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TNO report

TNO 2013 R10753

The Netherlands In-Service Testing Programme for Heavy-Duty Vehicle Emissions 2012

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Example number	TNO-060-DTM-2013-01307
Number of pages	42 (incl. appendices)
Number of appendices	2
Sponsor	Mr. H.L. Baarbé Ministry of Infrastructure and the Environment Directorate-General for Environment and International Coordination P.O. Box 20901, 2500 EX THE HAGUE
Project name	Steekproefcontroleprogramma voor vrachtwagens
Project number	033.27092

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, Por-table 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). Voorts zijn er metingen gedaan met een nieuw SEMS meetsysteem (Smart Emission Measurement System) dat op eenvoudige wijze de NO_x emissie van dieselvoertuigen kan screenen.

In 2012 zijn praktijkemissiemetingen gedaan aan twee Euro VI en drie Euro V vrachtwagens. Daarnaast zijn praktijkemissiemetingen gedaan aan een vrachtwagen met een retrofit dual-fuel systeem voor het rijden op diesel en aardgas en zijn er speciale tests uitgevoerd aan een batterij-elektrische bus op een testcircuit.

Het meetprogramma wordt gecontinueerd in 2013 met o.a. metingen aan nieuwe Euro VI voertuigen die op de markt komen, bussen met alternatieve aandrijflijnen en er worden metingen gedaan met het nieuwe meetsysteem SEMS.

Praktijkemissies Euro VI zeer laag
De twee gemeten Euro VI vrachtwagens, één uit de zware categorie (350kW) en één uit de middelzware categorie (250kW), presteren in de praktijk goed op de uitstoot van NO_x en NO_2. De resultaten zijn in lijn met de resultaten van eerder gemeten Euro VI vrachtwagens uit de zware categorie.
Het wordt aanbevolen om ook lichtere bedrijfswagens en bedrijfswagens voor andere toepassingen (stadsbus, distributietruck, vuilniswagen) te testen wanneer deze met een Euro VI keuring op de markt verschijnen.

Praktijkemissies Euro V bevestigen het bestaande beeld
De drie gemeten Euro V vrachtwagens, waaronder ook EEV varianten, presteren wisselend op de uitstoot van NO_x. Dit is een bekend beeld bij Euro V en EEV vrachtwagens.
Eén lichte vrachtwagen presteerde, net als een eerder getest ouder type, slecht op de uitstoot van NO_x. Dit ondanks de aangescherpte wettelijke EU eisen voor NO_x control en OBD (II) ten opzichte van het oudere type.
Een andere lichte vrachtwagen (GVW 3,5t) presteerde redelijk goed op de uitstoot van NO_x en de derde zware vrachtwagen liet een resultaat zien met een hoge NO_x uitstoot bij lage rijsnelheden, wat kenmerkend is voor deze categorie.

Verhoogde emissies van broeikasgassen met retrofit dual-fuel
Er zijn praktijkemissiemetingen gedaan aan een vrachtwagen met een achteraf-geplaatst (retrofit) systeem voor tweebrandstoffenbedrijf (dual-fuel), met diesel als hoofdbrandstof en aardgas (CNG) als hulpbrandstof. Deze metingen zijn gedaan in het licht van het mogelijke nationale typekeurregime, waarbij TNO ondersteunend is in het ontwerp van de testprocedure. De metingen in dual-fuel bedrijf zijn vergeleken met metingen in standaard dieselbedrijf.
In dual-fuel bedrijf:
- is de NO_x uitstoot van het voertuig wat lager dan in dieselbedrijf.
- stoot het voertuig veel methaan uit.
- is de totale CO_2 uitstoot, rekening houdend met een broeikaspotentieel van 25 van methaan, enkele tientallen procenten hoger dan in dieselbedrijf.

De werkzaamheden worden in 2013 opgevolgd met metingen aan een technisch geavanceerder dual-fuel systeem om te zien hoe een volgende technologiestap presteert.

Verkennende metingen met een batterij-elektrische bus
Verkennende praktijkmetingen zijn uitgevoerd aan een volledig elektrisch aangedreven bus. De concept SORT procedure is gebruikt op een testcircuit om zaken als het energieverbruik en de autonome actieradius te testen. Dit zijn enkele van de belangrijke parameters die de inzetbaarheid van dergelijke nieuwe aandrijfconcepten bepalen. Het wordt aanbevolen om de ontwikkelingen van de SORT procedure (UITP) voor het testen van nieuwe aandrijfconcepten als hybride en volledig elektrische bussen nauw te volgen en een onderzoek te starten naar de mogelijkheden om een algemene toets voor de inzetbaarheidscriteria van nieuwe aandrijfconcepten voor bussen te ontwikkelen.

Conformiteit van in-gebruik zijnde voertuigen
De emissiemetingen met PEMS zijn ook gedaan volgens de EU methode voor het bepalen van de 'in-service conformity' Volgens deze methode haalden 3 van de 5 voertuigen een 'conformiteitsfactor' lager dan 1,5. Eén voertuig haalde een 'conformiteitsfactor' net hoger dan 1,5 (CF=1,7) terwijl een ander voertuig een flink hogere 'conformiteitsfactor' had (CF=3,2). Voor de overige gereguleerde emissies, CO en THC, werd de conformiteitsfactor door alle voertuigen ruimschoots gehaald.

Eenvoudig en goedkoop voertuigemissies scannen met SEMS
Metingen zijn gedaan met een nieuwe relatief eenvoudige emissiemeetmethode. Deze methode meet NO_x en zuurstof in de uitlaat met een sensor en de voertuigsnelheid met een GPS. Bij de proefmetingen is de NO_x uitstoot vergeleken met een nauwkeurig en algemeen geaccepteerd meetsysteem: PEMS. De meetsystemen correleren goed. SEMS is hiermee een goedkoop alternatief om de NO_X uitstoot van dieselvoertuigen te screenen of te monitoren. In de toekomst kan het systeem mogelijk worden uitgebreid met meer sensoren voor andere schadelijke uitlaatgascomponenten. In 2013 zal SEMS worden doorontwikkeld en worden ingezet voor het screenen van voertuigen binnen het steekproefcontroleprogramma.

Terugblik op het in-service testprogramma van 2012
De uitgevoerde werkzaamheden in 2012 hebben op verschillende manieren bijgedragen aan het bronbeleid dat de Nederlandse overheid voert om brandstofverbruik en schadelijke emissies van wegvoertuigen te beperken. Op nationaal niveau heeft het programma aangetoond dat, de op dit moment verkrijgbare zware Euro VI voertuigen, zeer lage emissies hebben, waarmee er een objectieve onderbouwing is

voor de subsidieregeling voor Euro VI voertuigen. Tevens vormen de testresultaten de basisgegevens (emissiefactoren) voor de berekeningen van de luchtkwaliteitsvoorspellingen op nationaal niveau en wordt de data van het programma gedeeld binnen een internationale werkgroep van experts op het gebied van emissiemodellering van het wegtransport [ERMES].

Op internationaal niveau ondersteunen de metingen en de daarmee verkregen inzichten in praktijk emissies de beleidsmedewerkers van de RDW en het Ministerie van Infrastructuur en Milieu in het verbeteren van de EU emissieregelgeving. De inzichten zijn ingebracht in werkgroepen van de Europese Commissie (Brussel) en van de Verenigde Naties (Genève), vaak ondersteund door experts van TNO. Het is belangrijk dat onafhankelijke partijen als TNO deze inzichten hebben, Bij de onderhandelingen over bijvoorbeeld technische wijzigingsvoorstellen in de emissieregelgeving is het van belang om te kunnen vertrouwen op gegevens die op onafhankelijke wijze zijn bepaald. Hiermee heeft TNO in samenwerking met de RDW en het Ministerie van Infrastructuur en Milieu ook in 2012 verbeteringen in de Euro VI regelgeving kunnen realiseren.

In 2012 was er ook een voorbeeld van een fabrikant die zijn productieversie van Euro V voertuigen heeft aangepast, na feedback van TNO op de emissieprestaties van hun voertuigen tijdens reguliere inzet. Aanpassing van de productieversie was, vanuit het oogpunt van typekeuring niet noodzakelijk, desalniettemin heeft de fabrikan,t uit het oogpunt van duurzaamheid, deze wijziging wel doorgevoerd.

Deze greep uit voorbeelden van de impact van het programma in 2012 demonstreren het nut van het programma voor de Nederlandse en Europese luchtkwaliteit. De afgelopen decennia heeft dit actieve beleid eraan bijgedragen dat, ondanks een sterke groei van het wagenpark en het gereden aantal kilometers, de luchtkwaliteit in onze steden sterk is verbeterd.

Vooruitblik op het testprogramma in 2013
Het programma wordt in 2013 voortgezet met o.m. metingen met PEMS en SEMS. Er zullen steeds meer zware Euro VI bedrijfswagens op de markt komen. Het wordt aanbevolen vooral lichte vrachtwagens te meten en voertuigen die rijden onder specifieke bedrijfssituaties, zoals bussen en vuilniswagens. Daarnaast komen er mondjesmaat bussen op de markt met verschillende vormen van een alternatieve aandrijflijn (hybride, elektrisch). Het ontbreekt aan methodes die nodig zijn om dergelijke concepten goed te kunnen evalueren op zaken die de inzetbaarheid en praktijkemissies bepalen. Het verdiend de aanbeveling aandacht te besteden aan de ontwikkeling van gedegen methodes om dit eenduidig te kunnen doen.
Met deze activiteiten zal TNO ook in 2013 namens en samen met het Ministerie van Infrastructuur en Milieu op een effectieve manier bijdragen aan het Nederlandse en Europese bronbeleid ter verbetering van de luchtkwaliteit.

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.

The measurements have been performed with a Portable Measurement System (PEMS). Furthermore, measurements have been performed with a system that measures from the side of the road (RES: Remote Emission Sensing) and with a new measurement system which can screen the NO_x emission of diesel vehicles in a relative easy and cheap way (SEMS: Smart Emission Measurement System).

In 2012 real-world emission measurements have been performed on two Euro VI and three Euro V heavy-duty trucks. Furthermore, emission measurements have been performed on a truck retrofitted with a dual-fuel system for driving on diesel and natural gas. Also special tests have been performed on a battery electric bus.

The work will be followed up in 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, measurements on busses with an alternative powertrain (hybrid, full-electric) and new SEMS equipment.

Real-world emissions Euro VI are very low
The two tested Euro VI trucks, one heavy (350kW) and one medium heavy variant (250kW) performed well in real-world with regard to the NO_x and NO_2 emission. The results are in line with results of earlier measured Euro VI trucks from the heavy category.
It is recommended to also test lighter variants and vehicles for other applications, like garbage trucks and city busses, once they arrive on the market.

Real-world emissions Euro V confirm the existing picture
The three tested Euro V trucks, amongst which also two EEV's, showed a mixed performance with regard to the NO_x emission. This is stereotypical for Euro V and EEV heavy-duty vehicles.
One light distribution truck performed, just like an earlier tested older version, very bad on the NO_x emission. This despite the applicable stricter legal requirements for NO_x control measures and OBD (II).
Another light distribution truck performed reasonably well on $NO_{x,}$ whereas a third heavy truck showed for this group typical NO_x behaviour of high NO_x emission at low speeds.

Increasing emission of greenhouse gasses of retrofit dual-fuel systems
Real-world emission measurements have been performed on a heavy-duty truck with a retrofitted system for operation in dual-fuel mode, running on diesel as main

fuel and natural gas (CNG) as second fuel. The tests are performed in the light of the national type approval regime that the Dutch government is considering to introduce, and for which TNO provides support in the development of the test procedure. The tests in dual-fuel mode have been compared with tests in normal diesel mode.
In dual-fuel mode:
- the NO_x emission is somewhat lower than in diesel mode.
- the vehicle emits a lot of methane, see the next conclusion.
- the total CO_2 emission is 15 to 40% higher than in diesel mode, taking account of a global warming potential of methane of 25.

The work is followed up by measurements on a technically more advanced system to investigate how such a system is able to perform.

Exploratory measurements with a battery-electric bus
Exploratory measurements on a full electric bus were done over the draft SORT procedure on a test circuit to determine the energy consumption and the autonomous range. These are some of the important parameters which determine the applicability of new propulsion concepts.
It is recommended to closely follow the development of the SORT procedure for testing new propulsion concepts and to start an investigation into possibilities to develop a general test for the applicability of new propulsion concepts.

In-service conformity
Emission measurements with PEMS were done according to the formal EU procedure for determination of the in-service conformity of heavy-duty vehicles. According the method three out of five vehicles had a conformity factor lower than 1,5. One truck had a conformity factor just above 1,5 (CF=1,7), while another truck had a conformity factor clearly exceeding 1,5 (CF=3,2). For the other regulated emissions, that have to be measured wit PEMS, the conformity factors were well below 1,5.

Quick and inexpensive scanning of vehicle emissions with SEMS
A series of practical experiments have been done with a new and uncomplicated emission measurement method. This method measures NO_x and Oxygen in the tail pipe with a sensor and vehicle speed with a GPS. Comparative tests, measuring simultaneously with SEMS end PEMS, have shown good correlation and therefore SEMS is a cheap alternative to screen or monitor the NO_x emissions of vehicles with diesel engines. In the future the system could be extended with other sensors which enable the measurement of other noxious exhaust gas components. In 2013 SEMS will be developed as a stand-alone tool and will be applied for screening vehicles within the in-service testing programme.

Looking back on the in-service testing programme of 2012
The work that has been performed in 2012 has contributed in many ways to the policy of the Dutch government to reduce fuel consumption and pollutant emissions of vehicles. On a national level, it was demonstrated that the currently available long haulage Euro VI vehicles have low emissions, which is an objective justification to incentivise Euro VI vehicles. Furthermore, the test results are the basic input (emission factors) for the calculation of air quality predictions on a national level and the data is shared in an international working group with experts on emission modelling of road traffic [ERMES].

On an international level, the measurements of TNO and the retrieved insights in real-world emission behavior supports the policy staff of the Dutch type approval authority (RDW) and Ministry of Infrastructure and the Environment in their efforts to improve the emission legislation. The insight have been brought into working groups of the European Commission (Brussels) and United Nations (Geneva), often supported by experts of TNO. It is very important that independent parties like TNO have these insights, as in the negotiations regarding for instance technical changes in emission legislation it’s important to not only trust on the insights that the vehicle industry provide. With these efforts in 2012, TNO in cooperation with the Dutch policy staff of the RDW and the Ministry of Infrastructure and the Environment, again realized improvements in the Euro VI legislation.

In 2012 there was also an example of a manufacturer that adjusted its production version of a Euro V vehicle after feedback of TNO on the emission performance of the specific vehicle type during regular operation. Adjustment of the production version was not necessary from the perspective of type approval, as the vehicle type complied with the legislation. Nevertheless, the manufacturer adjusted the production version from the perspective of sustainability.

This selection of examples of the impact of the programme in 2012 clearly demonstrates how the programme contributes to the policy that improves the Dutch and European air quality. In recent decades, this active policy has contributed to the improved air quality in our cities, despite strong growth of the fleet and the number of kilometers driven,

Outlook on the in-service testing programme in 2013
The programme will be continued in 2013 with measurements with PEMS and SEMS. In this year, more and more Euro VI commercial vehicles will enter the market. It is recommended to measure especially the light trucks and vehicles which operate under very specific conditions, like busses and garbage trucks. Also entering the market are busses with different types of alternative powertrains (hybrid, full electric). It lacks good methods to evaluate such concepts on criteria that determine real-world emissions and the applicability for real-world operation. Therefore, it is recommended to focus on the development of methods which could evaluate the given concepts in a unambiguous manner.
With these activities, TNO together with the Ministry of Infrastructure and the Environment will have an effective contribution to the Dutch and European policies to improve air quality.

Contents

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 emis-0sions 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 proce-

dure 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 and can alternatively measure CH_4 when an additional analyser module is placed. 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).

Next to PEMS, a new method is applied [Vermeulen et al. 2012c] called SEMS (Smart Emission Measurement System). The SEMS method measures NO_x and O_2 in the exhaust. O_2 correlates well with CO_2 for diesel vehicles and this theoretic relation is used to estimate the CO_2 concentration from the measured O_2 concentration. The ratio of NO_x and CO_2 proved to be a good indicator for the emission level of NO_x. The emission data obtained over a test trip can be collected in speed intervals (speed binning) to reveal the emission behaviour over the operational speed range of a given type of diesel vehicle.

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 heavy-duty vehicles up to Euro VI and a direct comparison between two of the stages of Euro V (B2G versus B2D) to determine whether implementtation of improved requirements from one stage to the other has led to the expected improvements.

Next to the in-service tests other work has been performed. The programme for instance allows to perform additional or ad-hoc research on request. Furthermore, some non-testing activities are carried out. All these activities are discussed in **Chapter 3**.

In 2012 the following work was performed next to the regular PEMS test programme:

- Development of emission factors for heavy-duty vehicles
- Measurements with Remote Emission Sensing equipment.
- Measurements with a smart emission measurement method (SEMS).

2 In-service emission tests

2.1 Vehicles tested

The vehicle selection was based on multiple goals:

- to select the newest generation Euro VI heavy-duty vehicles available on the market (2 vehicles).
- to select an N2 vehicle in the 2,5 to 5t GVM range (1 vehicle).
- to select one of the same type Euro V N2 vehicles from the previous programme to check whether the high NO_x emissions observed for the first generation Euro V variant (OBD I) are also observed for the second generation Euro V variant (OBD II with NO_x measures).
- to select a retrofit dual-fuel vehicle running on diesel and natural gas. This was done to extensively check the real-world emission performance of this type of technology with regard to the NO_x and the CH_4 emissions. Furthermore, the goal was to validate the suitability of the SEMS tool to check the NO_x emissions of this technology. The results of this vehicle in dual-fuel mode are presented in paragraph 2.5. The results of in-service conformity of this vehicle in diesel-mode are presented in paragraph 2.2.
- to select a full electric bus (BEV) to gain experience with testing these kind of vehicles and to establish first insights in the energy consumption and range of such vehicles. The results are presented in paragraph 2.6.

Table 1: overview of the vehicles tested and some specifications.

Vehicle	Legislative category	Vehicle category	Fuel	Vehicle type	Model year	Emission reduction technology	Power range [kW]	Odometer [km]
Vehicle V	EEV C(K)	CI, N2	Diesel	Rigid	2011	EGR, DPF	100-150	47170
Vehicle W	EEV C(K)	CI, N2	Diesel	Rigid	2011	SCR	100-150	42395
Vehicle X	VI	CI, N3	Diesel	Tractor semi-trailer	2012	EGR, DPF, SCR	350-400	23595
Vehicle Y	VI	CI, N3	Diesel	Rigid - trailer	2012	EGR, DPF, SCR	250-300	18550
Vehicle Z	V B2(G)	CI, N3	Dual-fuel; Diesel and natural gas	Tractor semi-trailer, retrofit dual-fuel	2011	SCR	300-350	177578
Vehicle AA	-	-	Battery Electric vehicle	Bus	-	-	-	-

2.2 In-service conformity with PEMS

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

2.2.1 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 [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

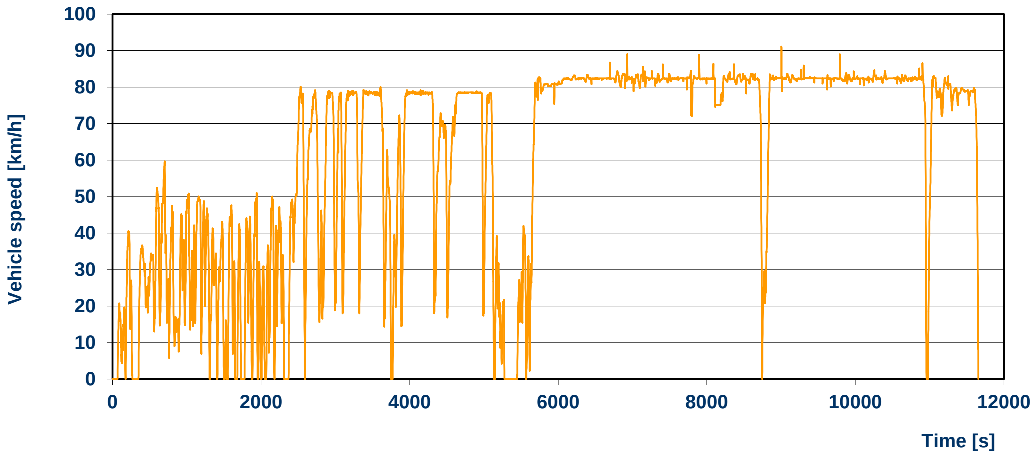

Figure 1: example of a speed trace of the N3 trip according to Euro VI specifications.

2.2.2 *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 ETC limit value in case of Euro V engines and the WHTC in case of Euro VI engines. A CF of 1.5 for NO_x means for Euro V that an equivalent of 1.5 times 2.0 g/kWh = 3.0 g/kWh is the result of the pass fail evaluation 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. For Euro VI engines the same CF is applicable. However, it now applies to the Euro VI WHTC limit values. For NO_x: 1,5 times 0,46 g/kWh = 0,69 g/kWh. 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, depending on the availability and quality of the broadcasted ECU signals needed for the calculation of work.
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 ºC, Altitudes > 1500 m, 10^{th} 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

2.2.3 *In-service conformity Results*

For NO_x one vehicle (W) clearly exceeds the conformity factor of 1,5. This type of vehicle was tested earlier (Vehicle F in 2009), however at that time being a so called first generation Euro V EEV (C(I)) with OBD I. The vehicle tested here (W) is of the same type but now a 'second generation' Euro V EEV (C(K)) with NO_x control measures and OBDII. Both vehicles perform more or less the same so no improvement was observed going from the first to the second generation.

Vehicle Z only just exceeds the conformity factor of 1,5 (CF=1,78). Also this type of vehicle was tested before (Vehicle P in 2011). Then it showed a comparable conformity factor for NO_x (CF=1,72).

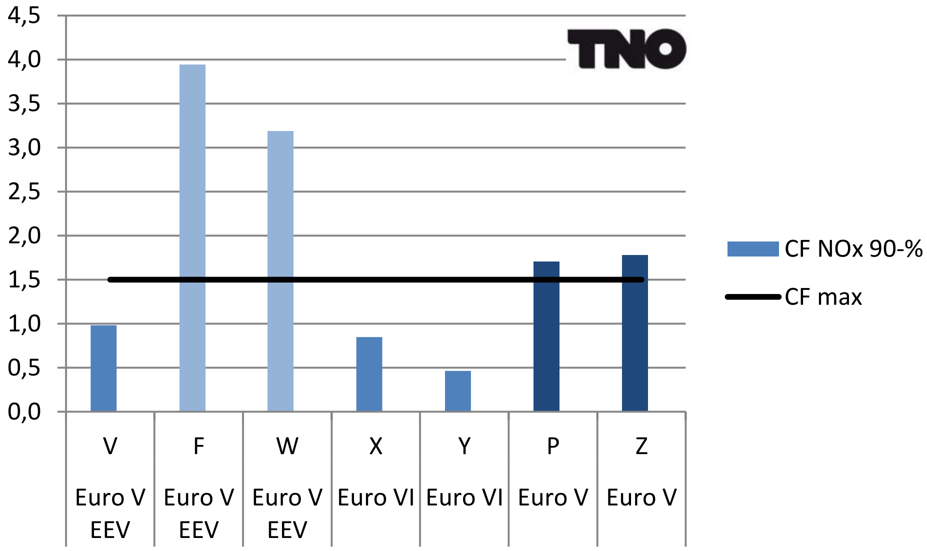

Figure 2: NO_x Conformity Factors. The light blue bars are from two different tested vehicles with the same engine type. The dark blue bars are also from two different tested vehicles with the same engine type.

For CO all vehicles are well below the limit.

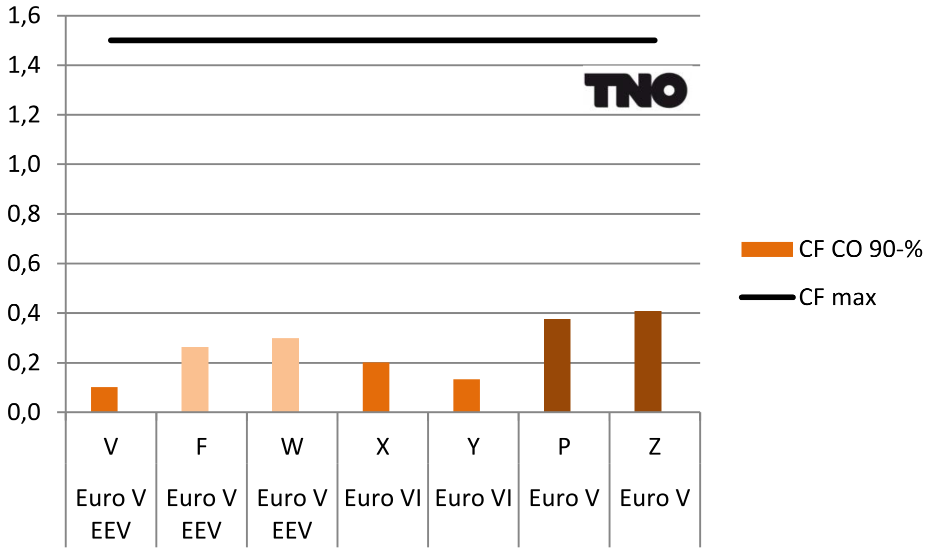

Figure 3: CO conformity factors. The light orange bars are from two different tested vehicles with the same engine type. The dark orange bars are also from two different tested vehicles with the same engine type.

For HC all vehicles are well below the limit.

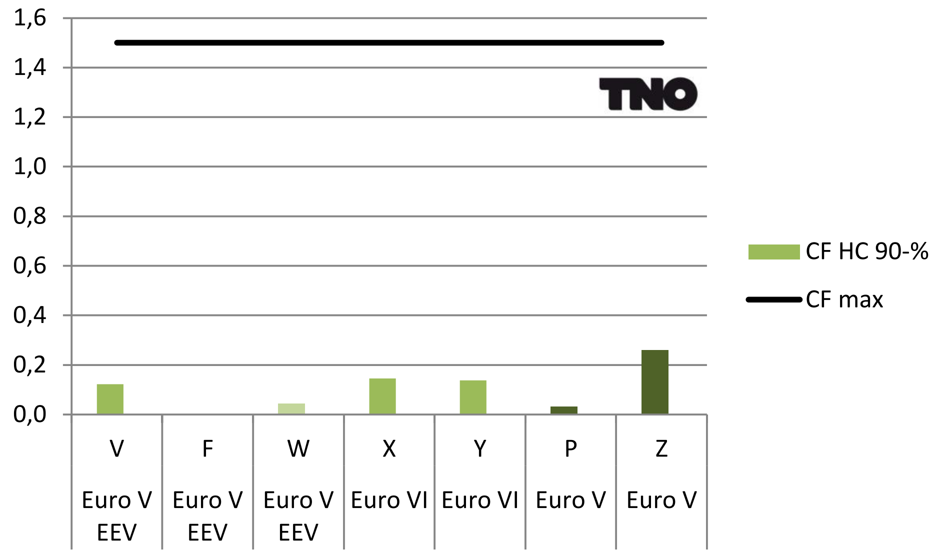

Figure 4: HC Conformity Factors. The light green bars are from two different tested vehicles with the same engine type. The dark green bars are also from two different tested vehicles with the same engine type.

2.3 Case vehicle Q

A vehicle which was measured in the previous programme (Vehicle Q) [Vermeulen et al. 2012b] showed high NO_x emissions only over motorway use, see Figure 5. This is atypical for Euro V EEV approved engines and therefore the results were send to and discussed with the manufacturer. The manufacturer decided to investigate the tested vehicle. Additional tests reproduced by the manufacturer on the same vehicle and on a vehicle with the same engine type confirmed the observed emission behaviour. The manufacturer has investigated the problem to find a possible cause. According the manufacturer the cause was found in the software of the control of the engine and the aftertreatment. The manufacturer explained to have taken action to fix the problem by making an adaption of the production process of the given engine type by installing other software.

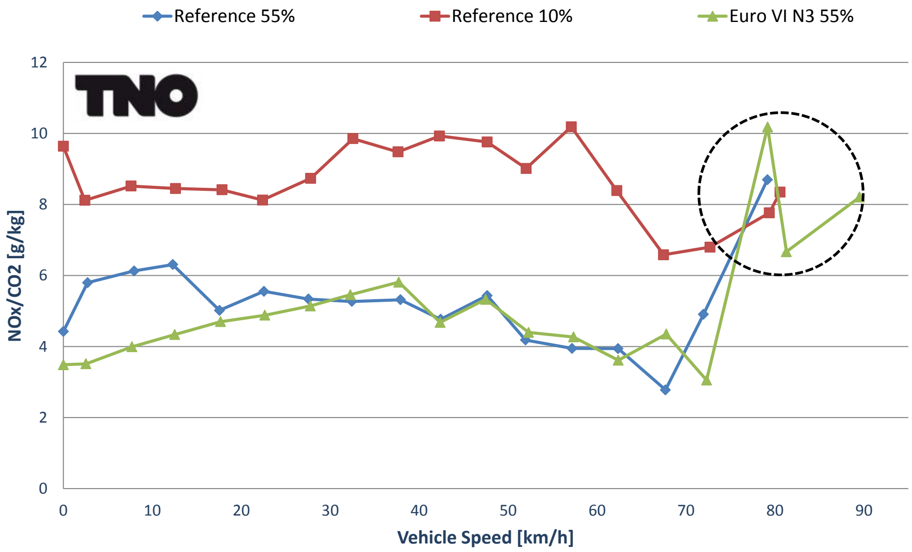

Figure 5: CO_2 specific NO_x emission of vehicle Q with high emissions at high operating speeds representative for motorway driving.

2.4 Real 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 2012. 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.

2.4.1 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:

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

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.

2.4.2 *Real Driving Emissions of the vehicles tested in 2012*

Below the real-world CO2 specific NOx emission of the tested vehicles are presented (vehicle+letter) applying the binning method for large speed intervals. Also averaged trends for European legislative classes (Euro class) are presented.

The two tested Euro VI vehicles (vehicle X and Y) have a similar good performance of the NOX emissions as the earlier tested Euro VI vehicles (vehicle M and U).

Vehicle V, a light commercial vehicle (Euro V EEV) with EGR and a DPF to reduce emissions, has a specific NOx emissions of about 3-5 g/kg, which does not deviate a lot from the average Euro V trends. This in contrast to an earlier tested vehicle (Vehicle R) [Vermeulen et al. 2012b] in this range of another brand, which showed high CO2 specific NOx emissions in the range of 5-15 g/kg. Apparently, the real-world emission behaviour of the specific NOx emissions in this light category may scatter heavily.

Vehicle W (Euro V EEV) has a very high CO2 specific NOx emission of 5-13 g/kg. This is in line with the results of an earlier tested vehicle with the same engine type (Vehicle F). This despite the fact that the here tested vehicle has to comply with stricter Euro V requirements (OBDII versus OBD I and the introduction of ‘NOx measures’) [2005/55/EC].

Vehicle Z has a CO2 specific NOx emission which is typical for a vehicle of this emission class: Euro V of the ‘second generation’, with NOx measures and OBDII.

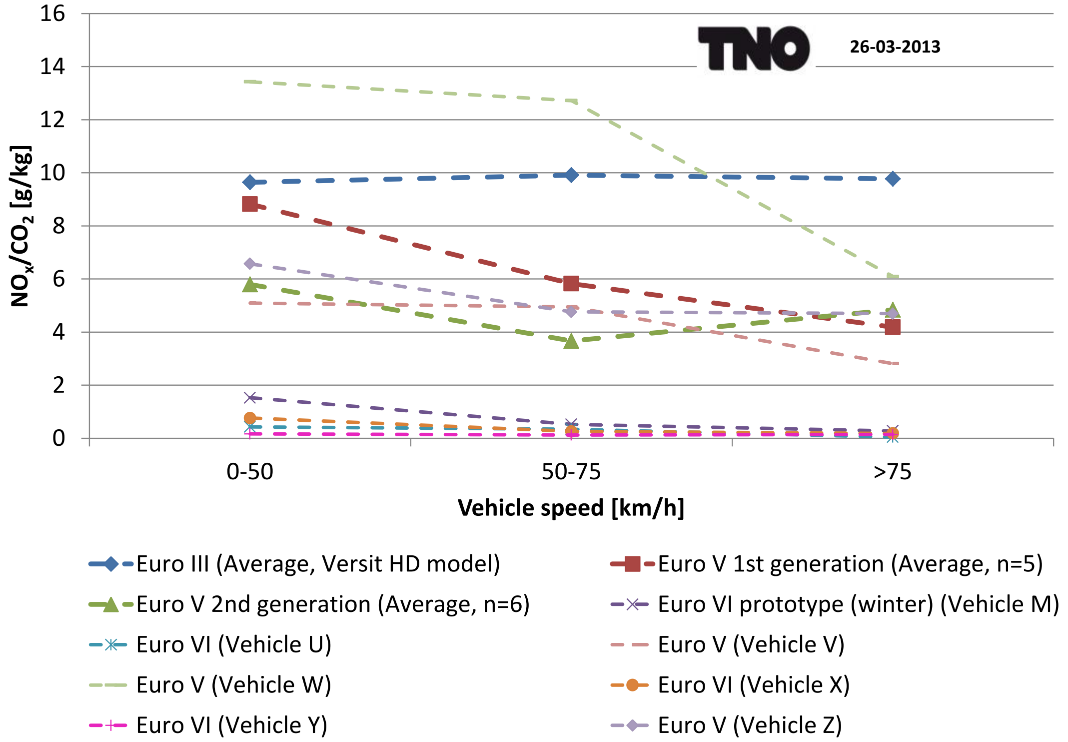

Figure 6: trend of the CO_2 specific NO_x emission over different legislative stages. A clear reduction of the CO_2 specific NO_x emissions can be noted towards Euro VI. Especially, for Euro V and EEV individual vehicles may deviate from the average as this groups has a large scatter in specific NO_x emissions.

2.5 Real-world driving emissions of a retrofit dual-fuel truck on diesel and compressed natural gas.

At request of the Ministry an additional dedicated emission test programme was performed to generate insights which are needed to develop a low-cost emission test procedure to screen the tail-pipe emissions of heavy-duty retrofit dual-fuel vehicles. This procedure could be used in a national approval scheme for retrofit dual-fuel vehicles.

The goal of the tests is to determine the real-world emission performance of a truck equipped with a retrofit dual-fuel system, with a focus on the NO_x and the CH_4

emissions and to compare the emissions in diesel mode and dual-fuel mode (diesel-natural gas).

A heavy-duty truck, a Euro V DAF FT XF105 equipped with a retrofitted dual-fuel system, running on diesel and compressed natural gas, was tested with a Portable Emission Measurement System on the road.

Figure 7: test vehicle for the PEMS measurements on a truck equipped with a retrofit dual-fuel system, running on diesel and compressed natural gas.

Various trips were driven with different payloads and repeated in diesel mode and dual-fuel mode to enable a comparison of the emission performance of the two fuel modes. The standard gaseous emissions, including methane (CH_4) were measured and analysed according the formal in-service conformity method (Annex II of 582/2011/EC) and according to alternative methods to judge the real-world emission performance.
This has led to the following conclusions:

- In dual-fuel mode the NO_x and NO_2 emissions are somewhat lower than in diesel mode.
- In dual-fuel mode the CH_4 emissions are very high. The high CH_4 emissions are highest during the for the vehicle typical motorway operation. The CH_4 emissions decrease at a lower blend ratio but are still high.
- In dual-fuel mode the CO_2 emissions are lower, as could be expected from the lower energy specific CO_2 emission of natural gas. However, when the high CH_4 emission and its Global Warming Potential of 25 in CO_2 equivalents are considered, the total CO_2 emissions are 14-40% higher in dual-fuel mode than in diesel mode, depending on the trip and blend ratio.
- With a high payload (100%), the CO_2 specific CH_4 emission decreases somewhat compared to lower payloads (55 and 10%).

This work is extensively reported in a separate report [Vermeulen et al. 2013].

2.6 SORT energy consumption and range of a BEV city bus

This work is extensively reported in a separate report [van Goethem et al., 2013].

Battery electric buses are an alternative for fossil fuel powered buses, because they produce no local emissions and almost no noise. (Local) air quality benefits from application of electric buses. Even if the total energy chain is taken into account, electric buses have a significant potential to reduce greenhouse gasses. To underline this, in 2012 The Netherlands Ministry of Infrastructure and the Environment signed a Green Deal with the Stichting ‘Zero Emission Busvervoer’ with the ambition to completely change the Dutch public transport buses to zero-emission by 2025, with a transition period between 2015 and 2025. If buses are to be replaced by zero-emission versions, it is important to know what the capabilities of those buses are and how they compare to other alternatives.

At this time no method is available to compare performances of electric buses and to determine which bus consumes the least energy per distance or what the range with a full charged battery is. TNO was asked by the Netherlands Ministry of Infrastructure and the Environment to gather practical experience regarding the energy consumption and range of a full-electric 12 m bus. This practical experience serves as input for the discussion how different zero-emission buses could or should be compared, in order to assess the actual applicability in daily practice.

Figure 8: Bus in action in the range test.

The performed dedicated test program, conducted with an electric bus from Ebusco, consisted of a combination of existing UITP SORT and UNECE R101 fuel and energy consumption measurement procedures. The test program is not an official UITP SORT procedure, as the revised SORT procedure for hybrid and full-electric buses is not published yet.

The obtained experiences lead to the following main conclusions.

1. The used test method carried out on a test track is a feasible and relative simple way to determine the energy consumption and range of a battery electric bus.
2. Each mission profile of a bus in practice is different, and therefore each generalised test procedure is partly representative. However, the performance in terms of energy consumption and range could, however, be compared with other buses tested according to the same procedure.
3. Some influencing factors like temperature, speed profile and cycle length errors caused by the driver could hardly or not be controlled on a test track and thus deviate from official procedures. To get a better understanding of these influences and the effect they have on the results, the test should be repeated in an environment where all parameters can be controlled and manipulated. A better understanding of the influences will lead to recommendations for adjustments of an on-road test procedure.

The performed exploratory research and obtained practical experiences have led to insights that form fertile ground for a follow-up towards a procedure that can be utilized to compare different zero-emission buses.

Table 4: Overview of the weight and load of the tested bus and the results of the energy consumption and range test.

	SORT 1	**SORT 2**	**SORT 3**	**Unit**
Vehicle specific information				
Manufacturer	Ebusco			
Model name	YTP1			
Dutch licence plate number	69-BBD-3			
Empty vehicle weight	11800			kg
Lump load	2610			kg
Total vehicle weight	14410			kg
Energy consumption test				
Travelled distance	5395,4	8386,2	11181,6	m
Energy charged after test	6,21	9,57	12,87	kWh
Energy consumption	**1,15**	**1,14**	**1,15**	kWh/km
Range test				
Travelled distance	-	-	**177**	km
Charged energy after test	-	-	210,85	kWh
Energy consumption	-	-	**1,19**	kWh/km
Net operational time	-	-	7,5	hours
Total time of interruptions	-	-	1	hour
Net energy consumption over time	-	-	28	kWh/hour

3 Other activities

Next to the common activities of the heavy-duty testing programme, like testing of the in-service emission with PEMS and ad-hoc activities, the programme constantly monitors for possibilities to develop new methods which could improve or simplify the generation of emission data. These methods could be used in procedures which need to generate emission data for different possible purposes, namely;

- the determination of emission factors.
- the determination of emission trends.
- checking of in-service conformity of the emissions.
- screening of applications, for instance checking the emissions of vehicles retrofitted with dual-fuel systems.
- screening of vehicles for use in procurement procedures.

In 2012, two of such methods have been under investigation, namely Remote Emission Sensing (RES) and SEMS (Smart Emission Measurement System). The progress of the work for the both emission measurement options is reported in this chapter in respectively paragraphs 3.1 (RES) and 3.2 (SEMS).

Furthermore, the programme contributes data to discussions in the EU running on the development of special requirements and test procedures for real-driving emissions (paragraph 3.3).

The programme also contributes to the development of The Netherlands emission model Versit+ through the development of emission factors and the selection of test vehicles which are needed to fill the data gaps. This is discussed in paragraph 3.4.

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 from the side of the road. One important question still is whether RES is a suitable method for the detection of these so-called high-emitters.

For 2012, the most important goal for RES was to extend the measurement data-base. With an extended database not only the level of experience is increased, but there is also more data available for analyses in different ways.
The extensions of the database is sought in two directions: both quantity and quality. The latter indicates that other data types are added to the database.
An experiment has been done using an optical gate, which indicates the number of axles of a truck (or trailer) passing by.

Figure 9: optical gate able to count the number of axles of a vehicle passing by.

Furthermore, a combined measurement of RES and a sniffer has been performed. The sniffer measured NO_x and CO_2.

Figure 10: RES test set-up with the additional sniffer pole, measuring NO_x and CO_2.

In addition to extending the database, also steps have been undertaken to improve the process for future measurements:

1. A list of test equipment has been made (what gear is needed, where can it be found)
2. A user manual has been written.
3. A software tool has been developed to automate and speed up the process of data-analyses.

Finally, a document has been made that describes possible future measurement locations. As summary of this document is attached as Annex B. Experience with measurements namely showed that not all locations are suitable to perform road-side measurements with RES. In the document all experience gained with selecting and evaluating the suitability of the measurement locations was gathered. With all this information gathered in one document future measurement locations can selected much faster. The document describes the directions of drive and wind, the road side condition and experiences from previous experiments.

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 real world (mostly 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.

At the request of the Dutch Ministry of Infrastructure and Environment a smart measurement system was developed to judge the real world NO_x emission of heavy-duty vehicles. The measurement system uses a NO_x - O_2 sensor for the measurement of the tail pipe concentration of NO_x and to estimate the tail pipe concentration of CO_2 for diesel engines. A GPS measures the time-based vehicle speed profile over the test trip. Furthermore, a special data-evaluation method helps to reveal emission performance over the speed ranges of a vehicle. The method is based on collecting (binning) emissions of NO_x and CO_2 in speed intervals and calculates the CO_2 specific NO_x emissions for each interval.

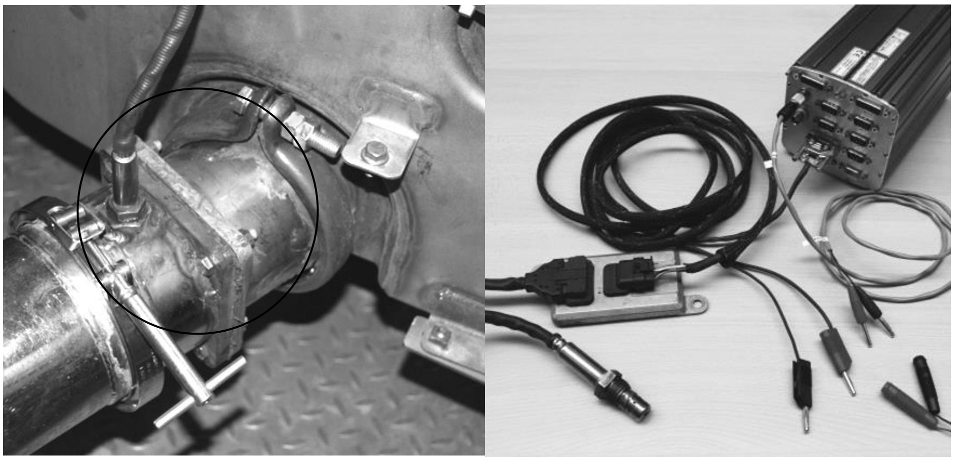

Figure 11 and Figure 12: left the NO_x - O_2 sensor installed at the tailpipe of a Euro VI heavy-duty vehicle. Right, the sensor and data-acquisition unit which logs the sensor data, GPS data and optionally the CAN data.

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. 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.

The method was evaluated in the 2012 programme by performing simultaneous measurements on trucks with PEMS and SEMS together. The measurement system proved to correlate well with PEMS, which can be seen as an accurate reference measurement. The method is less accurate than PEMS, but its merit to simply measure more and longer at lower costs increases the overall accuracy, because more of the often variable emission behaviour is captured.

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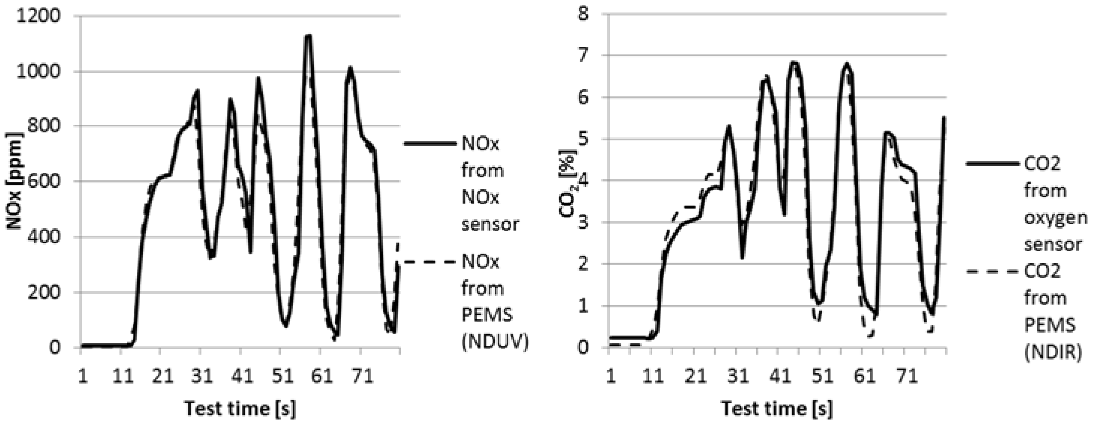

Figure 13 and Figure 14: left, the 1Hz signal of the estimated NO_x signal (from the NO_x – O_2 sensor), compared to the NO_x signal of PEMS (measurement principle non-dispersive ultraviolet). The signals correlate well. The NO_x sensor seems to have a somewhat higher response time. Right, the 1Hz signal of the estimated CO_2 (from the NO_x – O_2 sensor), compared to CO_2 signal of PEMS (measurement principle non-dispersive infrared). The signals correlate well. The NO_x-O_2 sensor seems to have a higher response time and has a minor offset compared to PEMS.

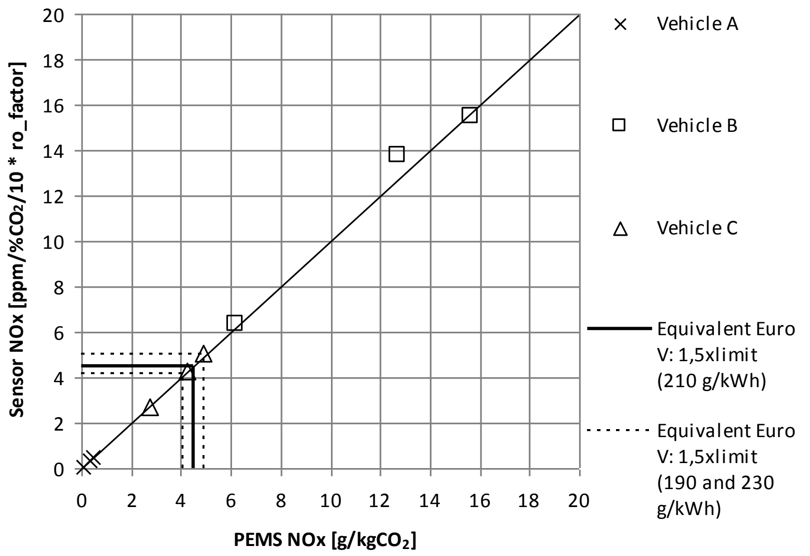

Figure 15: the CO_2 specific emissions as measured by the SEMS and based on measured concentrations, compared to the mass based emissions as measured by PEMS. Each point represents a speed interval of either 0-50, 50-75 or >75 km/h. Equivalent NO_x limits are calculated for three engine efficiencies (190, 210 and 230 g/kWh) including a conformity factor of 1,5. The inner square represents an equivalent limit based on a lower engine efficiency (230 g/kWh), the outer square represents a higher engine efficiency (190 g/kWh).

The method can be extended with more exhaust gas compounds like NH_3 and particulate matter once accurate sensors become available. The method however, is not yet suitable for testing SI (Otto) engines.

The method using SEMS was presented in a paper [Vermeulen et al. 2012c]. In 2013. SEMS will be developed as a stand-alone tool and will be applied for screening vehicles within the in-service testing programme.

3.3 Evaluation of the in-service conformity 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 in-service conformity emission legislation. At the moment the EC considers further improvement of the in-service conformity 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 in-service conformity. The latter is originnally meant to check if vehicles are in conformity with their original type approval over conditions similar to the engine test cycle, while the purpose of RDE would be to check/judge the emissions under a wider scope of real-world conditions than the engine test and the in-service conformity 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 in-service conformity 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 further elaborated in detail within a separate programme, The Netherlands MaVe project (Maatwerk Verkeersemissies), and are discussed in EU working groups which deal with PEMS, ISC and RDE. In the these programmes the focus lies on securing low NO_x emissions under all (in particular low load) driving conditions, but items like methane emissions of natural gas fuelled vehicles, durability and anti-tampering are also under the attention.

3.4 Emission modelling

In 2012 the emission data of the in-service testing programme has been analysed extensively. This resulted in two innovations:

First, the Euro V emission class with OBD II (B2G) appeared to have a signify-cantly lower NO_x emission than the preceding subclasses of Euro V (B2D and B2E) [Vermeulen et al. 2012b]. This distinction was observed by comparison of the data of these two groups once enough data was available. This distinction between the two classes of Euro V is now also integrated in the emission factors for NO_x and is taken into account in the GCN maps of RIVM as well. The start of the penetration of the fleet with Euro V B2G has been set at the 1st of January 2009.

Second, the emission model for heavy commercial vehicles has been adapted so that emissions can now be predicted, based on engine power and total mass of the vehicle (combination). The merit of the use of large trucks and tractor-trailer combinations with full payload for the transport of goods can now be valued. In the case of higher payload levels, the aftertreatment is also often functioning more efficiently than for smaller trucks with lower payloads.

For 2013 the goal is to gain more insight in Euro V subclasses and distinctive technologies. Slowly, more data becomes available for Euro VI trucks, so that these emission factors can be generated and improved. It still lacks data from the light category of Euro VI and of some specific technology classes (SCR only). It is expected that there will be more and better collaboration with international laboratories which runs similar emission testing programs.

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Relevant European Regulations and Directives:

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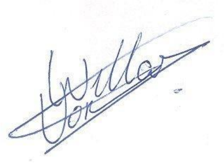
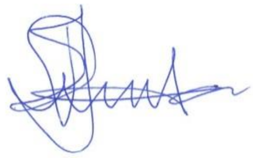
5 Signature

Delft, 23 May 2013





Willar Vonk
Project leader

Robin Vermeulen
Author

A Vehicle reports

A.1 Vehicle V

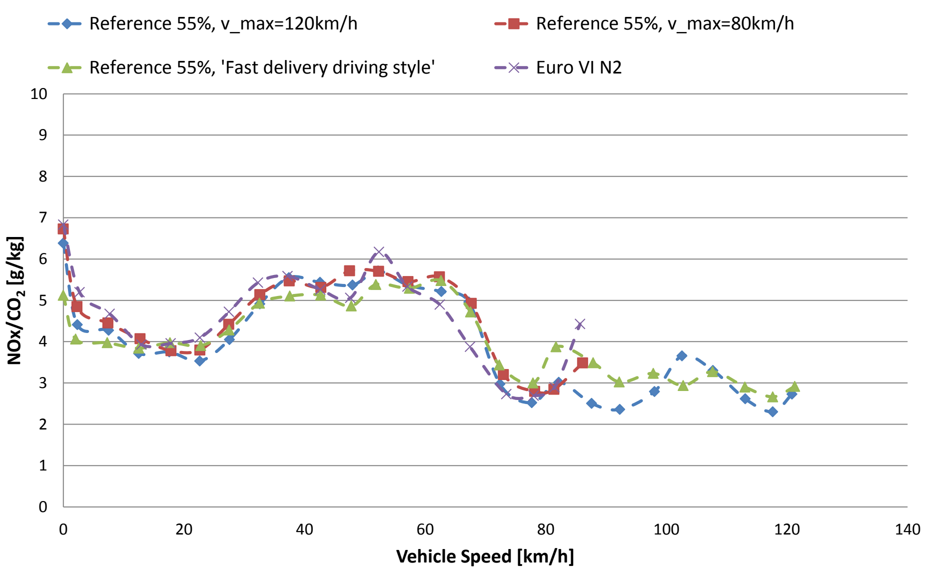
Test vehicle

Legislative category	N2, Euro V, B2(G) in NL re-approved as N1
Type	Rigid (distribution truck)
Engine capacity range	2,0-4,0 ltr
Engine power range	100-150kW
Emission reduction	EGR
Odometer	47170km

Test conditions

Trips	Payload [%]/ GCM [kg]	Weather	Traffic / driving style / special conditions
Euro VI N2 trip 55%	55/ 3460	22ºC, dry	Normal / Normal / vmax =80km/h
Reference trip 55% 120	55/3440	19ºC, dry	Normal / Normal / vmax=120km/h
Reference trip 55% 80	55/ 3440	25ºC, dry	Normal / Normal / vmax =80km/h
Reference trip 55%, 120, 'fast delivery'	55/3440	20ºC, dry	Normal / Fast delivery driving / vmax=120 km/h

Test results



Trips	**NO_x Conformity Factor [-]**	**NO_x max [-]**	**CO Conformity Factor**	**HC Conformity Factor**	**CFmax**
Euro VI N2 55%	0,98	1,05	0,10	0,12	**1,5**
Reference 55%, 120	1,10	1,18	0,19	0,01	
Reference 55%, 80	1,31	1,33	0,17	0,00	
Reference 55%, 120, ‘fast delivery’	1,31	1,34	0,16	0,00	

Trips	**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 total	268	0,95	0,32	0,64	33	3,56	0,23	0,02
Urban	299	1,49	0,50	0,98	34	4,98	0,43	0,00
Rural	279	0,84	0,29	0,55	35	3,02	0,16	0,03
Motorway	243	0,72	0,22	0,50	31	2,97	0,16	0,02
Reference 55%, 120	356	1,29	0,47	0,82	37	3,63	0,39	0,00
Reference 55%, 80	279	1,17	0,46	0,71	39	4,21	0,31	0,00
Reference 55%, 120, ‘fast delivery’	393	1,49	0,55	0,94	37	3,80	0,37	0,00

A.2 Vehicle W

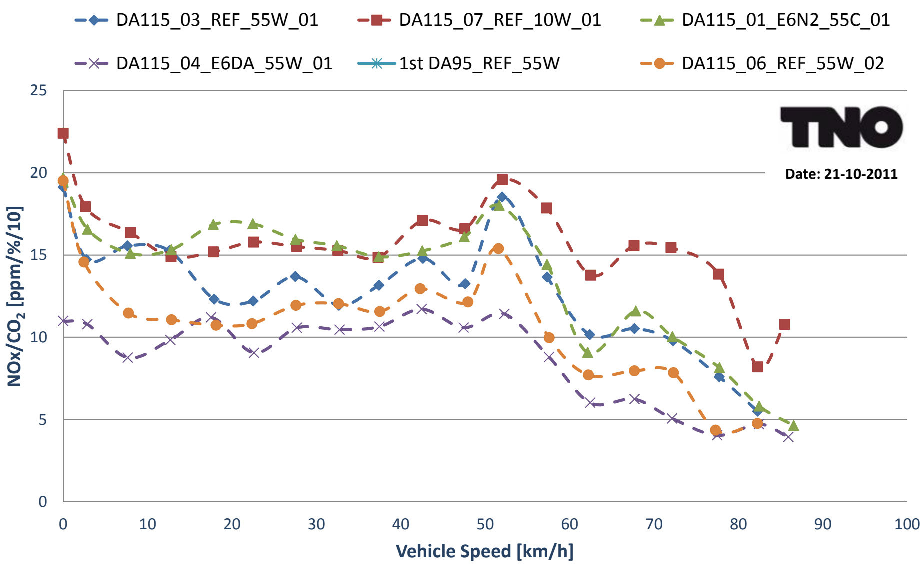
Test vehicle

Legislative category	**N2, Euro V EEV, C(K)**
Type	Rigid distribution truck, 4x2
Engine capacity range	4,0 – 6,0 ltr
Engine power range	100-150 kW
Emission reduction	SCR+NH_3 clean-up catalyst
Odometer	42395km

Test conditions

Trips	**Payload [%]/ GCM [kg]**	**Weather**	**Traffic /driving style/special conditions**
Euro VI N2 55%	55 / 8270	17ºC	Normal / Normal / n.a.
Reference 10%	10 / 6500	18ºC	Normal / Normal / n.a.
Reference 55% #1	55 / 8270	19ºC	Normal / Normal / n.a.
Reference 55% #2	55 / 8270	Light rain / 17ºC	Normal / Normal / n.a.
OEM trip 55%	55 / 8270	20ºC	Normal / Normal / OEM specified trip

Test results



Trips	**NO_x Conformity Factor [-]**	**NO_x max [-]**	**CO Conformity Factor**	**HC Conformity Factor**	**CFmax**
Euro VI N2 55%	3,19	4,39	0,30	0,04	**1,5**
Reference 10%	3,96	4,20	0,36	0,16	
Reference 55% #1	3,61	3,72	0,32	0,00	
Reference 55% #2	3,19	3,31	0,29	0,02	
OEM trip 55%	2,08	2,71	0,27	0,00	**1,5**

Trip name	**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	387	3,84	0,01	3,83	0	9,93	0,85	0,01
Urban	446	7,56	0,02	7,54	0	16,95	1,48	0,01
Rural	409	3,28	0,01	3,27	0	8,03	0,64	0,01
Motorway	341	2,12	0,00	2,12	0	6,22	0,64	0,01
Reference 10%	361	4,79	0,02	4,77	0	13,24	0,77	0,05
Reference 55% #1	395	4,13	0,04	4,08	0	10,45	0,75	0,00
Reference 55% #2	392	3,44	0,01	3,43	0	8,77	0,66	0,01
OEM 55%	401	2,85	0,04	2,82	0	7,12	0,68	0,00

A.3 Vehicle X

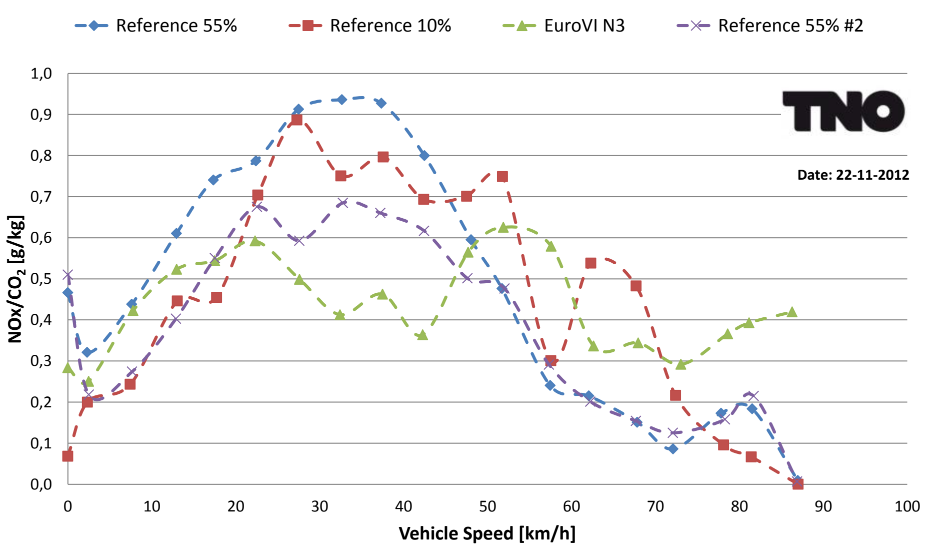
Test vehicle

Legislative category	**N3, Euro VI**
Type	Tractor semitrailer, 6x2 3-axle semitrailer
Engine capacity range	10-13 ltr
Engine power range	350-400 kW
Emission reduction	EGR, SCR, DPF, AMOC
Odometer	23595km. Is below the formal ISC requirement for testing but negligible influence is expected.

Test conditions

Trips	**Payload [%]/ GCM [kg]**	**Weather**	**Traffic /driving style/special conditions**
Euro VI trip N3 55%	55 / 34760	Dry, 15-20 ºC	Calm / Regular / With pusher tandem dead axle raised
Reference 15%	10 / 19360	Dry, 15-20 ºC	Calm / Regular / With pusher tandem dead axle raised
Reference 55% #1	55 / 34760	Dry, 15-20 ºC	Calm / Regular / With pusher tandem dead axle down
Reference 55% #2	55 / 34760	Dry, 15-20 ºC	Calm / Regular / With pusher tandem dead axle raised

Test results



Trips	**NO_x Conformity Factor 90-% [-]**	**NO_x max [-]**	**CO Conformity Factor**	**HC Conformity Factor**	**CF max [-]**
Euro VI N3 55%	0,91	1,10	0,2	0,2	**1,5**
Reference 10%	0,63	1,39	0,2	0,0	
Reference 55% #1	1,12	1,26	0,2	0,0	
Reference 55% #2	1,35	1,39	0,2	0,2	

Trips	**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	975	0,57	0,30	0,27	53%	0,58	1,02	0,01
Urban	1698	2,45	0,69	1,77	28%	1,45	2,44	0,01
Rural	1127	0,43	0,19	0,23	45%	0,38	1,12	0,03
Motorway	835	0,39	0,29	0,10	74%	0,47	0,81	0,00
Reference 10%	903	0,39	0,17	0,22	44%	0,43	1,19	0,01
Reference 55% #1	1201	0,56	0,27	0,29	49%	0,47	0,99	0,02
Reference 55% #2	1259	0,51	0,25	0,26	49%	0,41	1,23	0,00

A.4 Vehicle Y

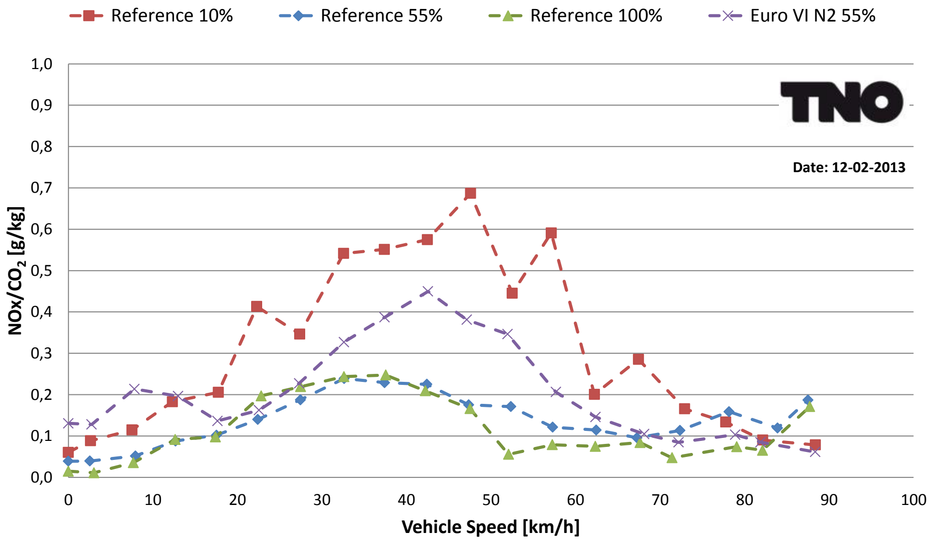
Test vehicle

Legislative category	**N3, Euro VI**
Type	Rigid truck 4x2 + trailer
Engine capacity range	6,0-10,0 Ltr
Engine power range	250-300kW
Emission reduction	EGR, SCR, DPF, AMOC
Odometer	18550km

Test conditions

Trips	**Payload [%]/ GCM [kg]**	**Weather**	**Traffic /driving style/special conditions**
Euro VI N2 55%	55 / 24120	0-7 ºC, light rain on one trip, but mostly dry and overcast, 2bft	Calm / OEM test driver, regular / n.a.
Reference 10%	10 / 15080		Jam at end of trip / OEM test driver, regular / no trailer
Reference 55%	55 / 24120		Calm / OEM test driver, regular / n.a.
Reference 100%	100 / 33030		Calm / OEM test driver, regular / n.a.

Test results



Trips	**NO_x Conformity Factor [-]**	**NO_x max [-]**	**CO Conformity Factor**	**HC Conformity Factor**	**CF max [-]**
Euro VI N2 55%	0,46	1,38	0,1	0,1	**1,5**
Reference 10%	0,35	0,53	0,2	0,0	
Reference 55%	0,31	0,40	0,2	0,0	
Reference 100%	0,27	0,54	0,2	0,2	

Trips	**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	1011	0,51	0,02	0,48	5	0,50	0,88	0,04
Urban	1280	1,89	0,07	1,82	4	1,48	1,85	0,21
Rural	1028	0,32	0,02	0,30	5	0,31	0,72	0,00
Motorway	890	0,06	0,01	0,05	13	0,06	0,58	0,00
Reference 10%	882	0,28	0,00	0,28	0	0,32	1,09	0,00
Reference 55%	1203	0,18	0,00	0,17	1	0,15	1,24	0,05
Reference 100%	1370	0,19	0,00	0,19	1	0,14	1,43	0,00

A.5 Vehicle Z

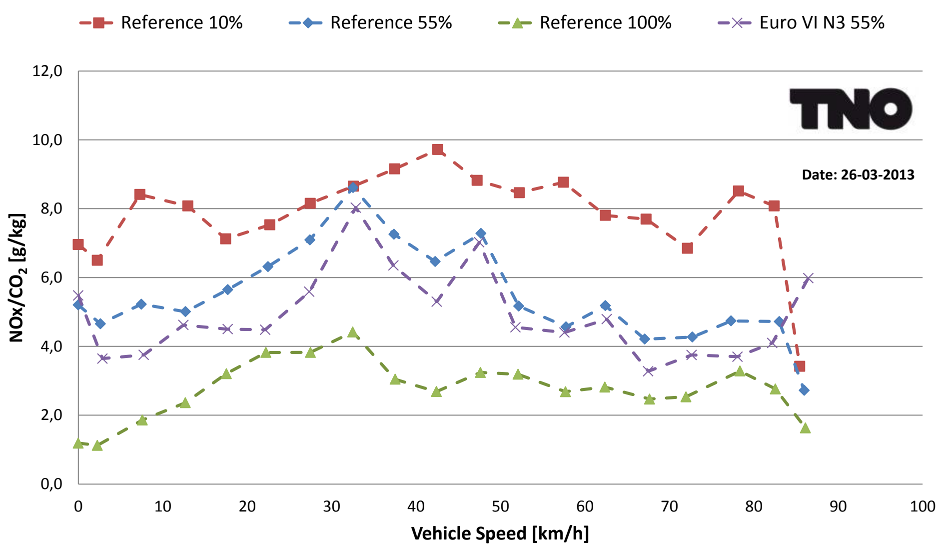
Test vehicle

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 [kg]**	**Weather**	**Traffic /driving style/special conditions**
Euro VI N3 #1	55 / 34200	5-18ºC, dry	Calm / regular / n.a.
Euro VI N3 #2	55 / 34200		Calm / regular / n.a.
Reference 10%	10 / 18320		Calm / regular / n.a.
Reference 55%	55 / 34200		Calm / regular / n.a.
Reference 100%	100 / 50000		Calm / regular / n.a.

Test results



Trips	**NO_x Conformity Factor [-]**	**NO_x max [-]**	**CO Conformity Factor**	**HC Conformity Factor**	**CF max**
Euro VI N3 #1	1,78	2,14	0,41	0,26	**1,5**
Euro VI N3 #2	1,57	2,00	0,39	0,23	**1,5**
Reference 10%	2,57	2,78	0,55	0,30	
Reference 55%	1,95	2,02	0,72	0,27	
Reference 100%	1,26	1,40	0,67	0,25	

Trips	**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 #1	1041	5,05	0,74	4,31	15	4,85	1,97	0,14
Urban	1410	9,89	1,05	8,84	11	7,01	5,40	0,23
Rural	1261	4,37	0,75	3,62	17	3,46	2,52	0,28
Motorway	902	4,52	0,69	3,83	15	5,01	1,23	0,08
Euro VI N3 55% total #1	1077	4,73	0,59	4,14	13	4,39	1,93	0,07
Urban	1467	9,01	0,85	8,15	9	6,14	5,49	0,09
Rural	1275	4,37	0,46	3,90	11	3,42	2,57	0,25
Motorway	944	4,22	0,60	3,62	14	4,47	1,16	0,00
Reference 10%	946	7,85	0,60	0,00	0,08	8,30	3,76	0,22
Reference 55%	1332	7,68	0,77	0,00	0,10	5,76	4,80	0,21
Reference 100%	1645	4,99	0,39	0,00	0,08	3,04	4,74	0,30

B RES measurement locations overview

Nr	Location	Direction of drive	Slope	Road Side	N	NE	E	SE	S	SW	W	NW
1	Waddinxveen	NW	★	★★	☆	★	★	☆	★★	★★	☆	☆
2	Delfgauw	SSE	★	★★★	☆	★	★	☆	☆	★★	★★	☆
3	Zaandam	ENE	★	★★★	★★	☆	☆	★	★	☆	☆	★★
4	Pijnacker	WSW	★★	★★	★★	☆	☆	★	★	☆	☆	★★
5.1	Aalsmeer	NW	★	★	☆	★	★	☆	☆	★★	★★	☆
5.2	Aalsmeer	SE	★	★★★	☆	★★	★★	☆	☆	★	★	☆
6.1	Botlek	E	★★	★★★	★★	★★	☆	★	★	★	☆	★★
6.2	Botlek	W	★★★	★	★	★	☆	★★	★★	★★	☆	★
7	Nieuwegein	?	?	?	?	?	?	?	?	?	?	?
8.1	Moerdijk	NE	★★	★	☆	☆	★★★	★★★	☆	☆	★	★
8.2	Moerdijk	SW	★	★	☆	☆	★	★	☆	☆	★★★	★★★
9	Moerdijk	WNW	★	★	★★★	★★★	☆	☆	★★	★★	☆	☆
10	Moerdijk	NW	☆	★	☆	★	★	☆	☆	★★	★★	☆
11	Amsterdam	SE	★★★	★	☆	☆	★★	★★	☆	☆	★	★
12	Veghel	SW	★★	★	★	☆	★★	★★	★★	☆	★	★
13.1	Vinkeveen	NW	★	★★★	★	★	☆	☆	★★	★★	☆	☆
13.2	Vinkeveen	SE	★	★★★	★★	★★	☆	☆	★	★	☆	☆
13.3	Vinkeveen	W	★	★★★	★	★	☆	★★	★★	★★	☆	★
13.4	Vinkeveen	E	★	★★★	★★	★★	☆	★	★	★	☆	★★
14.1	Den Dolder	NE	☆	★★★	★★	☆	☆	★	★	☆	☆	★★
14.2	Den Dolder	WSW	☆	★★★	★	☆	☆	★★	★★	☆	☆	★
14.3	Den Dolder	ENE	★	★★★	★★	☆	☆	★	★	☆	☆	★★
15.1	Naaldwijk	NE	★	★	★	☆	☆	★★	★★	☆	☆	★
15.2	Naaldwijk	SW	★	★	★★	☆	☆	★	★	☆	☆	★★
16	Delft	E	★★	★★★	★★★	★★★	☆	★★	★★	★★	☆	★★★

☆	0 = negative slope	0 = unsafe	0 = not suitable
★	1 = no slope	1 = soft	1 = suitable, not for sniffer
★★	2 = positive slope	2 = semi-paved	2 = suitable, but traffic behind it
★★★	3 = positive slope > 2%	3 = hard	3 = suitable in any case