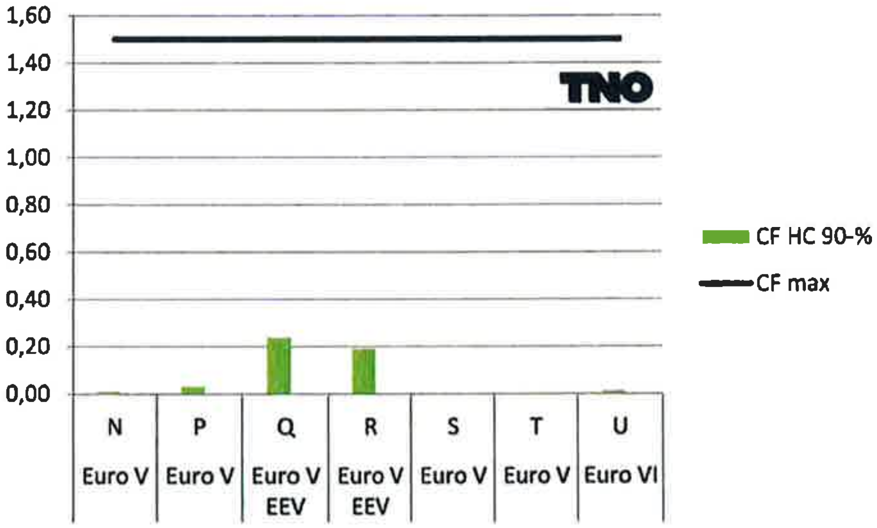

Figure 4: HC Conformity Factors

2.2 Real World Driving Emissions

This paragraph presents the analyses of real-world emissions and trends from the data. The data is analysed, applying a special method which will be explained first. Thereafter, results are presented for the vehicles tested in this year's programme, followed by trends which can be observed from the complete dataset of tested vehicles in the PEMS programme from 2009 until 2011. This includes observed trends from Euro III to Euro VI and of the different Euro V sub stages. The focus is on the NO_x emission, as these emissions are most relevant measureable emissions with PEMS for the air quality problems in the Netherlands.

2.2.1 Method using data binning

The primary purpose of the binning method is to facilitate the use of large amounts of PEMS data as input to calculate emission factors for urban, rural and motorway conditions and to gain insight into the emission behavior over the speed range of a vehicle. The method collects all emission data belonging to a defined speed interval and determines the average emissions for every interval over the complete speed range of a truck.

As preparation for the binning method PEMS data of the trips were pre-processed with EMROAD. EMROAD performs a data quality check and aligns the test signals. Since the tests were started with a warm engine no data was excluded. There were no big altitude differences during and between the trips.
Vehicle speed bins with a width of 5 km per hour were selected to distinguish emission data for low, intermediate and high vehicle speeds easily. In each bin of vehicle speed, the emissions [g/s] and CO_2 [kg/s] or engine power [kW] from the data points belonging to that speed bin are collected. In the end the average speed

within a bin, the average emissions in [g/kg CO_2] or [g/kWh] and the amount of data points within a bin are calculated.

The binning method can also be used to calculate brake specific emissions in gram per kilowatt-hour.

In the box below a calculation example is given to explain the binning method;

Example binning method calculation:

$$gNOx\ per\ kgCO2 = \frac{\sum_{v=vl}^{v=vl+5} NOx[g/s]}{\sum_{v=vl}^{v=vl+5} CO2[kg/s]}$$

Data points in a bin: 1 g/s NO_x, 10 kg/s CO_2
1 g/s NO_x, 0.1 kg/s CO_2
(In reality many more data points are needed)

Weighing of the contribution to the total emission in a bin:
Sum of the emissions / sum of the CO_2
=> (1+1) / (10+0. 1) = 0.2 [gNO_x/kg CO_2]

And not: Arithmetic average of the specific emissions
(1/10+1/0.1) / 2 = (0.1+10)/2 = 5.1 [g/kg CO_2]

The CO_2 specific emission results can be related to brake specific emission results assuming a constant average engine efficiency and fuel consumption. With an average engine efficiency of 40% (BSFC = 200 g/kWh), the g/kg CO_2 results can be divided by 1.6 to get a corresponding g/kWh result. Lower average engine efficiencies lowers this factor and would thus increase the brake specific results accordingly. For comparison, the Euro V NO_x emission limit of 2,0 g/kWh would amount 3,2 g/kg CO_2. When the ISC conformity factor of 1,5 is taken into account, this would amount to 4,8 g/kg CO_2.

2.2.2 *Real Driving Emissions of the vehicles tested in 2011*

The SCR equipped Euro V and Euro V EEV vehicles P, Q, S and T all have more or less the same emission behaviour, with exception of vehicle Q, which has a remarkable high NO_x emission at motorway speeds and vehicle S which has a somewhat high emission in the low speed range. All SCR equipped Euro V and Euro V EEV vehicles do emit a relatively high NOx emission at lower vehicles speeds, as was observed earlier
[Verbeek et al., 2010] for this type of vehicles. These Euro V vehicles are of a later Euro V sub generation than some of the earlier tested vehicles. How these Euro V sub generations compare will be discussed in paragraph 2.2.4.

Vehicle R an Euro V EEV N2 truck with EGR and DPF has a very high specific NO_x emission. Vehicle U, a Euro VI N3 truck with EGR, SCR and DPF, shows a very low specific NO_x emission over the entire speed range.

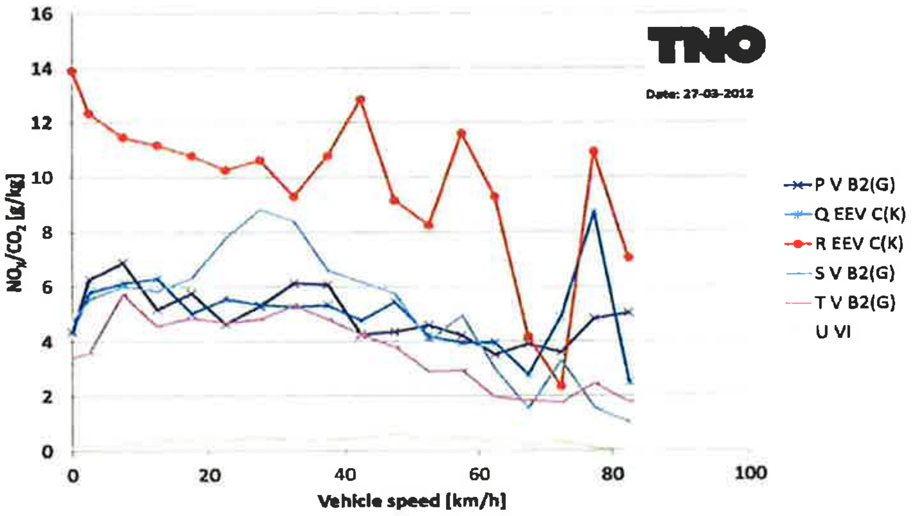

Figure 5: binned CO_2 specific NO_x emissions over the speed range of the vehicles tested in the 2011 programme

Just like most earlier measured Euro V vehicles with SCR the vehicles discussed here prove to be sensitive to payload, this is demonstrated in the figure below. The Euro VI vehicle is also sensitive to payload but to a lesser extent. The effect of payload on NO_x emissions for SCR equipped vehicles can be explained by the fact that an SCR catalysts needs to be warm, generally above about 200 °C, to reduce NO_x. With less payload in the vehicle the exhaust gas flow is lower and cooler, hence the SCR catalyst remains cooler and less NO_x can be reduced. When modelling NO_x emissions of this category of HDV this effect should be taken into account.

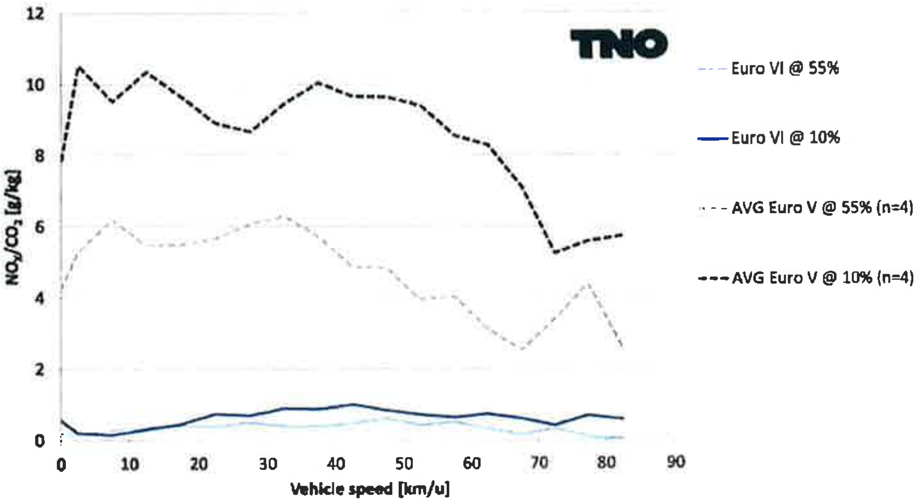

Figure 6: binned CO2 specific NOx emissions over the speed range of the SCR equipped vehicles for different payloads (10% and 55%): For the Euro V B2G vehicles (4 pcs) the payload clearly affects the specific NOx emission. For the tested Euro VI vehicle (1 pc) this effect is small.

2.2.3 Real driving emission trends from the database

To compare the NO_x emissions of the different measured legislative emission categories the binned CO_2 specific results of all measured HDV are plotted in the figures below. The following can be observed;

- The emission performance of the CO_2 specific NO_x emission of the Euro V vehicles is very scattered.
- The emission performance of EEV (Environmentally Enhanced Vehicles) is very scattered as well. EEV mainly stands for a somewhat lower PM limit over the ETC test (20 mg/kWh as opposed to 30 mg/kWh for regular Euro V vehicles) and a difference exists in the opacity limit over the ELR test. For EEV there are no special requirements for NO_x compared to Euro V. The results of the real world measurements show that an EEV label for diesel vehicles does not guarantee low NO_x emissions, or for instance lower NO_x emission than regular Euro V vehicles.
- The two tested Euro VI long haulage vehicles clearly have a very low CO_2 specific NO_x emission compared to the preceding generations of Euro V vehicles.

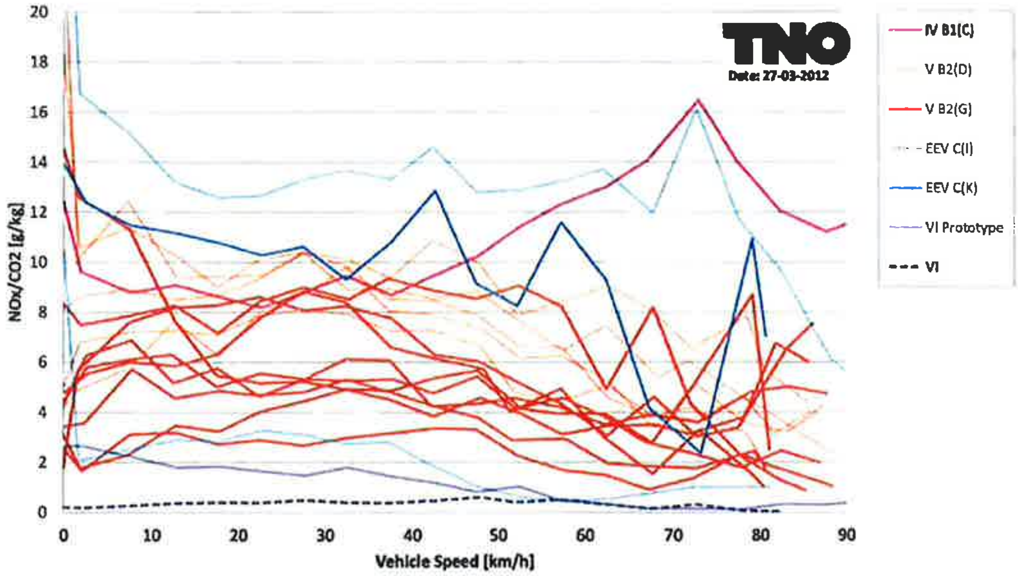

Figure 7: CO_2 specific NO_x emissions of all vehicles tested with PEMS on the road over the same (reference) trip with more or less the same payload factor (50-55%). Vehicles with engines of different legislative stages are shown. The performance of the Euro V and EEV vehicles is very scattered.

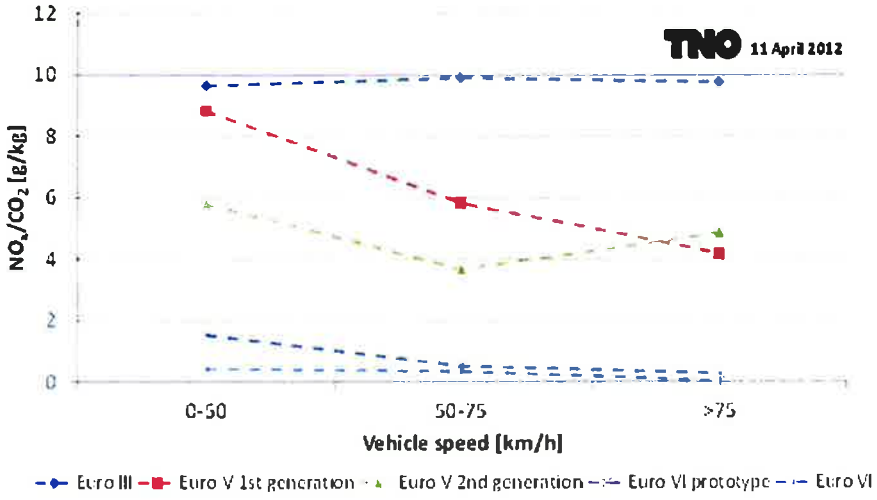

Figure 8: trend of the CO_2 specific NO_x emission over different legislative stages. A clear reduction of the CO_2 specific NO_x emissions can be noted.

2.2.4 *Emission performance of the latest generation Euro V vehicles (B2G)*

When the results of the first PEMS testing programme (2009) were analysed it appeared that the results of the then tested vehicles, mainly of the first generation of Euro V, showed relatively high specific NO_x emissions, especially under low speed/urban driving conditions. This first generation Euro V vehicles was introduced earlier than the official date of entry into force of the EU Euro V regulation, mostly because the German Maut incentivized the Euro V vehicles. Euro V vehicles entered the fleet as of 2005. Euro V is mandatory as of 2009. For the vehicles registered before 2009 and after 2009 different requirements apply. Also in 2007 a step is made in requirements. An overview of the different Euro stages is depicted in the table below. The main differences for Euro V and EEV can be found in OBD (I vs. II) and NO_x control measures.

Table 4: overview of Euro III, IV and Euro V (sub-)stages and applicable requirements.

Popular name	Letter	Row (Year of Type Approval)	OBD phase I	OBD phase II	Durability and ISC	NO_x control***
Euro III	A	A	-	-	-	-
Euro IV	B	B1(2005)	Y	-	Y	-
Euro IV	C	B1(2005)	Y	-	Y	Y
Euro V	D	B2(2008)	Y	-	Y	-
Euro V	E	B2(2008)	Y	-	Y	Y
Euro V	F	B2(2008)	-	Y	Y	-
Euro V	G	B2(2008)	-	Y	Y	Y
EEV	H	C	Y	-	Y	-
EEV	I	C	Y	-	Y	Y
EEV	J	C	-	Y	Y	-
EEV	K	C	-	Y	Y	Y

Requirements to ensure correct operation of NO_x control measures apply as of 9 november 2006 for Type Approvals and 1 Oktober 2007 for new registrations, included in the NO_x measures are:

- Maximum concentration of 25ppm for NH_3
- MIL Malfunction Indicator Light
- Use of NO_x sensors, 1,5 g/kWh higher than limit->MIL+faultcode
- driver inducement (torque reduction)
- Reagent control with indication for level
- Monitoring reagent consumption
- Anti-tampering discouragement

The PEMS data contains vehicles of both the early as well as the latest generation Euro V's and therefore these groups can be compared on NO_x emission performance. For this comparison the characteristics of both groups were first compared. The groups differ in power-to-mass ratio. Because the specific NO_x emission level is sensitive to this ratio (mass affects the specific NO_x emission of a given vehicle) this effect is compensated for. This was done by modelling the effect after which the model is used to calculate the corrected specific NO_x emission.

Table 5: overview of some characteristics of the compared groups

2005/78/EC Emission class	Euro V B2D	Euro V B2G
2007/46/EC Vehicle Category	N3	N3
After treatment	SCR	SCR
Mean Power [kW]	276	325
Mean Power-to-mass ratio [kW/tonne]	11,2	10,1
Sample size, n	5	6

The corrected specific mean NO_x emission of both groups is shown in the figure below. Error bars represent the 95% confidence interval (T-test). Given the statistical analyses based on this data it is not likely that the groups behave differently for the high speeds and the very low speeds. For the intermediate and low speed range it seems more likely that the groups differ.

For the group of B2G vehicles the CO_2 specific NO_x level is comparable to about 3,5 g/kWh. For this group, which has to fulfil the requirements with regard to NO_x measures, this is the same value as the threshold for the MIL and fault codes to be stored. For the early Euro V generation this was not yet required.

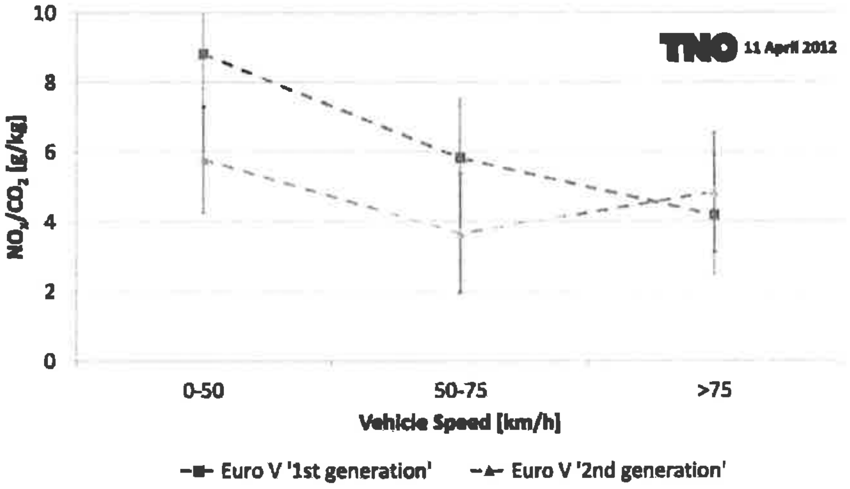

Figure 9: CO_2 specific NOx emission of first generation Euro V vehicles (B2D) and of last generation Euro V vehicles (B2G). The horizontal lines represent mean values per emission (sub-) class. The vertical lines represent the calculated 95% confidence interval (student T test).

3 Other activities

3.1 Remote Emission Sensing

High emitters are vehicles that emit much more pollutants than expected based on their type-approval. Knowing how many vehicles fall into this high emitter category is essential for determining realistic emission factors and for effectively defining measures aimed at improving air quality. With the Remote Emission Sensing (RES) unit it is possible to measure the emissions of vehicles in real-world conditions. Using RES a measurement session was performed at the flower auction in Aalsmeer aimed specifically at heavy duty vehicles. These measurements were used to determine whether the RES instrument is sensitive enough to identify high emitters amongst heavy duty vehicles. Despite a small sample size, there is evidence that RES can identify high emitters of CO, HC and black smoke (a possible proxy for particulate matter). For NO no high emitters are found, which is due to the large intrinsic scatter in NO emissions. For a small subgroup of vehicles with detailed vehicle information the RES measurements indicate that Euro 3 heavy duty vehicles emit more NO than Euro 5 heavy duty vehicles, as expected. The small sample size prohibits a robust statistical analysis and therefore it is not possible to make a quantitative statement on the fraction of high emitters per Euro class. Significantly increasing the number of vehicles with further measurements could alleviate this and make it possible to do a detailed quantitative analysis. The findings are reported in a separate report [Kuiper, 2012]

3.2 Smart Emission Measurement: NO_x screening method.

The Euro V requirements for diesel engines for trucks and buses have shown not to guarantee low NO_x emissions during urban driving conditions. A change in the Euro V test cycle or the development and introduction of specific off cycle provisions (Euro VI) to improve real life urban emission behaviour would take too much time due to the EU legislative process to play a role in the remaining years of registration of new Euro V vehicles. Furthermore, it would take years before the fleet is refreshed with the cleaner Euro VI vehicles.

The Netherlands Ministry of the Environment and Infrastructure suggested that a label guaranteeing adequate urban emission behaviour might be a feasible alternative for vehicle operators and local authorities when purchasing trucks and buses intended for urban use. This labelling would not be used to prohibit the sale of vehicles without a favourable label, but for instance serve as a means for operators of vehicles and (local) authorities to know whether vehicles have low NO_x and NO_2 emissions in urban operation and to subsequently for instance grant privileges to such vehicles.

For this labelling approach criteria are needed and a way to check vehicles against these criteria. The PEMS data of the In-Service Testing programme was used to perform a data evaluation exercise to learn more about different possibilities to develop a method and criteria. For the exercise the binning method was used as a starting point because this method is able to discriminate vehicles with high and low NO_x emission pretty well.

The procedure is based on measurement on a HDV with a NO_x – oxygen sensor and GPS under representative driving conditions and uses a dedicated method of data analyses to calculate the NO_x performance.

Figure 10: overview of basic instruments for the NO_x screening method

A database with tested Euro V vehicles as obtained from this testing programme is used to demonstrate the feasibility of the calculation method for the discrimination between vehicles with low and high NO_x emission. A small pilot program where the NO_x sensor and GPS are employed next to a PEMS (Portable Emission Measurement System) allows the validation of the tool and method against an accurate reference system.

For the development of a pass-fail method the available PEMS data is analysed. The next figure shows the CO_2 specific NO_x emissions of all vehicles tested with PEMS. The data is binned in large bins of 0-50, 50-75 and >75 km/h respectively. Clear differences can be noted in vehicle NO_x emission performance within the same emission class and also between the speed ranges. For most vehicles the CO_2 specific NO_x emission increases substantially in the speed range of urban driving. It is recommended to further elaborate this method and to try it in real life on a test vehicle, e.g. a city bus to gain more experience with feasibility, practicability and accuracy of this approach. Possible applications of the method are:

- National approval schemes, like for dual-fuel vehicles, retrofit systems for HDV and possibly also inland vessels.
- As a method to be used in public procurement to regularly check vehicles or to apply a pass-fail method with special requirements.
- In-service conformity screening method. A simple method to perform more tests to screen for vehicles suspected to be not in conformity or for erratic emission behaviour.

- Input for emission modelling for the determination of emission factors. The data can be complementary to the data measured with more accurate and expensive systems, like PEMS.

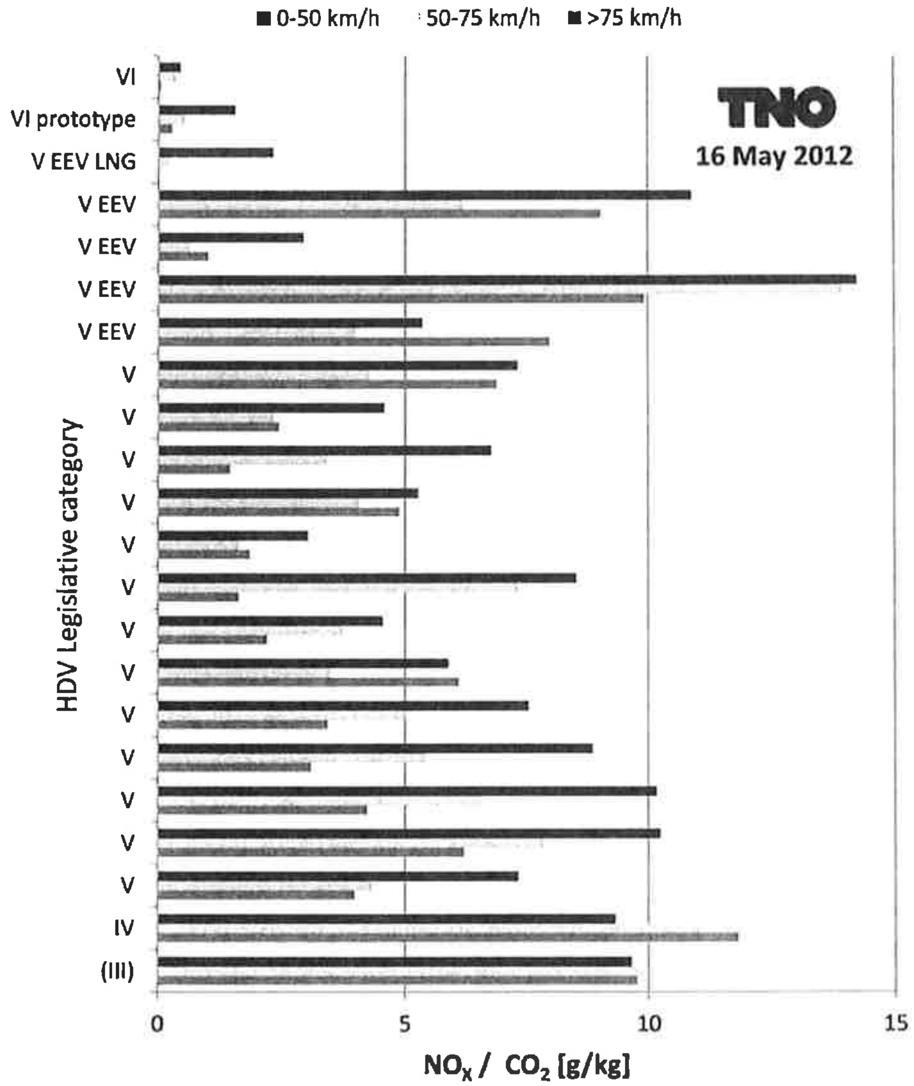

Figure 11: evaluation of all HDV measured with PEMS, analysed applying the data binning method as described in paragraph 2.1.1 and using large speed intervals. The evaluation shows the power of the method to distinguish NO_x emissions between individual vehicles and between the typical driving speeds. A simplified measurement method will be developed with a purpose to distinguish the vehicles and speeds based on the same evaluation method.

3.3 Support for the EU CO_2 HDV programme

The HD programme supported an EC programme with the delivery of useful data. The gain for the Netherlands In-Service Testing programme is that it keeps hold of the latest developments of a test procedure for the determination of the CO_2 emission of HDV. The EC programme and the tests performed for this programme will be discussed hereafter.

The paragraph will start with a general overview of the aim and approach of the project. Further the CO_2 certification procedure will be discussed more in depth, the position of the stakeholders will be explained, and an overview of the work that lies ahead in the further development of the CO_2 certification procedure is presented. This paragraph will conclude with an overview of the work that was performed with the Netherlands In-Service Testing programme to support the work of the European Commission.

3.3.1 General overview of the aim and approach of the CO2 certification procedure development project

TNO participates in a Framework programme (LOT 2) for the European Commission. The consortium is led by the TU Graz. The goal of the programme is to develop a CO_2 certification procedure for HD vehicles. Other members of the consortium are: TUV Nord, Heinz Steven, AVL-MTC, VTT and LAT. The project started in 2010 and is almost finished.

The options under investigation for the CO_2 certification procedure are:
- testing in real world on the road and
- simulation, the vehicle including its powertrain are modelled.

Position European Commission
The EC, DG CLIMA, wants to developed instruments which could support their policy to realize the long term CO_2 target for transport, which is approximately a 60% CO_2 reduction in 2050 (white paper). There is also an intermediate target of 20% reduction in 2030 compared to 2008 (~ 1% per year).
For HD vehicles DG CLIMA issued 2 projects:
- LOT 1: European statistical data, measures for CO_2 reduction and possible instruments. The final report was issued in January 2011.
- LOT 2: Development of a CO_2 certification procedure for the whole truck (including base truck + superstructure + auxiliaries). Final report was due for January 2012.

The timeline in which the project takes place is:
- Public hearing Q3 2011, stakeholders Q1 &Q2 2012.
- 2012 (+2013?): completion simulation tool ('demonstrator'), pilot phase and validation
- Impact assessment: ready by end of 2012. HD CO_2 emission strategy adaptation in first half of 2013 (tentatively).

Possible next steps after the project is finished are:
- First step: Official (European unified) monitoring / certification
- Second step: Labelling / declaration
- Third step: Foot print / life cycle CO_2 calculation (transport), customised fuel calculation for HDV customers

3.3.2 HD CO2 certification method

In the LOT 2 project, the model approach has been selected as the preferred method. Input to the model are the measured engine fuel consumption map and the measured or pre-set driving resistance. Simple models or pre-set values for

transmission losses and auxiliaries are included as well, but can be improved over time in order to provide the best incentives for parts- and systems suppliers.
This model approach is thought to give the best accuracy and is able to cover all truck-body and truck-trailer configurations at acceptable costs. It can also provide a tool for truck selection by fleet owners. A schematic overview of the HDC CO_2 simulator tool is depicted in the figure below

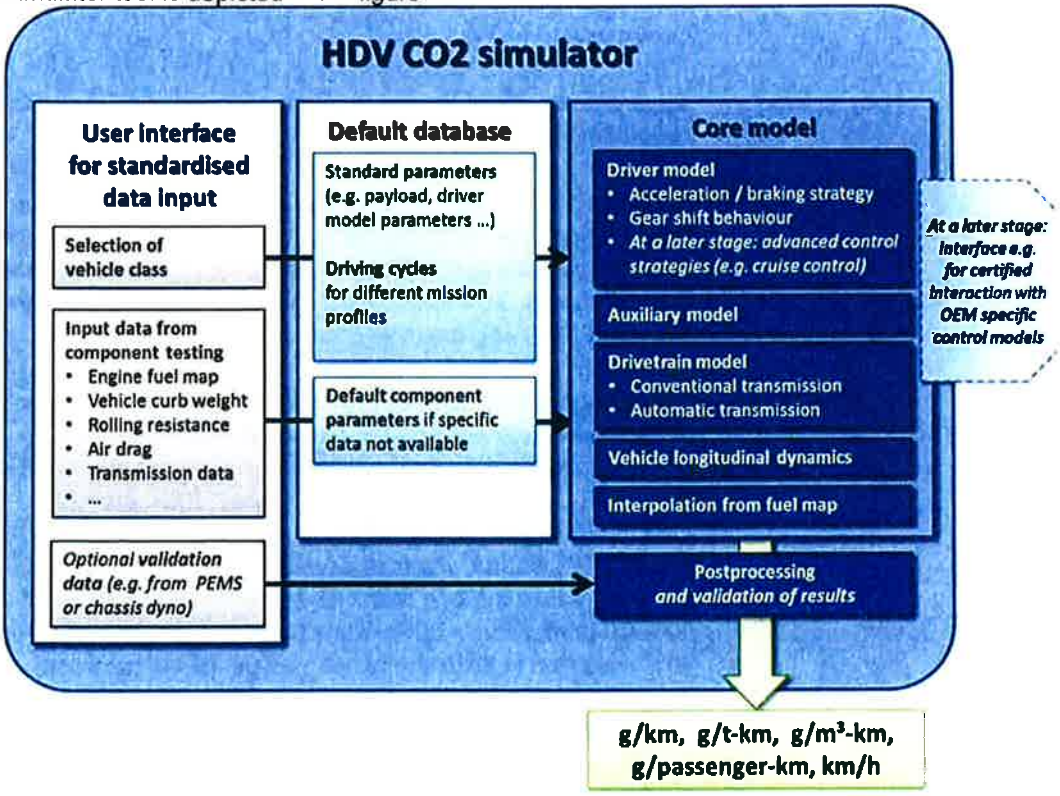

Figure 12: schematic of the draft HD CO_2 certification method

3.3.3 *Position stakeholders*

The stakeholders, especially ACEA, are very much involved. ACEA carries out a large parallel project and basically has fed their ideas and vision into the LOT 1 and LOT 2 projects. ACEA probably sees the CO_2 method as a way to reduce energy consumption by:

a) having a tool for fleet owners to select more efficient trucks and
b) realizing a better focus in product development for lower energy consumption.

Other industrial stakeholders such as large body and trailer manufacturers and their European stakeholder organisations are also cooperating in the development. The Road Transport Association prefers an integrated approach including traffic flow, driving behaviour and logistics.

3.3.4 *Conclusions of the work to-date:*

- The model approach came out as the best method for HD CO_2 certification. Main reasons are the relative high accuracy and a practical way to cover all (several thousands of) truck configurations.

- A relative detailed approach including all components (engine, driveline, auxiliaries, chassis and body), with realistic test cycles, is expected to give best incentives and tools to optimise the entire vehicle.
- The method makes good progress, but still needs a lot of work. Certain features, such as for auxiliaries, can be phased in over time.
- Europe has chosen for a much more detailed approach than currently included in methods for USA, Japan and China
- The industry is strongly involved in the development of the CO_2 method.
- A truck selection tool, supported by ACEA, can be based on the official method with freedom to reprogram in-use parameters (such as load and cycle).

3.3.5 *Work ahead / next phases:*

- Build and publish the demonstrator simulation tool:
- Include a vehicle simulator with development work for driver model, gear box models, aux. models
- Include test cycles (dependent on vehicle class)
- Define a precise methodology and pre-processing tools for aerodynamic drag, transmission efficiency and auxiliaries
- Collection of data to establish default values and definition of standard formats for relevant components (cooperation with OEM's)
- Organisation of pilot phase and validation of developed method(s)
- Definition of family criteria, definition of responsibilities, metrics
- Writing of the regulation
- Development of IT environment with features like data base, efficient interfaces for uploading data for a large number of vehicle components and variants. Security and confidentiality needs to be guaranteed

3.3.6 *Contribution of the Netherlands In-Service Testing programme to the work*

To investigate and develop the modelling approach, information is required from different parts of the vehicle configuration, of two reference vehicles, regarding its contribution in the total energy budget. For instance, drag and rolling resistance have been measured by means of the coast down procedure. Engine efficiency has been measured on a dedicated dynamometer. Information lacking was that of the efficiency of the drive line. In the driveline, usually composed of a gear box, cardan, a final reduction and a differential, a significant amount of energy is lost mostly due to friction. A small measurement programme was set up to measure the friction loss in the drive line and to learn about the influence of conditioning (warming up) of the drive line.

One of the reference vehicles, a 12t category rigid truck was mounted on the powertrain test bed at TNO Helmond. The engine of the vehicle has known specifications regarding fuel efficiency at given output over the engine map (engine speed, torque). The torque and speed were measured at the hubs of the rear wheels and the fuel consumption was measured over the complete engine map in all gears. The measured torque at the hubs minus the expected torque from the engine results in an estimate of the friction torque (loss) of the drive line. The main results of this exercise are presented in the figures below.

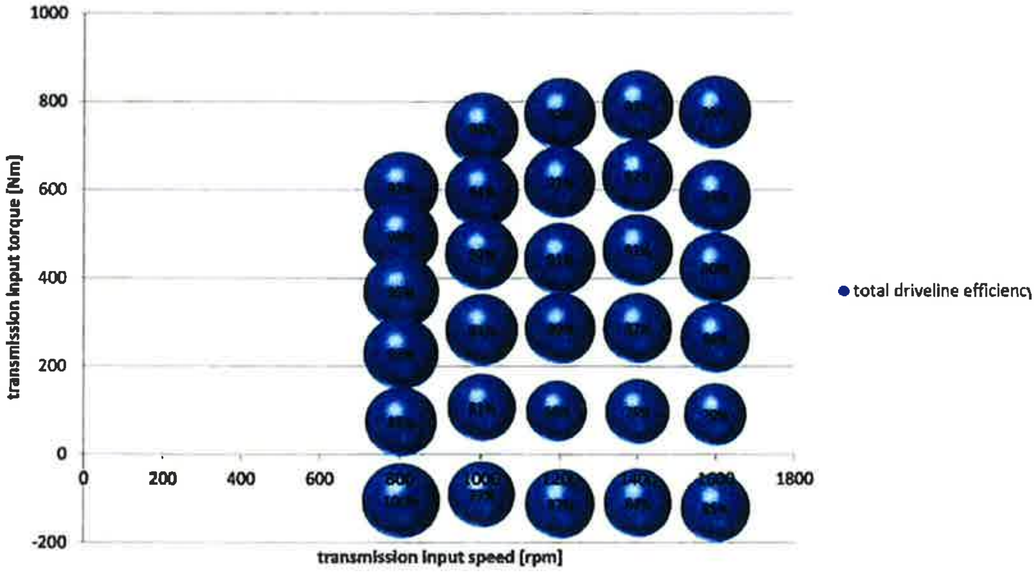

Figure 13: calculated friction loss in the total drive line (from flywheel to wheel hubs, thus excluding tyre rolling resistance). The friction loss was calculated from the difference between the power output of an engine on a test bed (flywheel) and the rear wheel hubs of a vehicle with the same engine type on a powertrain test bed.

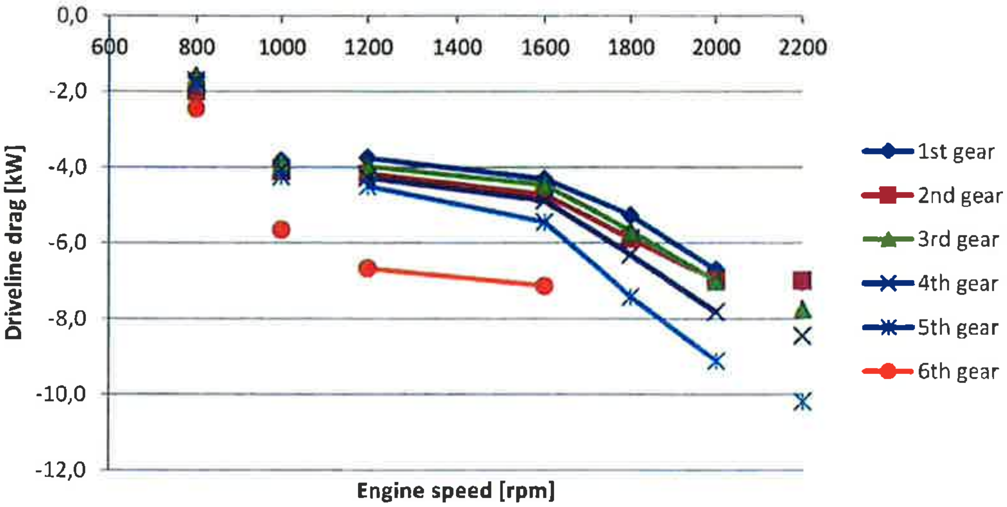

Figure 14: driveline drag as calculated from the difference between measured engine drag at the engine test bed and the measured drag at the vehicle powertrain test bed at the wheel hubs

3.4 Evaluation of the ISC procedure using PEMS

During the test programme of recent years, experience has been gained with PEMS measurements, real world emissions and the pass-fail method and the test procedure as used for the EU ISC emission legislation. At the moment the EC considers further improvement of the ISC procedure and the implementation of further measures to improve the real world emissions of HDV in the form of a procedure covering Real Driving Emissions (RDE), in earlier stages also called Off-Cycle Emission (OCE). Such a procedure would have a wider scope of conditions and a different purpose than ISC. The latter is originally meant to check if vehicles are in conformity with their original type approval over the engine test cycle, while the purpose of RDE would be to check/judge the emissions under a wider scope of representative conditions than the engine test and the ISC procedure do.

The obtained data set from the PEMS measurements allows the evaluation of emission performance of HDV under the wide range of relevant conditions. The PEMS data is shared with DG-JRC and also the experience gained within the test programme is shared with the EC. In this way the measurements contribute to the development of effective procedures for ISC and RDE.

With regard to the ISC method using PEMS and the possible use of PEMS for checking the RDE, issues were noted with regard to the measurement of emissions, the pass-fail method and with some of the administrative provisions. The issues are summarized hereafter, but are mostly further elaborated in detail within a separate programme (The Netherlands MaVe project (Maatwerk Verkeersemissies) and are discussed in working groups which deal with PEMS, ISC and RDE.

3.4.1 *Issues regarding the measurement*

- Time alignment: the signals of the exhaust flow meter and analysers need to be aligned correctly to calculate the mass emission accurately. Currently, EMROAD and the legislative requirements (Annex II) demand the use of a fixed time alignment. A variable time alignment may be required to compensate for dynamic behaviour. This may be especially required for engines with large fluctuations in exhaust flow, like for instance Otto engines. Dynamic inaccuracies can be solved by using an approach which does not rely on exhaust mass flow measurement anymore, expressing results in for instance g/kgCO_2. For emission modelling a possible influence of time alignment also needs to be minimized within acceptable limits. In the next year there will be a focus on quantifying the influence of incorrect time alignment and possible ways to minimize the influence.
- Drift correction: at the low concentrations of the tail pipe emissions of Euro VI vehicles the relative influence of signal drift becomes important (up to 10-20ppm of drift is relatively high considering average NO_x concentration levels of around 10-50ppm for current Euro VI vehicles). This might also be an issue for some of the Euro V vehicles which perform well on NO_x. Newer types of PEMS or upgrades for PEMS are available to solve this issue.
- For Euro V vehicles the ECU torque signal is not very reliable. It is a broadcasted signal which has no further specification with regard to what it exactly means and how accurate it should be. Therefore, for most engines the calculated work is unreliable which affects the robustness of the method. The method using CO_2 relies on a measured value and is therefore recommended for use. The CO_2 method however requires a CO_2 mass over the ETC (Euro V) or WHTC (Euro VI) to serve as a reference value for the pass-fail calculation. Often this CO_2 mass value is not available for Euro V vehicles as it is not required to be measured and therefore an estimate has to be used which is merely based on default values, assumptions of the cycle work and the brake specific fuel consumption. Also this uncertainty affects the robustness.

3.4.2 *Issues regarding the test procedure*

In general the test procedure, including requirements for the trips, trip composition, ambient conditioning and driving style needs to be in line with the purpose of the procedure. Different requirements may be needed if ISC and RDE are judged separately. For instance, for ISC the requirements should focus on similar conditions as the lab (engine test bed) tests, while for RDE the conditions should probably be defined much wider. The latter to ascertain that low emissions are guaranteed under most relevant driving conditions (ambient, driver, trip (including conditioning)) and not only under lab / test cycle alike conditions.

During the PEMS test programme one light N2 truck proved to drive completely different compared to the applicable ETC test cycle when engine speed and load are compared. Also the NO_x emission proved to be different from what was expected taking into account the TA limit (much higher than anticipated). The picture below shows that in real world the vehicle was tested at lower speeds and engine loads then the ETC. Partly this offset could be due to a difference in driving style between the real world situation and the ETC, but the vehicles driveline configuration, which was typical for this type of vehicle, could be a possible cause as well. The ISC procedure prescribes to drive representative trips while for the ETC this is implicitly fixed in the cycle. In this case (of the N2 truck) the interpretation of representative driving and the given vehicles driveline configuration resulted in rather different engine loads and speeds than the ones occurring on an ETC. It is the question whether this is a generic problem for this category of vehicles.

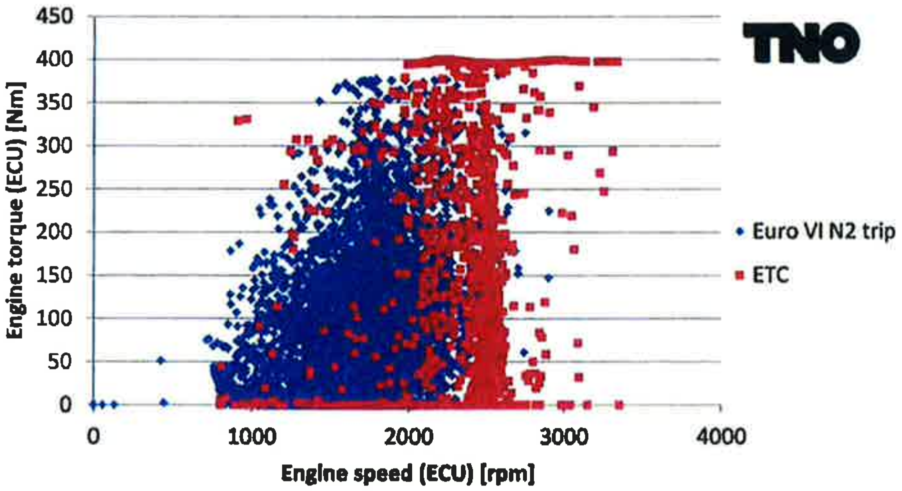

Figure 15: engine operation points over the type approval engine test cycle (ETC) and during real world operation in an N2 distribution truck: the engine operation points are quite different for both situations

3.4.3 *Issues regarding pass fail method and calculation tool*

- Currently, the EMROAD tool (currently version 5 build 10) is generally employed to perform the numerous calculations required to determine the Conformity Factors. The tool takes care of the checking of the data, data alignment, emission calculations according ISO 16183 and pass fail calculations with certain data exclusions and has many more features. Altogether, the tool seems to overshoot the mark for simply calculating the CF for the checking of ISC of a vehicle. The tool became complex and with that came the risk for errors.
- The EMROAD (public) development stopped and the manual is no longer updated (The web page is about to disappear). Basically the EMROAD add-in was only a 'research' tool developed to support some official PEMS projects and should be replaced by 'professional' products. These products will need to be predefined or developed by an independent third party, to minimize the risk of different interpretations of the ISC regulation by TAA, Member States and the industry.

3.4.4 *Further issues and recommendations*

It is recommended to elaborate further issues in the next year's programme and in the MaVe project and discussed them with the stakeholders. Recommended topics for investigation and discussion are:

- The sensitivity of the pass fail-method for data exclusion.
- Possibilities for simplification of the pass-fail method
- Possibilities for simplification of the EMROAD tool, for instance to make it suitable for ISC only
- Possibilities for improving the robustness of the pass-fail method
- Possibilities to better define the requirements for the trip, warm up and conditioning
- Possibilities to demand for clearly specified input values instead of the possibility to use default values.
- Possibilities to demand data from manufacturers for use in Member State programs
- The coverage of the ISC procedure. Currently, an engine must be tested in its most representative application for instance haulage. The same engine can be mounted a city bus and in principle has to fulfill the same requirements, however due to the rule of checking the most representative vehicle will never be checked for ISC. Only when ISC would focus on test cycle conditions one could consider to check an engine in an application which would meet the test cycle conditions the most. Widening the scope could be arranged by the RDE procedure to ascertain good emission performance for the whole fleet under a wider scope of driving conditions and ambient conditions.

It is recommended to evaluate the Euro V and Euro VI measurement data in the following way to learn about the influence for the outcome of the procedure:

- without the 10% per cent data exclusion
- without the 20% power threshold
- expressing the outcome in different ways as g/km, g/s, g/kWh and g/kgCO_2
- using time windows, distance windows and data binning an evaluate different window and bin sizes

3.5 Emission modelling

The emission factors for heavy-duty vehicles are in transition. The ongoing PEMS programme has enabled to make more and better distinctions in the heavy-duty emissions, both in truck specifications as in road types. The amount of data and the fact that it can be attributed directly to the real-world conditions of the driving makes it a significant improvement over the older emission factors. These older factors were produced based on measurements on the engine test bed and with the stationary modes on the chassis dynamometer. The transition has been made by utilizing on-road measurements with the PEMS. Also additional data from the chassis dynamometer at VTT Finland truck emissions under real-world driving has become available for Euro-III.

The transition to PEMS-based emission factors is not complete. An intermediate stage has been introduced through the step of specific emissions from PEMS, i.e. g NO_x per kg CO_2, such that the CO_2 emission could be related with previous results which were compared with fuel-consumption data on the road.

The deviation in NO_x emission between heavy trucks and light trucks, clearly visible in the raw PEMS data, when plotted as a g/ton*km emission, is included into the current analysis. The parameter of specific power: "kW/ton" (engine power per GVW) accounts for the variation and it attributes more of the urban NO_x emission to light trucks, i.e., two-axle rigid trucks, than previously assumed.

Ongoing is the research to incorporate fuel-consumption, idling temperature, and effects of specific legislation (Euro V stage 1 and 2) into the analysis, to arrive at even better specified and a more attributable emission factors.

4 References

Relevant European Regulations and Directives:

[582/2011/EC], [2011/595/EC], [2007/46/EC], [2005/78/EC], [70/156/EC] and amendments: http://eur-lex.europa.eu/nl/index.htm

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5 Signature

Delft, 17 August 2012

Willar Vonk
Project leader

Robin Vermeulen
Author

A Vehicle reports

A.1 Vehicle N

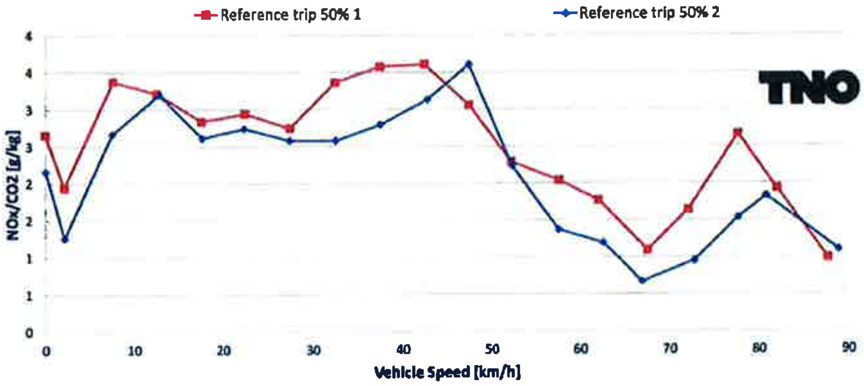
Test vehicle

Legislative category	N3, Euro V, B2(G)
Type	Tractor semitrailer, 4x2 3-axle semitrailer
Engine capacity range	10-13 ltr
Engine power range	350-400 kW
Emission reduction	SCR+NH_3 clean-up catalyst
Odometer	4747km

Test conditions

Trips	Payload / GCM	Weather	Traffic
Reference trip 1	50% / 27900 kg	20-30°C, dry	Calm, no congestion
Reference trip 2	50% / 27900 kg	20-30°C, dry	Calm, no congestion

Test results



	NO_x Conformity Factor [-]	NO_x max [-]	CO Conformity Factor	HC Conformity Factor	CFmax
REF 55% #1	0,67	0,83	0,92	0,02	1,5
REF 55% #2	0,56	0,73	0,95	0,01	1,5

Trip name + payload	NO_x	NO_2	HC	CO	CO_2
	[g/km]	[g/km]	[g/km]	[g/km]	[g/km]
Reference 50% trip 1	2,5	0,18	0,1	5,8	1078
Reference 50% trip 2	2,1	0,21	0,0	5,8	1034
Difference	-19%	15%	-100%	1%	-4%

A.2 Vehicle P

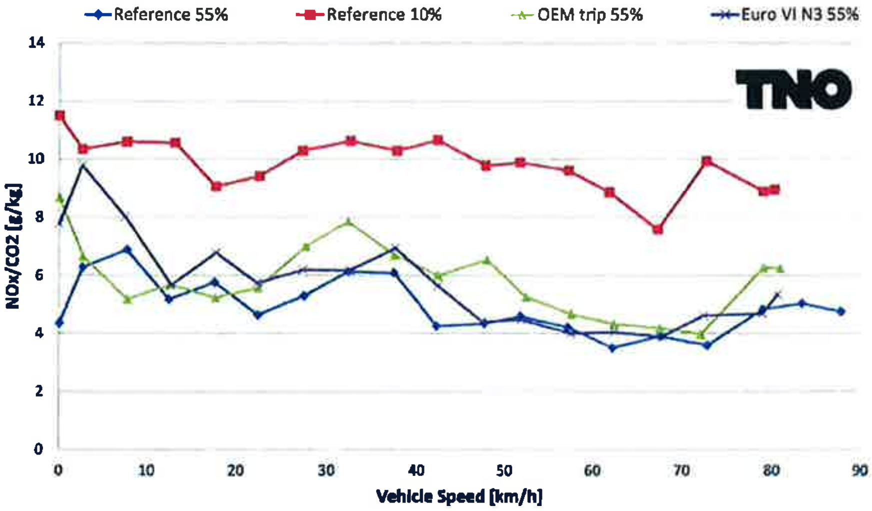
Test vehicle

Legislative category	N3, Euro V, B2(G)
Type	Tractor semitrailer, 4x2 3-axle semitrailer
Engine capacity range	10-13 ltr
Engine power range	300-350 kW
Emission reduction	SCR+NH_3 clean-up catalyst
Odometer	206121km

Test conditions

Trips	Payload % / GCM	Weather	Traffic
Reference trip	55% / 34421 kg	20-30°C, dry	Calm, no congestion
Reference trip	10% / 18842 kg	20-30°C, dry	Calm, no congestion
Euro VI trip N3	55% / 34421kg	20-30°C, dry	Calm, no congestion
OEM specified Euro V trip	55% / 34421kg	20-30°C, dry	Calm, no congestion

Test results



	NO_x Conformity Factor [-]	NO_x max [-]	CO Conformity Factor	HC Conformity Factor	CFmax
Euro VI N3 55%	1,72	2,00	0,38	0,03	1,5
REF 55%	1,60	1,64	0,89	0,07	
REF 10%	2,89	2,92	0,44	0,05	
OEM Euro V trip	2,08	2,15	0,38	0,05	1,5

Trip name + payload	**CO_2**	**NO_x**	**NO_2**	**NO**	**Perc NO_2**	**NO_x per CO_2**	**CO**	**HC**
	[g/km]	[g/km]	[g/km]	[g/km]	[%]	[g/kg]	[g/km]	[g/km]
Euro VI N3 55% total	1021	5,34	0,13	5,21	2%	5,2	2,1	0,02
Urban	1742	10,94	0,16	10,77	2%	6,3	7,5	0,03
Rural	1198	5,39	0,12	5,27	2%	4,5	2,6	0,02
Motorway	880	4,69	0,13	4,57	3%	5,3	1,4	0,02
Reference 10%	877	8,43	0,27	8,16	3%	9,6	2,9	0,04
Reference 55%	1319	6,40	0,16	6,24	2%	4,9	5,5	0,07
OEM spec Euro V trip	1176	6,98	0,23	0,23	3%	5,9	2,8	0,04

A.3 Vehicle Q

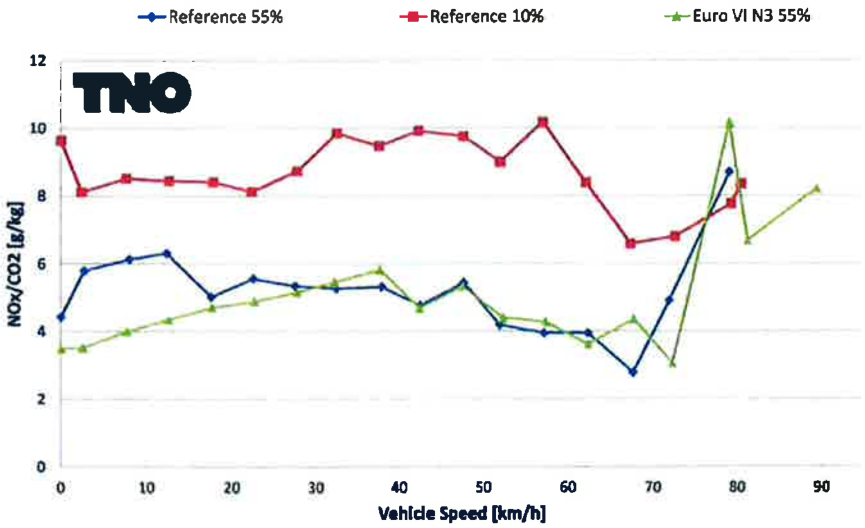
Test vehicle

Legislative category	N3, Euro V EEV, C(K)
Type	Tractor semitrailer, 4x2 3-axle semitrailer
Engine capacity range	10-13 ltr
Engine power range	300-350 kW
Emission reduction	SCR+NH$_3$ clean-up catalyst
Odometer	87255km

Test conditions

Trips	Payload % / GCM	Weather	Traffic
Reference trip	55% / 34220 kg	10-20°C, dry	Calm, no congestion
Reference trip	10% / 18480 kg	10-20°C, dry	Calm, no congestion
Euro VI trip N3	55% / 34220 kg	10-20°C, dry	Calm, no congestion

Test results



Trip	NO$_x$ Conformity Factor 90-% [-]	NO$_x$ max [-]	CO Conformity Factor	HC Conformity Factor	CF max [-]
Euro VI N3 55%	3,09	3,17	0,56	0,24	1,5
REF 55%	2,06	2,18	0,51	0,07	
REF 10%	2,53	2,69	0,63	0,13	

Trip name + payload	**CO_2**	**NO_x**	**NO_2**	**NO**	**Perc NO_2**	**NO_x per CO_2**	**CO**	**HC**
	[g/km]	[g/km]	[g/km]	[g/km]	[%]	[g/kg]	[g/km]	[g/km]
Euro VI N3 55% total	904	7,06	0,49	6,58	7%	7,8	2,3	0,15
Urban	1595	8,94	0,28	8,66	3%	5,6	9,4	0,42
Rural	1056	6,75	0,53	6,22	8%	6,4	2,7	0,19
Motorway	778	6,97	0,50	6,47	7%	9,0	1,4	0,11
Reference 10%	857	7,40	0,14	7,26	2%	8,6	4,1	0,19
Reference 55%	1179	6,59	0,51	6,09	8%	5,6	4,9	0,07

A.4 Vehicle R

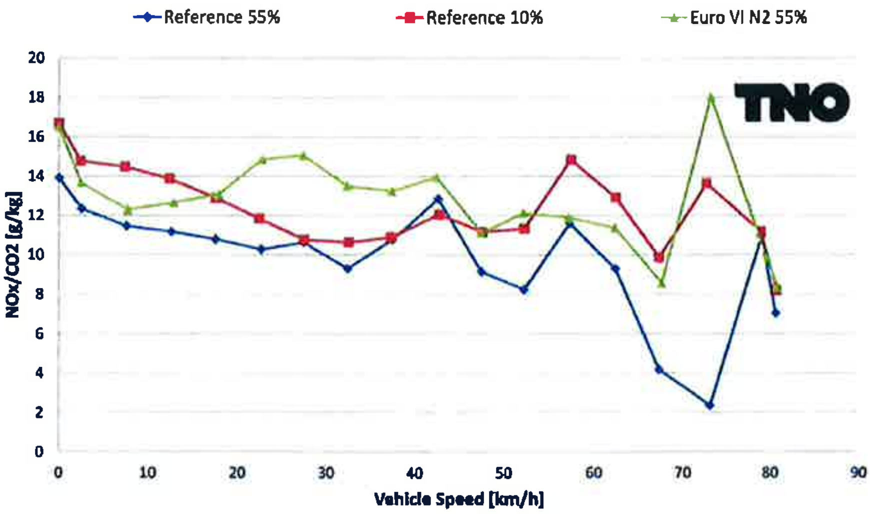
Test vehicle

Legislative category	N2, Euro V EEV, C(K)
Type	Rigid truck 4x2
Engine capacity range	2,5-3,0 Ltr
Engine power range	100-150kW
Emission reduction	EGR + DPF
Odometer	144566km

Test conditions

Trips	Payload % / GCM	Weather	Traffic
Reference trip	55% / 3760 kg	10-20°C, dry	Calm, no congestion
Reference trip	10% / 3180 kg	10-20°C, dry	Calm, no congestion
Euro VI trip N2	55% / 3760 kg	10-20°C, dry	Calm, no congestion

Test results



Trip	**NO_x Conformity Factor [-]**	**NO_x max [-]**	**CO Conformity Factor**	**HC Conformity Factor**	**CF max [-]**
Euro VI N3 55%	5,17	5,30	0,15	0,19	1,5
REF 55%	2,99	3,06	0,22	0,01	
REF 10%	3,73	3,76	0,27	0,00	

Trip name + payload	**CO_2**	**NO_x**	**NO_2**	**NO**	**Perc. NO_2**	**NO_x per CO_2**	**CO**	**HC**
	[g/km]	[g/km]	[g/km]	[g/km]	[%]	[g/kg]	[g/km]	[g/km]
Euro VI N2 55% total	313	4,13	0,70	3,43	17%	13,2	0,4	0,06
Urban	342	4,83	0,25	4,59	5%	14,1	0,7	0,11
Rural	316	5,17	1,04	4,12	20%	16,4	0,3	0,05
Motorway	295	3,08	0,74	2,34	24%	10,4	0,2	0,03
Reference 10%	313	3,59	0,59	3,00	16%	11,5	0,6	0,00
Reference 55%	326	2,84	0,38	2,47	13%	8,7	0,5	0,00

A.5 Vehicle S

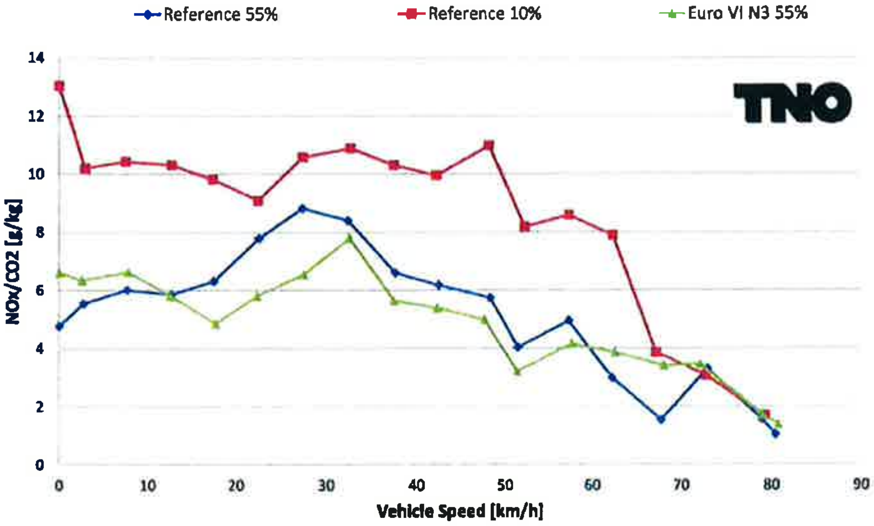
Test vehicle

Legislative category	N3, Euro V, B2(G)
Type	Tractor semitrailer, 4x2 3-axle semitrailer
Engine capacity range	10-13 ltr
Engine power range	300-350 kW
Emission reduction	SCR+NH_3 clean-up catalyst
Odometer	45562 km

Test conditions

Trips	Payload % / GCM	Weather	Traffic
Reference trip	55% / 34220 kg	10-20°C, dry	Calm, no congestion
Reference trip	10% / 18480 kg	10-20°C, dry	Calm, no congestion
Euro VI trip N2	55% / 34220 kg	10-20°C, dry	Calm, no congestion

Test results



Trip	NO_x Conformity Factor [-]	NO_x max [-]	CO Conformity Factor	HC Conformity Factor	CF max
Euro VI N3 55%	1,09	1,56	0,30	0,00	1,5
REF 55%	1,37	1,48	0,33	0,00	
REF 10%	1,63	1,77	0,30	0,00	

Trip name + payload	CO_2	NO_x	NO_2	NO	Perc NO_2	NO_x per CO_2	CO	HC
	[g/km]	[g/km]	[g/km]	[g/km]	[%]	[g/kg]	[g/km]	[g/km]
Euro VI N3 55% total	958	2,90	0,01	2,89	0%	3,0	1,6	0,00
Urban	1602	9,24	0,04	9,20	0%	5,8	4,4	0,00
Rural	1143	2,99	0,02	2,98	1%	2,6	2,1	0,00
Motorway	818	2,11	0,00	2,11	0%	2,6	1,1	0,00
Reference 10%	844	5,99	0,04	5,96	1%	7,1	1,9	0,00
Reference 55%	1139	5,25	0,01	5,24	0%	4,6	2,5	0,00

A.6 Vehicle T

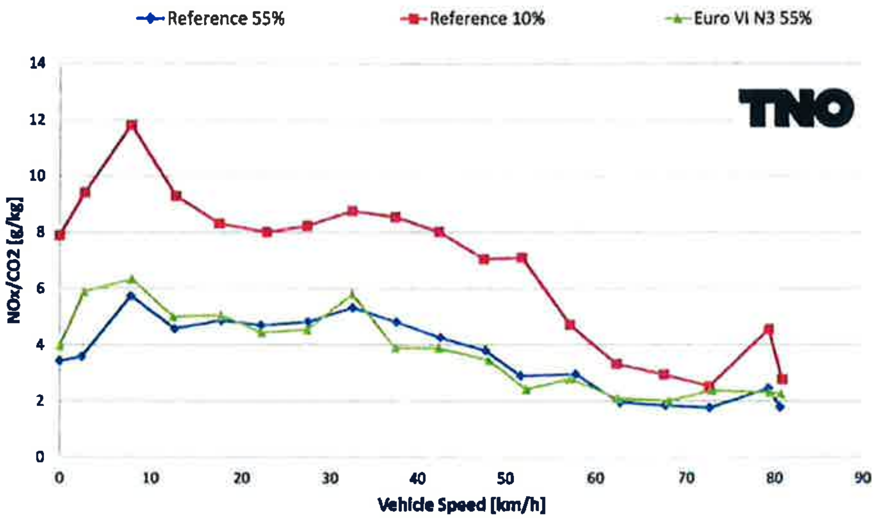
Test vehicle

Legislative category	N3, Euro V, B2(G)
Type	Tractor semitrailer, 4x2 3-axle semitrailer
Engine capacity range	10-13 ltr
Engine power range	300-350 kW
Emission reduction	SCR+NH_3 clean-up catalyst
Odometer	169436

Test conditions

Trips	Payload % / GCM	Weather	Traffic
Reference trip	55% / 34753kg	0-10°C, dry	Calm, no congestion
Reference trip	10% / 19505kg	0-10°C, dry	Calm, no congestion
Euro VI trip N2	55% / 34753kg	0-10°C, dry	Calm, no congestion

Test results



Trip	NO_x Conformity Factor [-]	NO_x max [-]	CO Conformity Factor	HC Conformity Factor	CF max
Euro VI N3 55%	1,00	1,19	0,33	0,00	1,5
REF 55%	1,12	1,27	0,45	0,00	
REF 10%	1,75	1,80	0,48	0,00	

Trip name + payload	**CO_2**	**NO_x**	**NO_2**	**NO**	**Perc NO_2**	**NO_x per CO_2**	**CO**	**HC**
	[g/km]	[g/km]	[g/km]	[g/km]	[%]	[g/kg]	[g/km]	[g/km]
Euro VI N3 55% total	891	2,59	0,10	2,49	4%	2,9	1,8	0,00
Urban	1575	6,46	0,05	6,41	1%	4,1	4,4	0,02
Rural	1094	2,28	0,06	2,22	3%	2,1	1,9	0,00
Motorway	737	2,21	0,12	2,09	5%	3,0	1,4	0,00
Reference 10%	837	5,15	0,12	5,03	2%	6,2	2,7	0,00
Reference 55%	1187	4,11	0,13	3,98	3%	3,5	3,3	0,00

A.7 Vehicle U

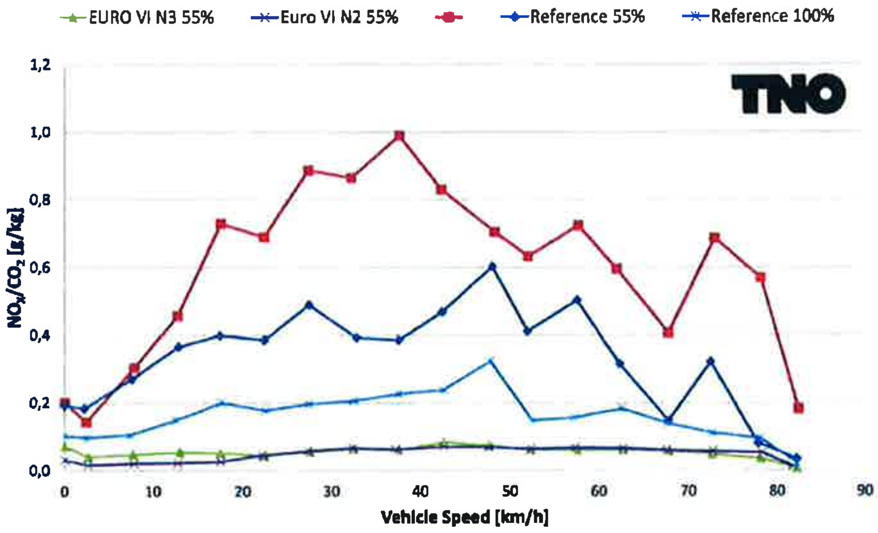
Test vehicle

Legislative category	N3, Euro VI
Type	Tractor semitrailer, 4x2 3-axle semitrailer
Engine capacity range	10-13 ltr
Engine power range	300-350 kW
Emission reduction	EGR+SCR+DPF
Odometer	10900km

Test conditions

Trips	Payload % / GCM	Weather	Traffic
Reference trip	55% / 30900kg	5-15°C, dry	Calm, no congestion
Reference trip	10% / 17800kg	5-15°C, dry	Calm, no congestion
Reference trip	100% / 44040	5-15°C, dry	Heavy traffic jam
Euro VI trip N2	55% / 34753kg	5-15°C, dry	Calm, no congestion
Euro VI trip N3	55% / 34753kg	5-15°C, dry	Calm, no congestion

Test results



Trip	NO_x Conformity Factor 90-%	NO_x max	CO Conformity Factor	HC Conformity Factor	CF max
	[-]	[-]	[-]	[-]	[-]
Euro VI N3	0,12	0,20	0,2	0,0	1,5
Euro VI N2	0,14	0,16	0,3	0,0	
REF 10%	1,14	1,56	0,2	0,0	
REF 55%	0,75	1,48	0,2	0,0	
REF 100%	0,13	0,15	0,1	0,0	

Trip name + payload	CO_2	NO_x	NO_2	NO	Perc NO_2	NO_x per CO_2	CO	HC

	[g/km]	[g/km]	[g/km]	[g/km]	[%]	[g/kg]	[g/km]	[g/km]
Euro VI **N3** 55% total*	800	0,07	0,02	0,05	31%	0,09	1,16	0,00
Urban*	1512	0,70	0,11	0,58	16%	0,46	2,03	0,04
Rural	927	0,06	0,05	0,00	93%	0,06	1,38	0,00
Motorway	669	0,00	0,00	0,00	12%	0,01	0,98	0,00
Euro VI **N2** 55% total*	916	0,13	0,03	0,10	22%	0,14	1,53	0,01
Urban*	1450	0,51	0,06	0,45	12%	0,35	2,35	0,03
Rural	952	0,07	0,05	0,02	75%	0,07	1,44	0,01
Motorway	649	0,01	0,00	0,01	15%	0,01	1,23	0,00
Reference 10%	774	0,43	0,20	0,23	45%	0,56	1,01	0,00
Reference 55%	975	0,29	0,14	0,15	50%	0,30	1,15	0,00

*Including cold start