Nederlandse Organisatie voor
toegepast-natuurwetenschappelijk
onderzoek/ Netherlands Organisation
for Applied Scientific Research

TNO Science and Industry

Stieltjesweg 1
P.O. Box 155
2600 AD Delft
The Netherlands

www.tno.nl

T +31 15 269 20 00
F +31 15 269 21 11
info-IenT@tno.nl

TNO report

MON-RPT-2010-02777

Real world NOx emissions of Euro V vehicles

Date	11 November 2010
Author(s)	Ruud Verbeek, Robin Vermeulen, Willar Vonk, Henk Dekker
Assignor	Ministerie van VROM T.a.v. de heer R.F.A. Cuelenaere Postbus 30945 2500 GX Den Haag
Project number	033.24502/01.01
Number of pages	43

Samenvatting

In het afgelopen decennium zijn de schadelijke uitlaatgasemissies van voertuigen aanzienlijk teruggebracht als gevolg van de Europese emissiewetgeving. In het bijzonder in stedelijke gebieden zijn er echter nog steeds luchtkwaliteitproblemen en is het moeilijk om aan de Europese eisen, vooral met betrekking tot NO_2, te voldoen. Om die reden zijn de emissieprestaties van voertuigen tijdens stadsgebruik belangrijk.

TNO was, in deze context, gevraagd door het ministerie van VROM om onderzoek te doen naar de NO_x emissies in de praktijk van Euro V vrachtwagens en bussen. Dit zijn relatief nieuwe voertuigen geleverd vanaf 2006.
Het onderzoek heeft naar voren gebracht dat er grote variaties zijn in de NO_x emissies van deze voertuigen vooral tijdens stadgebruik. Sommige voertuigen lieten zien dat lage emissies onder deze condities wel degelijk mogelijk zijn, hoewel dat niet geldt voor de meeste vrachtwagens.

Deze conclusie is gebaseerd op twee onderzoekslijnen:
Ten eerste zijn de emissies van elf vrachtwagens en één bus gemeten in de praktijk gebruik makend van een Portable Emissie-Meet-Systeem (PEMS). Daarnaast is het AdBlue verbruik geanalyseerd van een aantal Nederlandse voertuigvloten. AdBlue is een reagens dat zorgt voor NO_x vermindering in het katalysatorsysteem. De hoeveelheid gebruikte AdBlue is maat voor het gerealiseerde NO_x emissieniveau. De resultaten van beide onderzoekslijnen ondersteunen de uitkomst van het onderzoek.

Gemiddeld hoge NO_x emissies tijdens stadsgebruik en gebruik op secundaire wegen en grote variaties in de NO_x emissies in de praktijk tussen verschillende vrachtwagentypen

Het PEMS systeem is gebruikt om de emissies van elf vrachtwagen en één bus in de praktijk te meten. De voertuigen waren van het type Euro V of EEV[1]. Eén vrachtwagen was van het type Euro IV. Het onderzoek laat een groot verschil zien in het NO_x emissieniveau tussen de verschillende voertuigen. Over een groot deel van het snelheidsbereik is een factor 6 verschil gemeten in NO_x emissie tussen het beste voertuig (een bus) en het slechtste Euro V voertuig. De resultaten laten ook zien dat bij snelheden boven de 70 km/h, waar de motoren relatief hoog belast zijn, veel voertuigen wel redelijk presteren. Geconcludeerd wordt dat de huidige test procedure voor de typekeuring, welke gekenmerkt wordt door een relatief hoge belasting, geen goede NO_x emissies in de praktijk waarborgt, vooral tijdens de lage en gemiddelde snelheden typisch voor stadsgebruik.
De invloed van belading van de vrachtwagen is eveneens onderzocht. Deze invloed kan relatief groot zijn. Een onbeladen vrachtwagen kan een hogere emissie hebben dan een beladen voertuig. Er worden (nog) geen speciale wettelijke eisen gesteld in relatie tot verschillende beladingen.

---

[1] variant op Euro V norm met iets strengere norm voor fijnstof uitstoot

De analyse van AdBlue verbruik bevestigt de grote verschillen in NO_x emissie tussen verschillende voertuigtypen.

De meeste Euro V voertuigen zijn voorzien van een NO_x reductiekatalysator. Hierbij is de NO_x vermindering proportioneel met de hoeveelheid stroomopwaarts van de katalysator geïnjecteerd AdBlue. Vijf voertuigvloten zijn onderzocht met in het totaal 166 voertuigen.

Drie van deze vloten bestaan uit bussen voor openbaar vervoer in de stad. Het gemeten AdBlue verbruik varieert tussen 0,5% en 5,7% (relatief t.o.v. brandstofverbruik). Dit is laag in vergelijking met het door de fabrikanten zelf gespecificeerde verbruik van ca 5% tot 7%. De resultaten van de AdBlue verbruiksanalyse ondersteunen die van de metingen met PEMS: beiden laten een grote variatie zien in NO_x emissies tussen verschillende voertuigen. Voor alle onderzochte toepassingen variërend van stadstransport (bussen) tot regionaal en internationaal, zijn er voertuigen met lage en relatief hoge NO_x emissies. De gemiddelde NO_x emissies in de praktijk kunnen tot een factor twee of drie hoger zijn dan de tot nu toe verwachte niveaus op basis van de tot voor kort gebruikte emissiefactoren[2].

Een belangrijk punt is of latere generaties Euro V voertuigen een betere NO_x emissie hebben dan de eerdere. De AdBlue verbruiksanalyse laat zien dat bouwjaar 2009 en 2010 voertuigen gemiddeld wat beter scoren, hoewel het aantal voertuigen te klein is om dit onomstotelijk aan te tonen. De metingen met PEMS laten zien dat nieuwere voertuigen nog steeds een hoge NO_x emissie kunnen hebben.

Samenvattend wordt geconcludeerd dat er Euro V voertuigen zijn die lage NO_x emissies laten zien onder de meeste gebruikscondities in de praktijk, maar dat een relatief groot deel van de vrachtwagens een veel hogere NO_x emissie laat zien gedurende stadsgebruik en gebruik op secundaire wegen.

---

[2] formele emissiegetallen welke gebruikt worden voor de Nederlandse luchtkwaliteitberekeningen

Executive summary

In the past decade, vehicle emissions have been reduced substantially as a result of the European emission legislation. Air quality problems are still present, however, in particular in urban areas where local authorities have difficulty meeting European limits regarding air quality (mainly NO_2). Therefore, the emission performance of vehicles under urban conditions is of increasing importance for air quality improvement in cities.

In this context, TNO was commissioned by the Dutch Ministry of Environment (VROM) to investigate the real-world NO_x emissions of Euro V trucks and buses during the past two years. The investigation has shown that, in general, there is a large variability in real-world emissions between different vehicles, in particular under urban conditions. Some vehicles demonstrate the possibility of achieving low emissions under urban conditions, but the results also clearly show that this is not the case for most of the trucks.

This outcome is based on two lines of research:

Firstly, the real world emissions of eleven trucks and one bus were measured on-road using a Portable Emission Measurement System (PEMS), under conditions typical of everyday use. Secondly, AdBlue consumption data for a number of Dutch vehicle fleets were analysed. AdBlue is the reagent that is used for NO_x emission reduction in SCR systems (catalytic after treatment systems), and the amount of reagent used in daily practice is related to the real-world NO_x emissions. Both lines of research support the general outcome.

High NO_x-emissions on average under urban and rural driving conditions, and large variations in real-world NO_x emissions between different truck types

The PEMS system was used to analyse the real-world emissions of eleven trucks and one bus (all Euro V or EEV except for one Euro IV truck). The results show a large difference in emissions between the vehicles. Across a large part of the speed conditions investigated, there is a factor of six between the NO_x emissions of the best vehicle (the bus) and those of the worst Euro V vehicle. The results also show that at speeds above 70 km/h, where the engines are relatively highly loaded, many vehicles perform reasonably well. The results demonstrate that the current type approval test procedure, with its test cycle with relatively high loads, does not necessarily secure low real-world emissions at low and medium vehicle speeds characteristic of urban use.

The influence of payload was also investigated. This influence can be rather large. An unloaded truck can have higher absolute NO_x emissions (in g/km) than a loaded truck. Currently there are no legal requirements for the exhaust emissions of these vehicles in relation to different payloads.

The AdBlue consumption data analysis confirms the findings of large variations between vehicle types

The majority of Euro V vehicles are equipped with SCR systems (catalytic after treatment for NO_x reduction). The NO_x reduction is directly proportional to the quantity of AdBlue, the reagent which is injected upstream of the catalyst. Five different fleets with a total of 166 vehicles were investigated. Three of those fleets are city bus fleets.

The AdBlue consumption ranges between 0.5 % and 5.7% (relative to the fuel consumption). The manufacturers themselves specify a relative AdBlue consumption between about 5 and 7%.

The results of the AdBlue consumption analysis support those of the PEMS measurements, both showing high variability. For all investigated applications, which range from typical city transport (buses) to regional distribution and long haulage, there are vehicles types with low and with relatively high real-world NO_x emissions. The average real-world NO_x emissions may be up to a factor of two to three higher than the expected level based on until recently used emission factors.

An important issue is whether newer generations of Euro V trucks show progressively better emission performance. The AdBlue consumption analysis showed that model year 2009 and 2010 vehicles may have lower NO_x emissions than older vehicles, although the number of vehicles to confirm this observation is rather small. The PEMS measurements show that some newer vehicles still have a rather high NO_x emission.

Summarizing, the results show that there are some Euro V vehicles achieving low emissions under most driving conditions, but also that a large proportion of the Euro V truck fleet has much higher NO_x emissions during real-world urban and rural driving.

Contents

1 Introduction

1.1 Background and aim

Commissioned by the Dutch Ministry of Environment (VROM) TNO regularly performs measurements to determine the emissions performance and durability of vehicles in-use in the Netherlands. The aim of this measurement programme is, amongst others, to gain insight into trends in real-world emissions of heavy duty vehicles, under the usage conditions relevant for the Dutch situation.

In the past decade, vehicle emissions in general have been reduced substantially as a result of the European exhaust emissions legislation. Air quality problems have been reduced to specific hot-spots, which are mainly situated in urban areas. Therefore, the emission performance of vehicles under urban conditions is of increasing importance for air quality improvement.

The recent Euro V legislation is now implemented, but Euro V vehicles already had a substantial market share since 2006. This was due to the introduction of toll reduction in Germany for these vehicles (LKW-MAUT) and other tax incentives in other countries. VROM has asked TNO to perform a measurement programme specifically aimed at assessing the emission performance of Euro V trucks under real-world conditions. The emission of this class of trucks is specifically relevant in the context of reaching the NO_2 air quality limits in urban areas, as imposed by European legislation.

In the past two years, TNO has performed a series of emission measurements on Euro V trucks. These measurements were performed using a Portable Emission Measurement System (PEMS). Parts of these results have been reported earlier [Ligterink, 2009]. In addition to the trucks and bus tested in this earlier study, 3 other trucks have been measured.

Any experimental study on vehicle emissions is necessarily limited to a small number of vehicles. This raises a question regarding the representativeness of the study for the whole vehicle fleet. Therefore, an additional study was done, in which the real-world AdBlue consumption statistics of a larger number of HD vehicles were analysed. Since there is direct relation between AdBlue injection and NO_x conversion, this allows a first order estimate of average NO_x emission, which can be compared to the PEMS results.

This report gives an overview of the main findings of the studies on Euro V trucks. More detailed findings of the PEMS results will be reported separately.

1.2 Structure of the report

Chapter 2 gives a summary of the emission measurement results using PEMS. The results on the AdBlue statistics results are reported in Chapter 3. In Chapter 4 the outcome of the two investigation methods are compared, and some general conclusions are drawn. These are stated in Chapter 5.

2 Evaluation of the PEMS emission results

2.1 Background and aim

PEMS was originally developed in the US and used for In-Use Compliance testing. The European PEMS pilot programme has resulted in a method for in-service conformity testing, e.g. to test whether a vehicle on the road complies with the emission type approval requirements.

PEMS testing generates a wealth of data. The manner in which these data are to be processed depends very much on the information one wishes to extract from the measurements. Here, two goals are distinguished:

1) In-service conformity – here PEMS is used to determine whether the engine mounted in a vehicle complies with the type approval requirements (emissions are below the emission limits, when tested on an engine test bench during the type approval test). For this, the software package EMROAD was developed by DG-JRC to process the PEMS data according to the ISC procedure.
2) Assessment of real-world emissions during representative use, to be used for determining emissions factors for air quality calculations. For this, no standard method is available, and we have used a method in which the results are collected in speed-bins.

In this study, the results are analysed according to both these methods. The methods are explained in more detail below.

The study has two basic aims:

- Assess the emission performance of Euro V trucks under real-world conditions

- Generate real-world emission data for deriving emission factors for Euro V trucks

2.2 Measurement programme

2.2.1 *Vehicles tested*

PEMS Measurements have been performed with 11 trucks and 1 bus. An overview of the vehicles is presented in Table 1. The first 8 vehicles were measured in 2009. The (first phase) results were already presented in December 2009 [Ligterink, 2009]. The trucks are from the N2 and the N3 categories. All trucks are tested with 50% payload and a number of trucks are also tested with 0% or 10% payload and 100% payload. The average payload of most truck categories in the Netherlands is around the 50% payload. The N2 category trucks were always rigid trucks with a test weight in the range of 7 to 10 ton (50% payload). The N3 trucks were, except for one rigid truck, always tractor-trailer configurations with a test weight of 20 to 32 tons for the 50% payload case (refer to Table 1). Also the model year and the legislation category are included in this table. Nine trucks have a Euro V B2 approval, while 1 truck has a Euro IV B1 approval (vehicle J). Two vehicles one bus (H) and one truck (F) have an EEV C approval.

Table 1: Specifications of the HD vehicles tested with PEMS

	legislative category	vehicle category	vehicle type	model year	test weight @ 50% payload [tonne]	Power / mass ratio @ 50% payload
Vehicle A	V B2(E)	N3	Tractor Semi-trailer	2008	29.6	10.1
Vehicle B	V B2(G)	N3	Tractor Semi-trailer	2008	29.0	11.2
Vehicle C	V B2(G)	N3	Tractor Semi-trailer	2008	29.8	10.4
Vehicle D	V B2(D)	N3	Rigid	2008	16.4	13.9
Vehicle E	V B2(D)	N3	Tractor Semi-trailer	2007	28.9	10.2
Vehicle F	EEV C(I)	N2	Rigid	2009	6.9	17.1
Vehicle G	V B2(D)	N3	Tractor Semi-trailer	2007	19.9	11.6
Vehicle H	EEV C(I)	M3	Bus	2008	12.0	13.8
Vehicle I	V B2(G)	N2	Rigid	2009	9.6	13.5
Vehicle J	IV B1(C)	N2	Rigid	2008	9.7	13.6
Vehicle K	V B2(G)	N2	Rigid	2010	9.4	19.1
Vehicle L	V B2(D)	N3	Tractor Semi-trailer	2007	32.4	10.0

Different legislative categories apply to the tested vehicles:

- Vehicles D, E, G and L are Euro V vehicles with OBD Phase I
- Vehicle A is a Euro V vehicle with OBD Phase I and additional NO_x control measures
- Vehicles F, H and G are Euro V EEV vehicles with OBD Phase I and additional NO_x control measures
- Vehicles B, C, I and K are Euro V vehicles with OBD Phase II and additional NO_x control measures

2.2.2 *Trip characteristics*

A few different trips have been used:

1) A standard reference trip.
2) Representative trips.
3) Two trips according to the Euro VI trip ISC guidelines (only for the N2 vehicles).

The test procedure consists of at least two days of testing on the road, driving the following trips:

- Standard Reference Test Trip; a predefined standard trip is applied for all vehicles. The trip includes different road types; urban, rural, highway; with most relevant traffic situations.
- Representative trip; according the PEMS documents [DG ENTR, 2007], [DG JRC, 2007], [DG JRC, 2009] for ISC testing a representative trip should be driven over which the emissions shall be evaluated. These trips and its results are also very useful for the development of representative driving cycles and emission factors. For the first test sequence in 2009 trips were driven as found representative for a vehicle. In one case real bus lines were driven. In other cases freight papers were asked from the owner of the truck to construct representative national distribution or long haulage trips.

Later on requirements were developed for the shares of urban, rural and motorway driving per legislative vehicle category (N2, N3, M3 …) to be applied for Euro VI ISC legislation [DG ENTR, 2010]. For vehicle I, J and K (all N2 vehicles) the typical required trip distribution was used as proposed (time shares of 45, 25 and 30% for urban, rural and motorway respectively).

An overview of the Euro VI representative trips for the different vehicle categories is given in Table 2. The TNO reference trip is the same for all truck categories. A distinction is made between three operation conditions:

- Urban: vehicle speeds between 0 and 50 km/h
- Rural: vehicle speeds between 50 and 75 km/h
- Motorway: vehicle speeds above 75 km/h

Table 2: Trip characteristics according to the Euro VI In-Service-Conformity requirements compared with the TNO reference trip.

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 of Class I, II or Class A	70	30	0
TNO reference trip	48	26	26

The speed time characteristic of the TNO reference trip is presented in Figure 1.

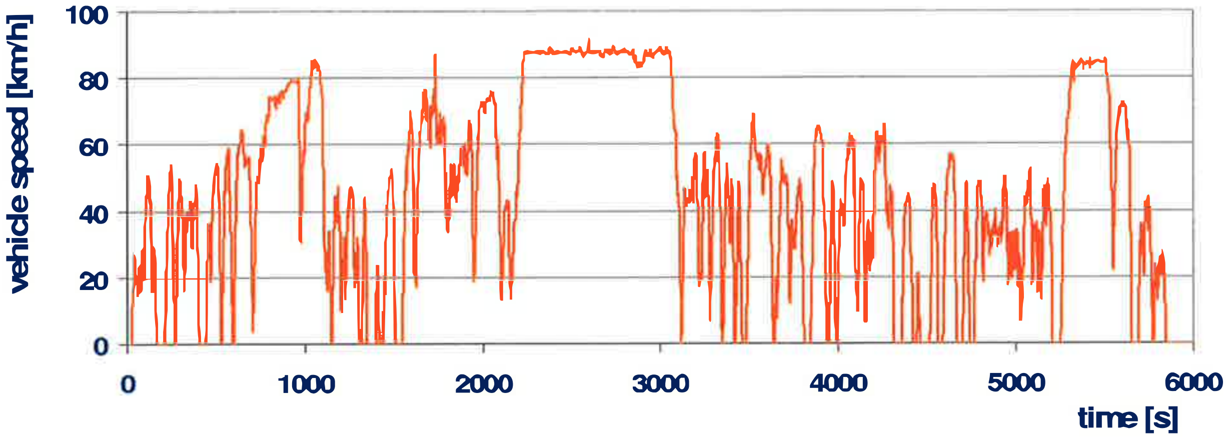


Figure 1: Vehicle speed trace of the TNO reference trip

The two trips chosen according to the Euro VI ISC requirements are very different, although both have an overall length of about 3 hours. Refer to Figure 2 and Figure 3. Version A in Figure 2 has the official layout with one urban, one rural and one motorway part. In version B, these operating conditions are about five times shorted and then this is repeated five times. Refer to Figure 3.

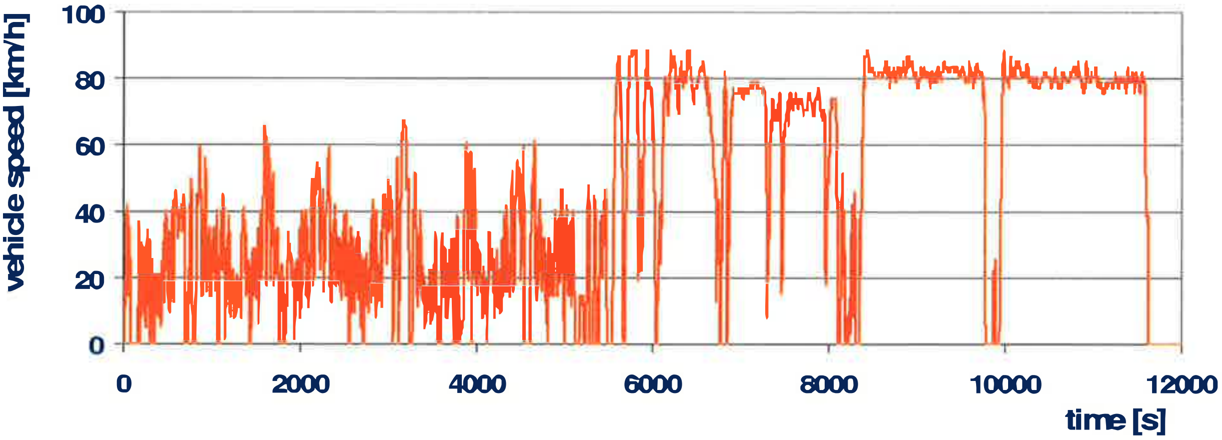


Figure 2: Euro VI trip A

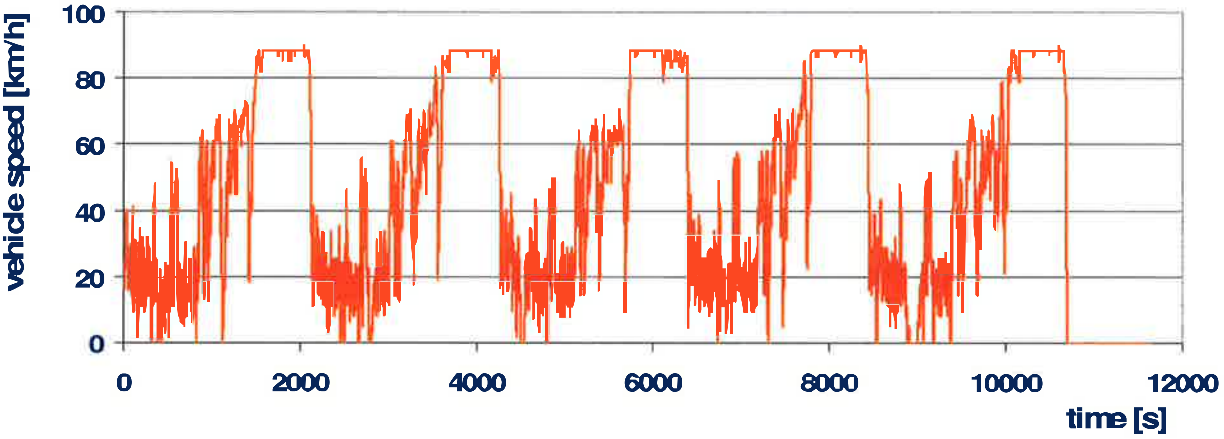


Figure 3: Euro VI trip B

The vehicles were tested in their condition as received from the owner. Before the tests a regular visual inspection was performed to check for irregularities, damage, MI lights activation, etc. For the tests regular commercially available fuel and reagent was used. Both representative trips and reference trips with around 50% payload were used for the data evaluation. The representative trips were generally one day long trips which have been cut in parts (after 2 hours a break and a calibration are required). Also the complete dataset from a whole day of driving a representative trip was analyzed.

2.3 Data analysis – real-world emissions

2.3.1 Introduction

A primary purpose of the current experiments is to facilitate the use of PEMS data as input to calculate emission factors for urban, rural and motorway conditions.

The common procedure for this until now is that these emissions factors are modelled based on normalized engine maps specific for the type of engine (Euro class and engine technology), vehicle models, trip profiles and statistical data (fleet composition, payload, vehicle driven miles etc.). A distinction is usually made between three types of use: urban, sub-urban or rural and motorway. Emission factors are determined in the Netherlands, but also in other EU countries (e.g. HBEFA, Versit).

The use of PEMS allows characterization of real-world emissions of vehicles under a wide range of conditions, but in order to deduce emission factors the data has to be processed in a suitable way, such that the effect of driving characteristics (speed, acceleration) on emissions is deduced from the data.

For this, we used a method in which PEMS data are collected into speed bins. This was done because there is a loose relation between average speed and the type of road (urban, rural, highway), and the distinction in road types is important for emission factors.

As introduced above the binning method was never intended as a method to assess in-service conformity, but it provided a method to visualise trends in real life emissions under urban, rural and motorway conditions.

2.3.2 *Calculation according to the binning method*

The calculation procedure for the binning method is as follows:

PEMS data of one or more trips were pre-processed with EMROAD. Only valid data points were used (i.e. where the coolant temperature was above or equal to 70°C). There were no significant altitude differences during and between the trips.

Vehicle speed bins with a width of 5 km/hour were selected to distinguish urban, rural and motorway operation easily. In each bin the vehicle speed [km/h], emissions [g/s] and CO_2 [kg/s] or power [kW] from the data points belonging to that bin are collected. In the end the average speed within a bin, the emissions in [g/kg CO_2] or [g/kWh], the percentage of data points within a bin etc. are calculated.

The method can also be used to calculate brake specific emissions, but it was necessary to use CO_2 specific emissions because the information necessary to obtain the parameters from the CAN bus to calculate the power of the engine was not available for all vehicles (see also 2.5.1).

Example of the calculation used for the binning method:

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
NO_x = (1+1) / (10+0. 1) = 0.2 [g/kg CO_2]

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

2.3.3 *Issues*

Two concerns were raised in relation to the application of the binning method:

First, the emissions within a bin may originate from different operation conditions such as acceleration, deceleration and cruising (steady state and transient emissions). The contribution of the decelerations will be small due to their relatively low mass (see cadre in paragraph 2.3.2 on page 15), but accelerations may contribute significantly in some cases. But this will also be true in real world conditions. Therefore much care was taken to design a reference trip that is as representative as possible for average Dutch truck usage.

Second, there is the question of how representative a speed bin is for an operating condition such as urban, rural or highway. Separation of different operating conditions using the vehicle speed will result in a contribution of some of the data from higher speed operation conditions to the lower speed bins. For example the rural part of the trip may also have a traffic light or a traffic jam. This is a valid point, although most of these contributions are relatively short transients. A number of things about this are worth mentioning:

1) Anyhow, inclusion of low speed motorway emissions in the speed bins associated with urban driving will probably lead to lower average emission results as the SCR system may still have an optimal operating temperature.
2) Using the vehicle speed to separate the different operating conditions was also the method used for the development of the WHTC. In general this is the simplest way to do the separation and to check the contribution of each type of operation to the trip.
3) To check the influence of different operating conditions on the speed bins, the Euro VI-ISC trip was binned into speed bins as well as into the different operating parts (urban, rural and motorway). Figure 4 to Figure 6 show the comparison between binned data and the data integrated over the different operating parts. Especially Figure 4 and 5 show an excellent correlation between the trip parts and the speed bins results. In Figure 6 there is some difference for the rural and motorway parts. In this case a significant part of the rural data has speeds above 75 km/h which leads to a difference between the trip parts and the speed bins results. The comparison of the CO_2 produced in the urban part and the speed bins up 50 km/h shows that for the reference trips of vehicles I, J and K about 3-10% of the CO_2 in the speed bins up to 50 km/h came from rural and motorway operation. This shows that the contribution of rural and motorway operation to the lower speed bins is sufficiently small. Of course this can be is influenced by traffic density and other vehicle speed influences.

The above points show that the influence of these issues does not really influence the general picture of the in-use emission results of Euro V vehicles provided by the binning method.

When calculating the emissions for a theoretical cycle, such as used for various emission factors, the result is calculated per second by using the emission versus vehicle speed relation from the speed bins. Also for example low speeds during motorway and rural parts are correctly included.

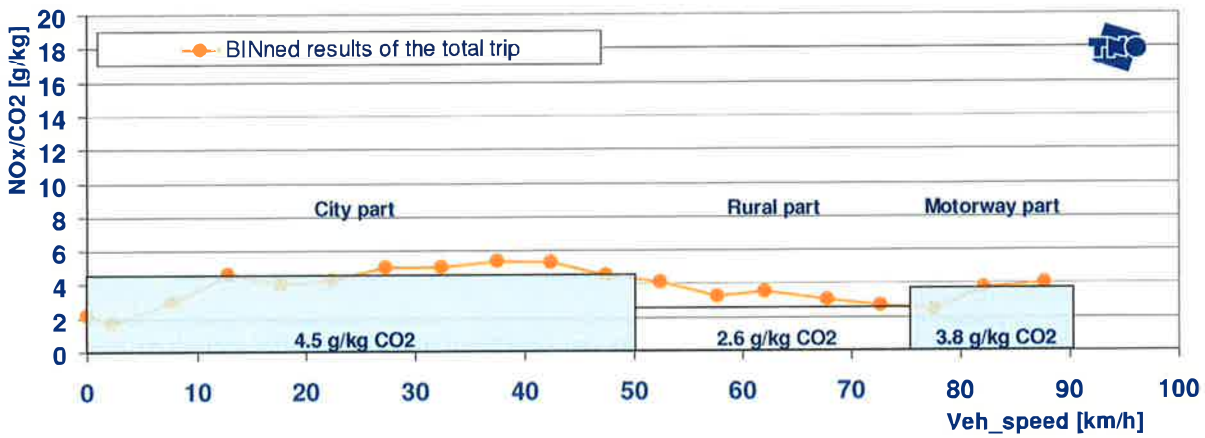


Figure 4: Emissions in the different parts of the Euro VI trip compared with the binned results - Vehicle I

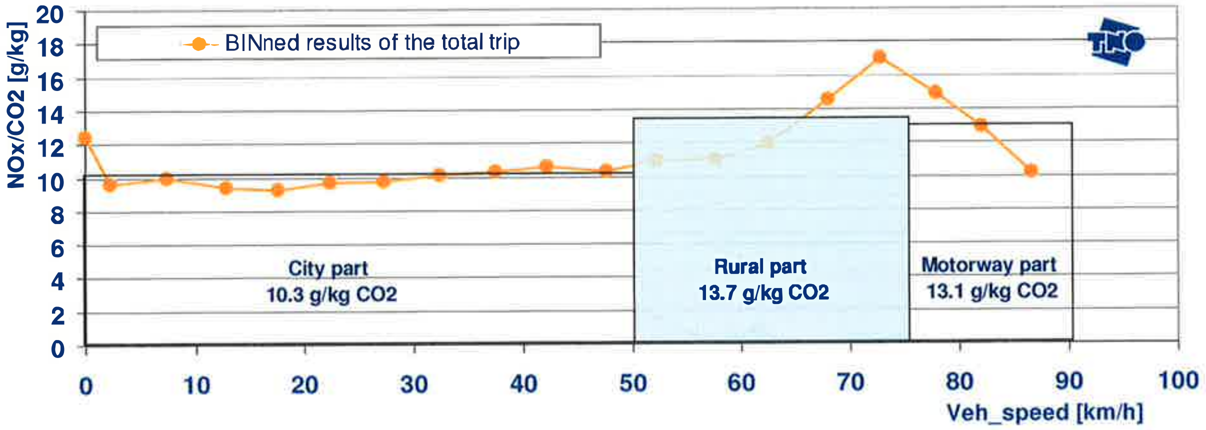


Figure 5: Emissions in the different parts of the Euro VI trip compared with the binned results – Vehicle J

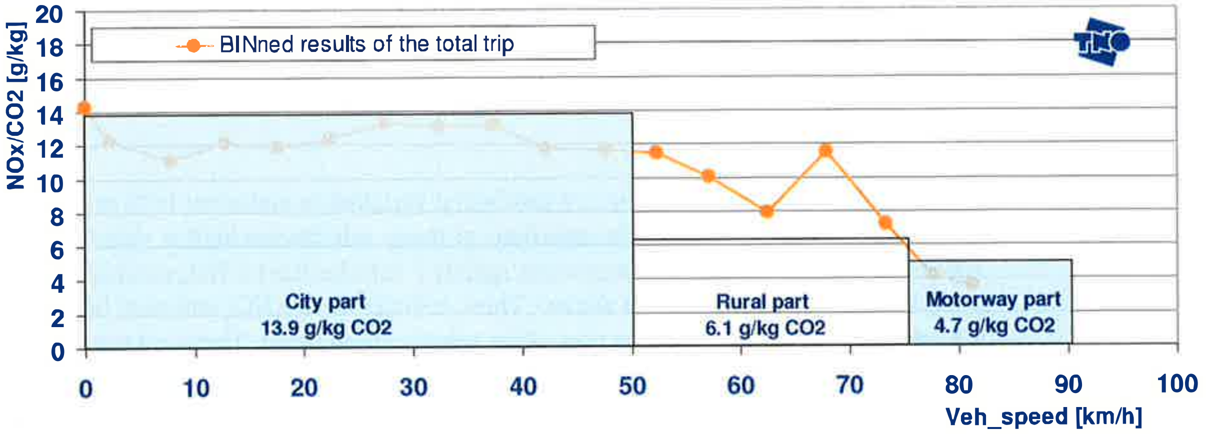


Figure 6: Emissions in the different parts of the Euro VI trip compared with the binned results – Vehicle K

2.4 Results of the binning method

The NO_x binning results of the 11 trucks and 1 bus with 50% payload[3] are presented in Figure 7. It appears that there is a wide variation of (real-world) NO_x emissions, in this Figure expressed in CO_2 specific NO_x emissions. It can be seen that the NO_x emissions vary from around 2 g/kg CO_2 for the best vehicle (the bus) to around 14 g/kg CO_2 over a large part of the vehicle speed range for one of the trucks despite the fact that these vehicles are either Euro V or EEV and complying with the same NO_x emission limit. For all but two vehicles, there is a trend of lower NO_x emissions with increasing speed.

The CO_2 specific emission results can be related to brake specific emissions assuming a constant average engine efficiency and fuel composition. With an average engine efficiency of 40% (BSFC = 200 g/kWh), the g/kg CO2 results can be divided by 1.6 to get a corresponding g/kWh result. Lower average engine efficiency lowers this factor and would thus increase the brake specific results accordingly.

For comparison, the Euro V NO_x emission limit of 2 g/kWh would amount to 3.2 g/kg CO_2.
When the ISC conformity factor is taken into account, this would amount to 4.8 g/kg CO_2.

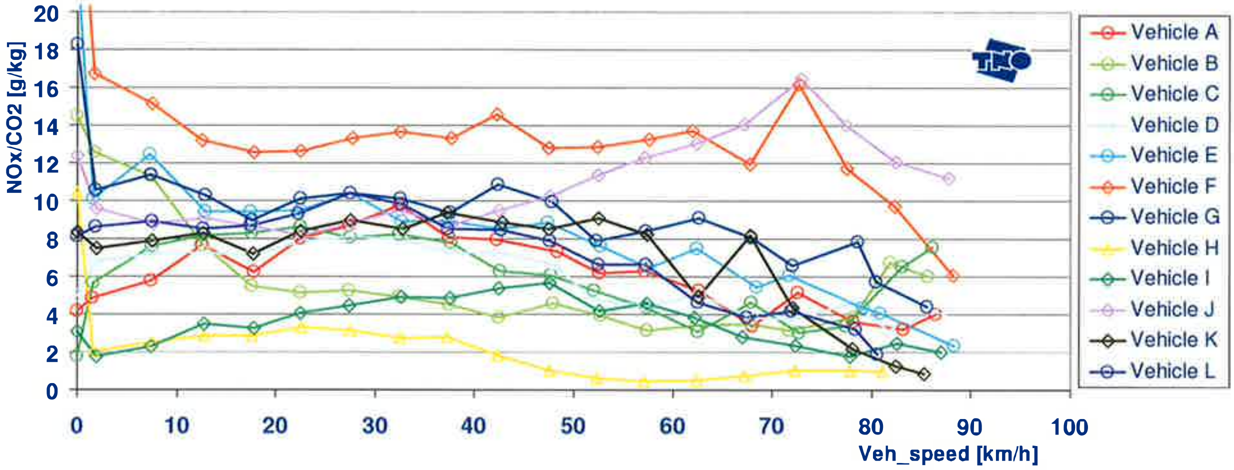


Figure 7: NO_x emission results for 11 trucks and 1 bus with 50% payload. All vehicles are Euro V or EEV except for vehicle J which is a Euro IV vehicle.

This comparison shows that there is a substantial variation in emissions between vehicles at all vehicle speeds. The emissions of many vehicles are high at vehicle speeds up to 60 or 70 km/h. At motorway speeds 7 vehicles have a NO_x emission below 4.8 g/kg CO_2. (refer to the cadre above). Three vehicles have a NO_x emission below 4.8 g/kg CO_2 across all or a large part of the vehicle speed range. These are truck I and bus H (at all speeds) and truck B (at speeds between 20 and 75 km/h). These trucks demonstrate that it is technically possible to have reasonable or good emissions during most real-world conditions.

---

[3] Payload according to ISC PEMS requirements

Within the following paragraphs, the influence of payload and trip composition is presented, since these are factors that could substantially influence the results.

2.4.1 *Influence of the payload on the emission results*

Four examples of the effect of the vehicle payload on the emissions are presented in Figure 8 to Figure 11. The first two are examples of trucks with a low or moderate influence of payload on NO_x emissions (NO_x in g/kg CO_2). With the other two trucks (Figure 10 and Figure 11) the influence of the payload is relatively large. With the lowest payload the specific emissions are 20% to 60% higher than with 50% or 100% payload. It can be seen that for vehicles with a low CO_2 specific NO_x emission (Figure 8 and Figure 9), the influence of payload on the emissions is small.

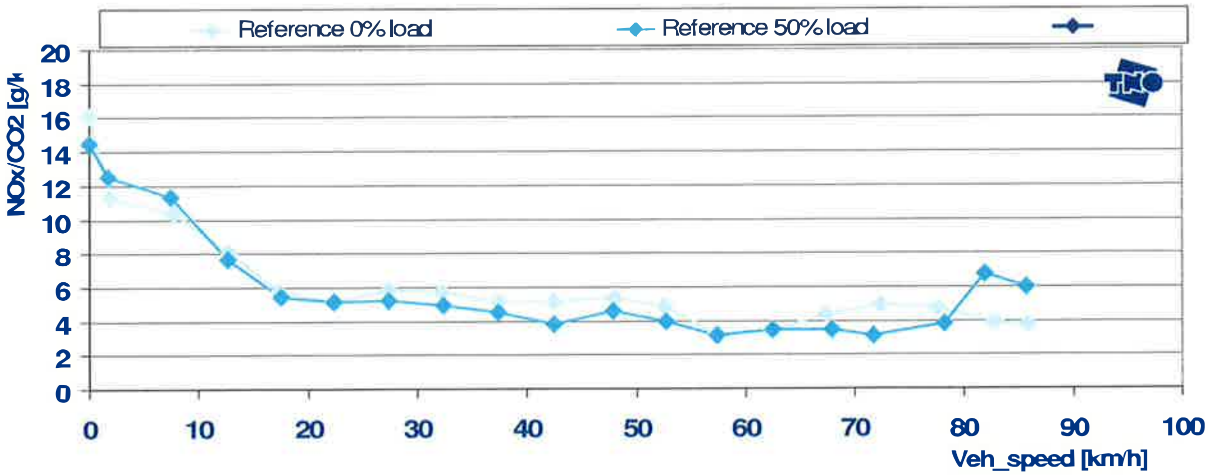


Figure 8: Effect of the payload on the NOx emissions – Vehicle B

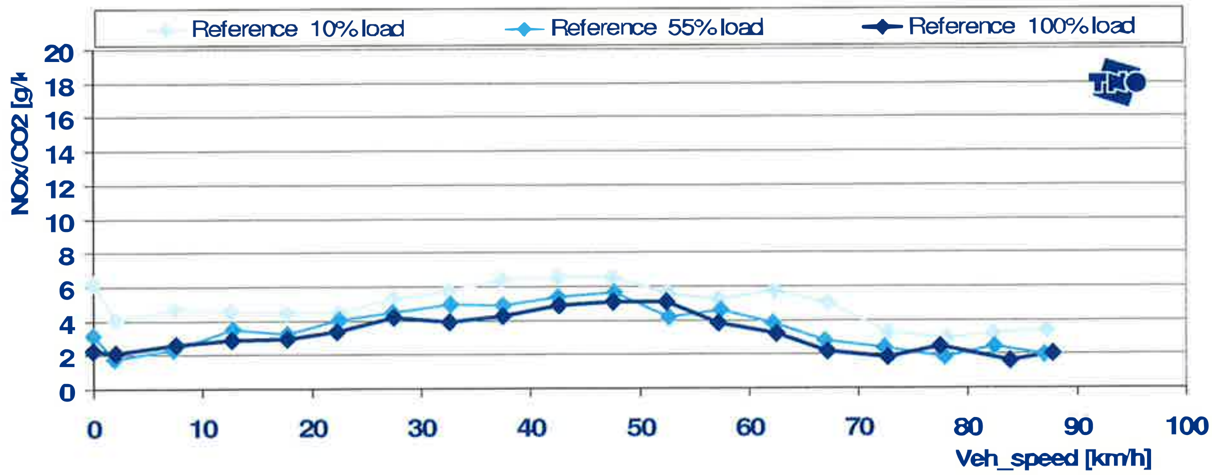


Figure 9: Effect of the payload on the NOx emissions – Vehicle I

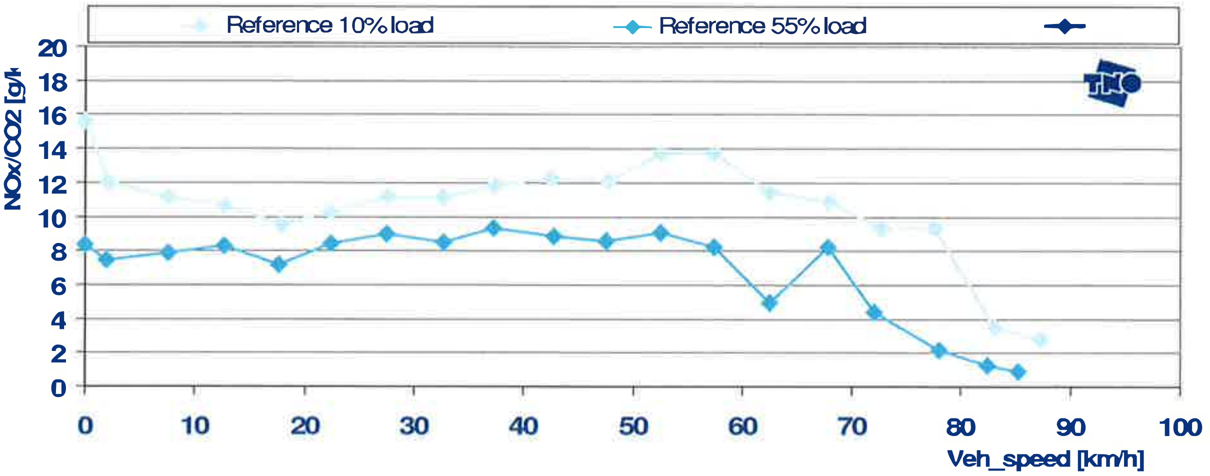


Figure 10: Effect of the payload on the NOx emissions – Vehicle K

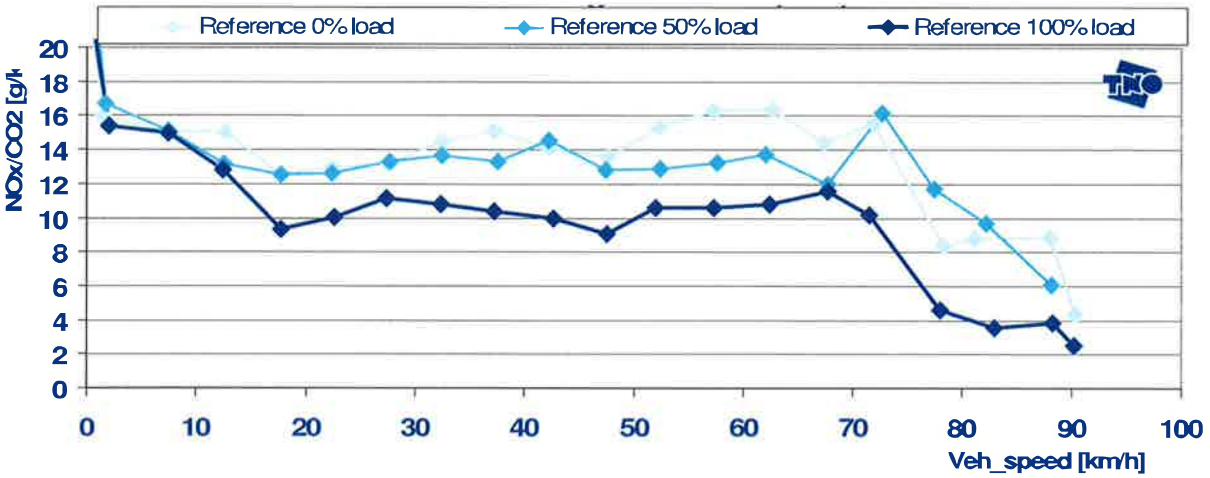


Figure 11: Effect of the payload on the NOx emissions – Vehicle F

2.4.2 *Combinations of trips with different payloads*

The effect of emissions on the air quality is not immediately clear when the emissions are expressed as brake or CO_2 specific emissions. For example, an empty truck may have high brake specific emissions, but low total emissions because the amount of power developed is low.

To show the effect of different payloads on air quality, the emissions are therefore usually expressed in either [g/km] or [g/s]. Figure 12 shows that the emissions in g/km with different payloads from a repeated reference trip with the same vehicle are equal at low vehicle speed, but at higher speeds the emissions with the lower payload exceed those of the higher payload.

Figure 12 and Figure 13 also show the effect of combining the emission results from this repeated reference trip with the same vehicle and different payloads. The masses of the emissions of both trips were combined in the speed bins to determine the CO_2 specific emissions. The fact that the combined result lies between the results of the separate trips, confirms that the emissions of the 10% payload trip cannot be neglected relative to those of the trip with 55% payload.

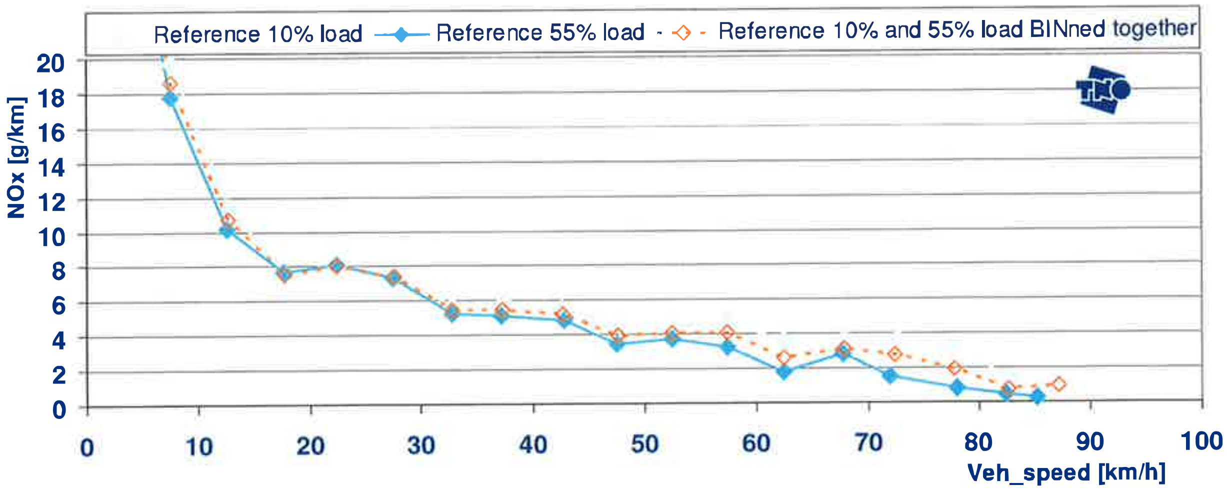


Figure 12: Effect of the payload on the NOx emissions in [g/km] - Vehicle K reference trips with different payloads combined.

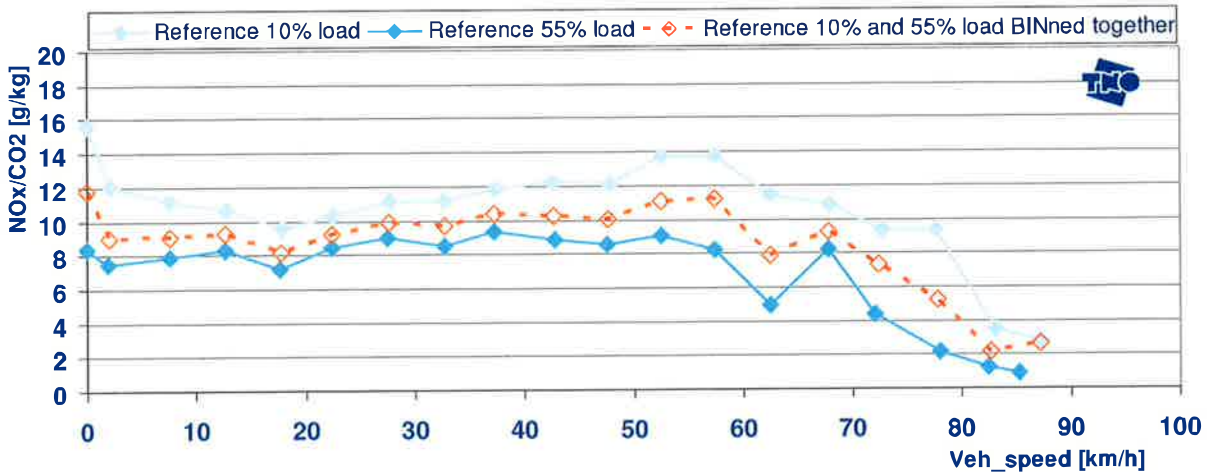


Figure 13: Effect of the payload on the NOx emissions – Vehicle K reference trips with different payloads combined.

2.4.3 *Influence of the trip on the emission results*

In order to explore the influence of the specific trip on the emission results, the results for three different trips are presented for three trucks in Figure 14, Figure 15 and Figure 16. Ideally the trip type would not have an influence on the results of the evaluation method. This is to a large extend true for the trucks in Figure 15 and Figure 16.

For the first truck (Figure 14) there is a relatively large difference of up to 50% at all vehicle speeds. It can also been seen that the emissions characteristic of a truck across the speed range is maintained and that the difference between truck types is larger than the difference between the trips with one truck.

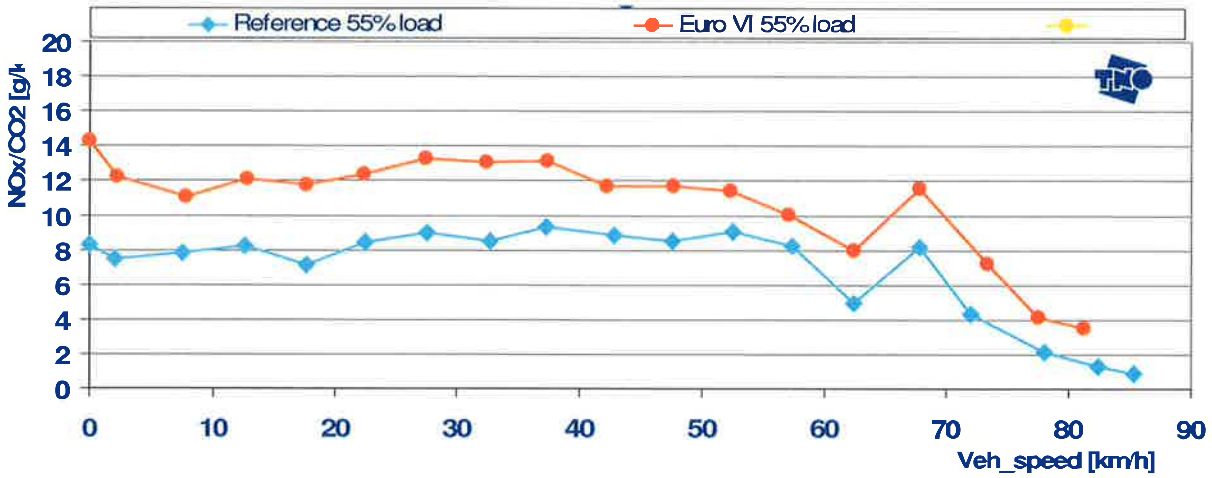


Figure 14: NO_x emission results from Vehicle K for different trips: TNO reference and Euro VI trip A

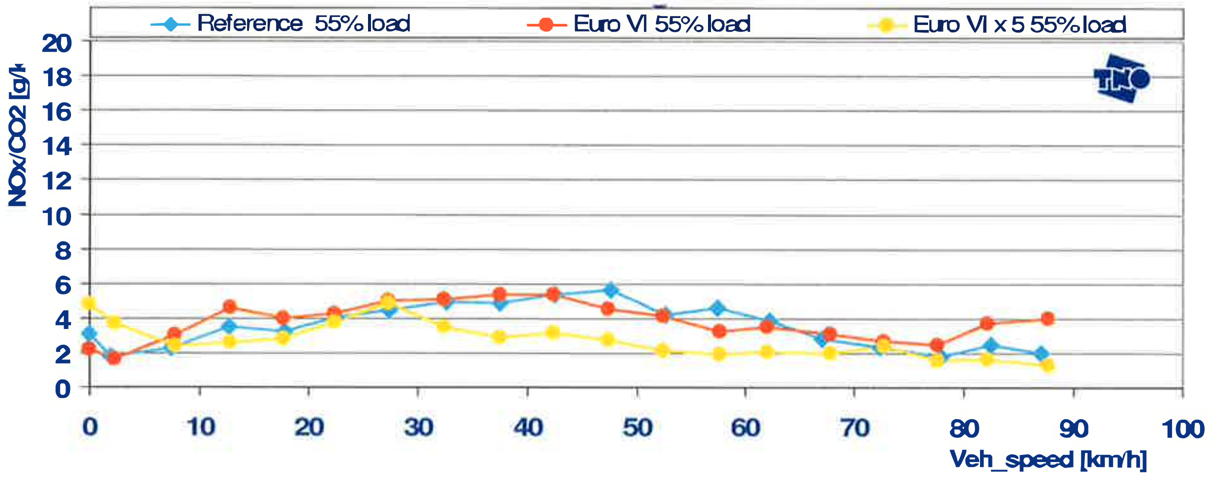


Figure 15: NOx emission results from Vehicle I for different trips: TNO reference and Euro VI trips A and B

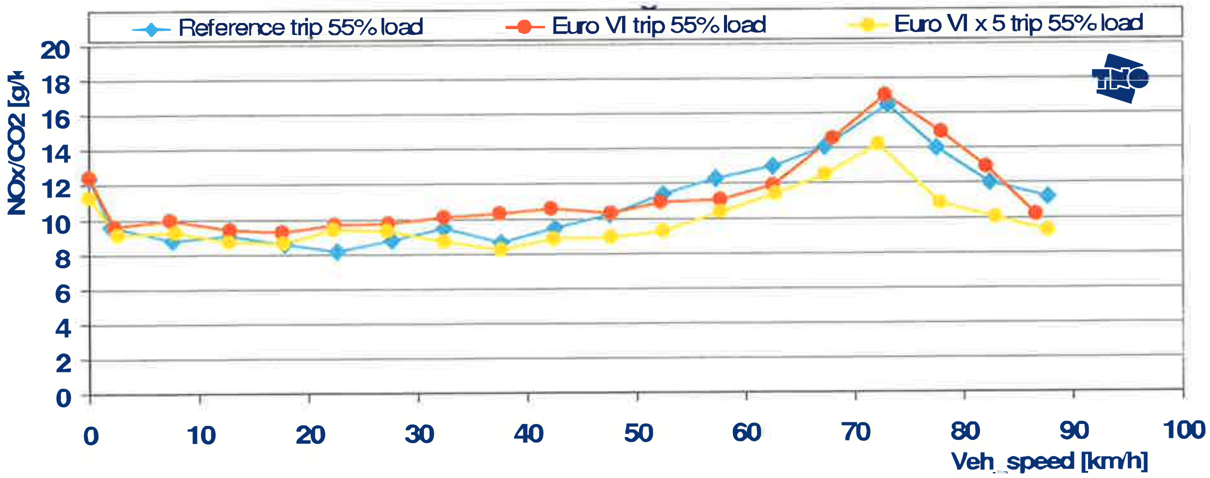


Figure 16: NOx emission results from Vehicle J (Euro IV) for different trips: TNO reference and Euro VI trips A and B

Another example of the influence of different trips comes from a city bus driven on three different lines through a city in the Netherlands. Figure 17 shows that the NO_x emission results of the different trips are very close. Up to a speed of 20 km/h some differences can be seen, but above that speed the emissions across different trips are very close.

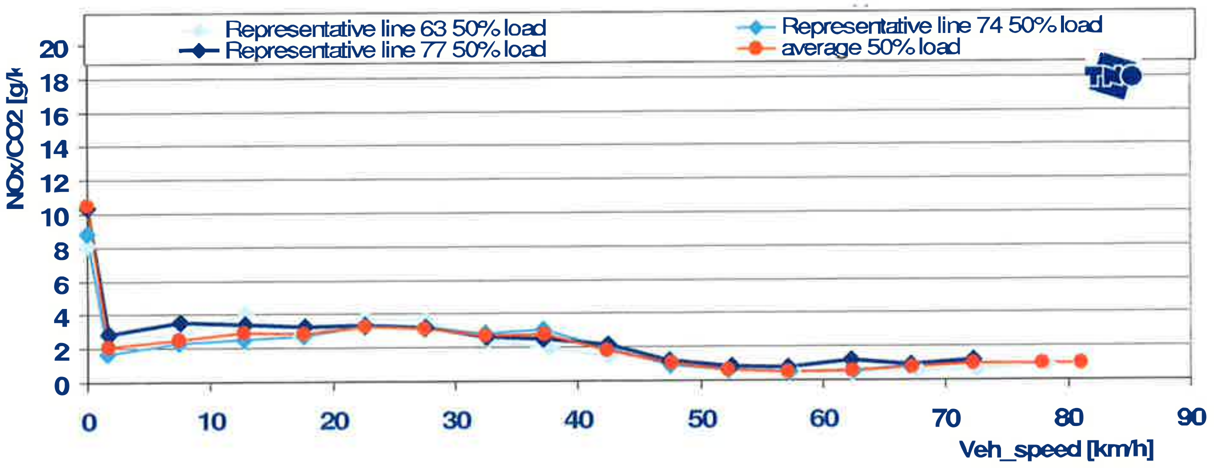


Figure 17: NOx emission results from Vehicle H for different bus lines within a city

The graphs for the Euro V vehicles (Figure 14, Figure 15 and Figure 17) indicate that for vehicles with low NO_x emissions (Figure 15 and Figure 17), the influence of the trip composition is small. On the other side a vehicle with a high NO_x emission (Figure 14) is sensitive to the trip composition. This is the same trend as was seen in paragraph 2.4.1, with the influence of payload: this influence is small for vehicles with a relative low NO_x emission

2.5 In service conformity

This chapter deals with the PEMS results of the tested Heavy Duty vehicles, applying the currently proposed In-Service Conformity checking methodology.

2.5.1 *Method used*

The pass-fail evaluation method has been applied, using the EMROAD tool (version 4 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 according to the draft In-Service Conformity rules. The next table shows the settings as used for the pass-fail data evaluation with EMROAD. For the data-evaluation the CO_2 method was used because from most vehicles not enough CAN data was available to estimate the work from a calculation of the ECU torque and engine speed signal. In one case no CAN signal was available at all. In about 75% of the cases a complete set of required torque signals was lacking (mostly reference torque and friction torque). Instead of the Work based window method the CO_2 window method, can be used to calculate the Conformity Factor in a different way, without having to rely on the availability of torque data from the ECU [DG ENTR, 2010].

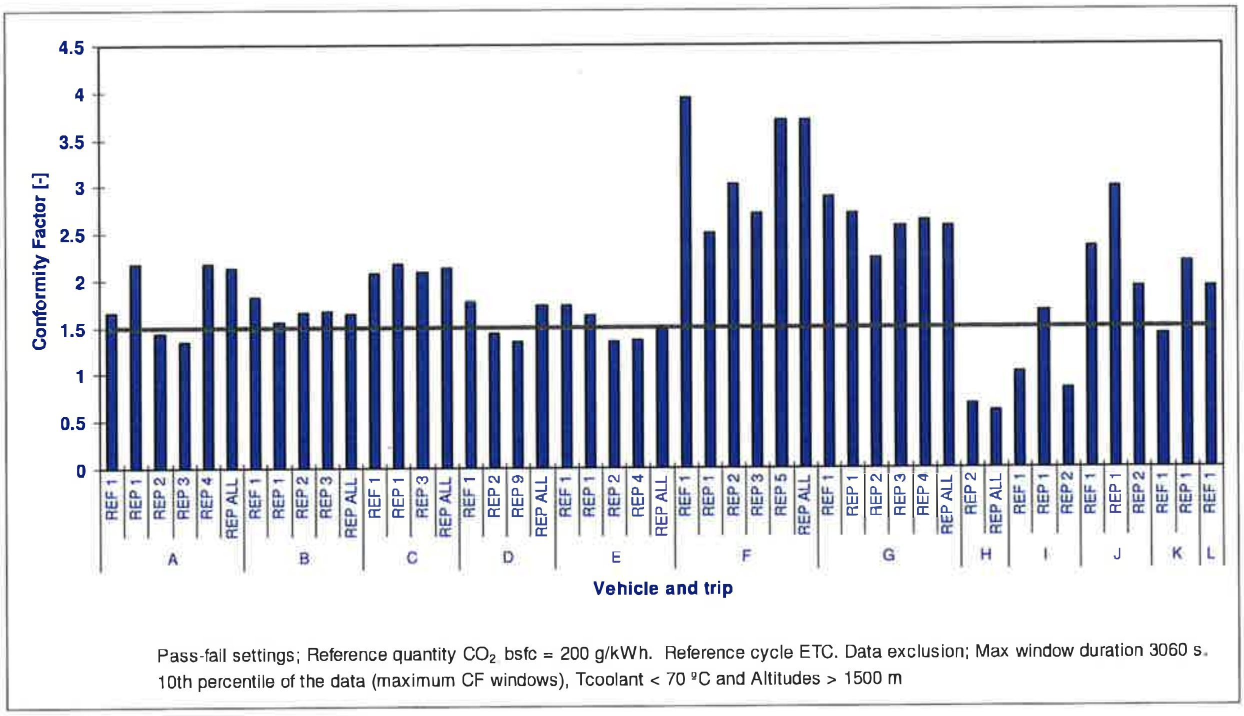
Table 3: Overview of the EMROAD data evaluation settings.

EMROAD version	4.0 build 8
Reference quantity	CO_2 mass
Reference cycle	ETC (average cycle power 34%)
CO_2 estimation	200 g/kWh bsfc
Data exclusion	Engine coolant temperature < 70 ºC, Altitudes > 1500 m, 10th percentile of the maximum values of the valid windows, Maximum window duration 3060 s
Time-alignment	On
Fuel density	0.84 kg/litre
Vehicles speed	GPS ground speed
Compliance factor	1.5

2.5.2 *Results of the ISC data evaluation*

The main results are summarised in Figure 18 and Table 4. These show the results of the exercise with the EMROAD tool and the proposed pass-fail evaluation method and settings. In Figure 18 both reference trips (REF 1) as representative trips (REP) with about 50% payload are presented. For the representative trips the results of the sub trips are shown (REP 1, REP2 ...) as well as the result over the complete trip (REP ALL). In general large differences can be observed between vehicles, but in some cases also between trips of one vehicle. The range observed for individual vehicles lies globally from a CF of 0.6 for the lowest value to 2.5 to 3.9 for the vehicle with the highest values. Vehicle H, the bus, was only tested on three actual bus lines within a city. Two of the eleven trucks have a CF below 1.5 during the reference trip. Assuming that the same results would be achieved on repeated tests these two trucks would pass the ISC procedure. One of these trucks has poor real-world urban emission results.

The sensitivity to the trips of the ISC evaluation method is quite large, since six vehicles have one or more trips with a conformity factor below 1.5.
For a real ISC evaluation at least 4 vehicles should be tested on the same route to prove a definitive compliance (3 fails for non-compliance). The results below are therefore just an indication of the ISC performance of a group of vehicles tested with PEMS.



Pass-fail settings; Reference quantity CO_2 bsfc = 200 g/kWh. Reference cycle ETC. Data exclusion; Max window duration 3060 s. 10th percentile of the data (maximum CF windows), Tcoolant < 70 ºC and Altitudes > 1500 m

Figure 18: The NOx conformity factors of the vehicles tested. Results are shown for a reference trip (REF 1), for representative sub-trips (REP 1, 2, 3…) and for complete representative trips (REP ALL).

Table 4: EMROAD result information for the reference trips of the different vehicles

	legislative category	90-percentile NOx Conformity Factor [-]	NOx MAX Conformity Factor [-]	% valid windows [%]	Data coverage index	min window duration [s]	max window duration [s]	number of valid windows
Vehicle A	V B2(E)	1.65	1.83	95	98	1698	3060	3677
Vehicle B	V B2(G)	1.83	1.91	99	100	1847	3060	3686
Vehicle C	V B2(G)	2.07	2.18	79	89	2147	3060	2779
Vehicle D	V B2(D)	1.77	1.80	85	92	2076	3060	2763
Vehicle E	V B2(D)	1.73	2.19	76	86	2170	3060	2869
Vehicle F	EEV C(I)	3.94	4.24	100	100	1725	2932	3218
Vehicle G	V B2(D)	2.85	3.02	100	100	1602	3029	4129
Vehicle H	EEV C(I)	0.60	0.66	70	89	2817	3221	8608
Vehicle I	V B2(G)	1.03	1.16	100	100	1751	3060	3969
Vehicle J	IV B1(C)	2.36	2.40	100	100	1610	2432	3828
Vehicle K	V B2(G)	1.43	1.61	68	83	2622	3060	2155
Vehicle L	V B2(D)	1.93	2.31	69	80	1949	3060	3516

2.6 Discussion

The speed binning method appeared to be a robust method to evaluate real-world emissions and to provide suitable input for emissions modelling. This is demonstrated by the comparison with the different parts of the trips measured (paragraph 2.3.3) and also by the fact that with constant performing vehicles the results are quite independent of the trip composition and even payload (for CO_2 specific NO_x emissions) (paragraph 2.4).

The PEMS results in paragraph 2.4 show that there is a large variation in real-world NO_x emissions. Especially during urban and rural driving conditions, the real-world NO_x emissions are generally high. Only one truck and the city bus perform well under all conditions. A second truck performs quite well between 20 and 75 km/h. The results also show that when the real-world emissions are low, the sensitivity towards the payload and the trip composition is also low.

The ISC results (paragraph 2.5.2) confirm the relatively high NO_x emissions. Only two trucks would pass ISC ($CF \leq 1.5$) on the reference trip. In addition a considerable variability between the different trips is shown. Six vehicles would pass when the best trip results are selected. Comparison of the CF's with the (vehicle speed dependent) real-world emissions shows the following:

- vehicles H and I have good real-world NO_x emissions and very low CF's (0.6 en 1.03)
- vehicle K, does not have good real-world emission emissions but the CF is 1.43
- vehicle B, has quite reasonable real-world emissions between 20 and 75 km/h, but the CF is 1.83

The differences for vehicle K can be explained by the number of valid windows (Table 4), which can be as low as 68%. This means that mainly the measured emissions data from rural and highway operation is used for the ISC, while with the binning method 100% of the valid data is used.

2.7 Conclusions

Ten Euro V trucks, one Euro IV truck and one Euro V/EEV bus were tested with a PEMS (Portable Emissions Measuring System) during various trips and with various payloads. A vehicle speed binning method was used as a methodology to assess real world emissions and to provide input for air quality modelling. This lead to the following conclusions:

- Binning of exhaust emissions collected with PEMS appears to be a robust method to assess real-world NO_x emissions under different driving conditions and to provide input for traffic emissions modelling.
- Many Euro V trucks show a poor real-world NO_x performance during urban and rural driving conditions, despite acceptable ISC factors in one case.
- Some vehicles of later Euro V series do show a good NO_x performance under all or almost all driving conditions, but others have a very poor NO_x performance.
- The vehicles with good NO_x performance were less sensitive to trip composition and differences in payload.
- The current ISC PEMS procedure is not always able to detect vehicles with poor real-world emission performance, and may also sometimes reject vehicles with acceptable real-world emissions depending on the trips used.

3 Evaluation of the NO_x emissions of vehicle fleets on the basis of AdBlue consumption

3.1 Background and aim

The PEMS results presented in the previous chapter were limited to a relatively small number of vehicles. In this chapter the AdBlue consumption is analysed of a larger number of vehicles. The real world AdBlue consumption gives an indication of the NO_x reduction of the SCR catalysts and consequently can give an indication of the real-world tailpipe NO_x emissions.

In particular the aim of this analysis is on the following points:

- How does the recorded AdBlue consumption compare to the AdBlue consumption specified by the manufacturers. A relatively low AdBlue consumption would indicate a relative high NO_x emission.
- How does the estimated NO_x emission based on the AdBlue consumption compare to the PEMS results.

Below, the method of data analysis is outlined, and the most important results are shown.

3.2 Analysis method and assumptions

With SCR deNO_x the most important reactions are the hydrolysis of urea leading to the formation of NH_3 and the SCR reaction itself when NO and NO_2 react with NH_3 and form N_2 and H_2O.
The stoïchiometry of the reactions is slightly dependent on which reaction path is followed. In practice a nominal ratio of 2.0 is used, taking into account the urea mass percentage of 32.5% in the urea solution (AdBlue). This means that a nominal 2 g AdBlue per g NO_x conversion is consumed at a reaction efficiency of 100%.

The overall calculation is presented in Table 5 below. Per kWh 2 g AdBlue is needed to reduce 1 g of NO_x. With the assumption of a specific fuel consumption of 200 g/kWh for a heavy-duty diesel engine, this corresponds to an AdBlue quantity of 1 mass % of the fuel quantity. Taking into account the density of AdBlue and fuel, respectively 1.09 kg/dm^3 and 0.845 kg/dm^3, it can be calculated that a volume of 0.78% of AdBlue per volume of fuel is required to reduce 1 g/kWh of NO_x.

Table 5: Amount of AdBlue needed to reduce 1 g/kWh of NO_x

NO_x reduction	AdBlue consumption	AdBlue/fuel	AdBlue/fuel
g/kWh	g/kWh	mass%	Volume%
1	2.0	1.0%	0.78%

The relation between NO_x reduction and AdBlue consumption is linear. This is depicted in Figure 19. An assumption is made for the engine out NO_x emission. For this analysis an engine out NO_x emission of 9 g/kWh is used which is supported by [Mueller, 2001], [Frank, 2003] and [Cloudt, 2009]. The AdBlue consumption specified by the truck OEMs is within the range of 5.5% to 7% for Euro V trucks depending on the truck type. This fits within the bandwidth of Figure 19 and confirms the approximately 9 g/kWh engine out NO_x level.

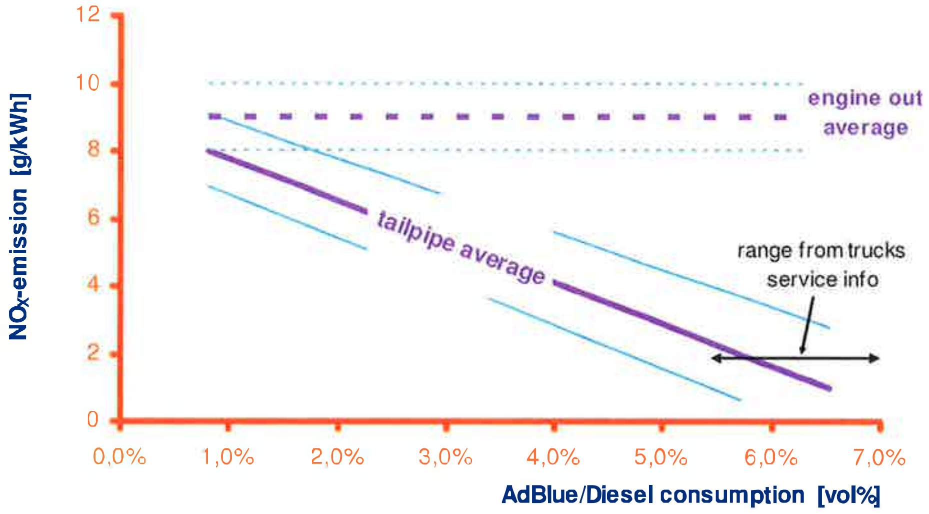


Figure 19: Relationship between relative AdBlue consumption and tailpipe NO_x-emissions.

3.3 The vehicle fleets

AdBlue consumption data was obtained of 315 HD vehicles. After evaluation of the data 169 vehicles were judged to be reliable and consistent. These vehicles were used for the evaluation. The 169 vehicles come from five different vehicle fleets (3 for freight transportation and 2 for public transportation).

An overview of the truck fleets used for the analysis is presented in Table 6. The table also lists the number of vehicles per emission category; Euro IV, Euro V or EEV. The majority of the vehicles are Euro V or EEV vehicles which are developed to the same NO_x standard.

Table 6: Overview vehicle fleets

Fleet	1	2	3	4	5
Number of vehicles	19	69	12	40	29
Type	Distribution trucks	International transport	International bulk transport	City bus	City bus
Euro IV	3	0	0	0	0
Euro V	16	69	12	19	0
EEV	0	0	0	21	29

3.4 Results

Only the data from the Euro V and EEV vehicles is used for the evaluation in this chapter. The results of the data analysis per vehicle fleet are summarised in Table 7. This includes the time period, the total driving distance, the fuel and AdBlue consumption and the AdBlue/diesel volume ratio. The estimated NO_x emissions are also included. The estimation is based on an engine out NO_x level of 9 g/kWh. The engine-out NO_x emissions of the bus fleets may be 1 to 1.5 g/kWh lower because these engines could have been optimised for low emissions during city driving. The total driving distance of the 166 vehicles during the period evaluated is 8.700.000 kilometres.

Table 7: Overview of the analysis results per fleet

Fleet	1	2	3	4	5
Number of vehicles	16	69	12	40	29
Type	Distribution trucks	Int. transport	Int. bulk transport	City bus Euro V / EEV	City bus EEV
Registration time [month]	3	5	7	12	12
Average distance per vehicle [km]	15715	42182	78966	61563	73176
Total distance [* 1000 km]	251	2911	948	2463	2122
Fuel cons. [l/100 km]	26.4	33.3	31.7	42.5	56.8
AdBlue consumption [l/100 km]	0.83	1.35	1.02	1.18	1.35
AdBlue / fuel [vol%]	3.0	4.1	3.2	4.5 / 1.8	2.4
Estimated NO_x emission* [g/kWh]	~5	~4	~5	~3 / ~ 7	~6

* based on engine out NO_x emission of 9 g/kWh

The relative AdBlue consumption for all vehicles is plotted in Figure 20. The AdBlue consumption varies between less than 0.5% and 5.7 vol%. The vehicles within a fleet generally group together in a certain fuel and AdBlue consumption range. For the fleets grouped together the vehicles are generally from the same brand and type. Also driving pattern and payload are often comparable. Exceptions are the distribution trucks for which the types and age vary. Figure 20 shows that there are large differences between vehicle types and applications. It can be concluded that for international transport and for fluid bulk transport, the relative AdBlue consumption is frequently on a level of 3-6%, which is on or not far below the level indicated by the truck OEM's.

For trucks used in a mix of national and international distribution and for city buses, the variability is very large with around 50% of the vehicles with less than 3% relative AdBlue consumption. So compared to the manufacturers specifications (5.5% to 7% AdBlue consumption), real-world AdBlue consumption varies more strongly and is often on a low level. This indicates high real-world NO_x emissions in a number of cases.

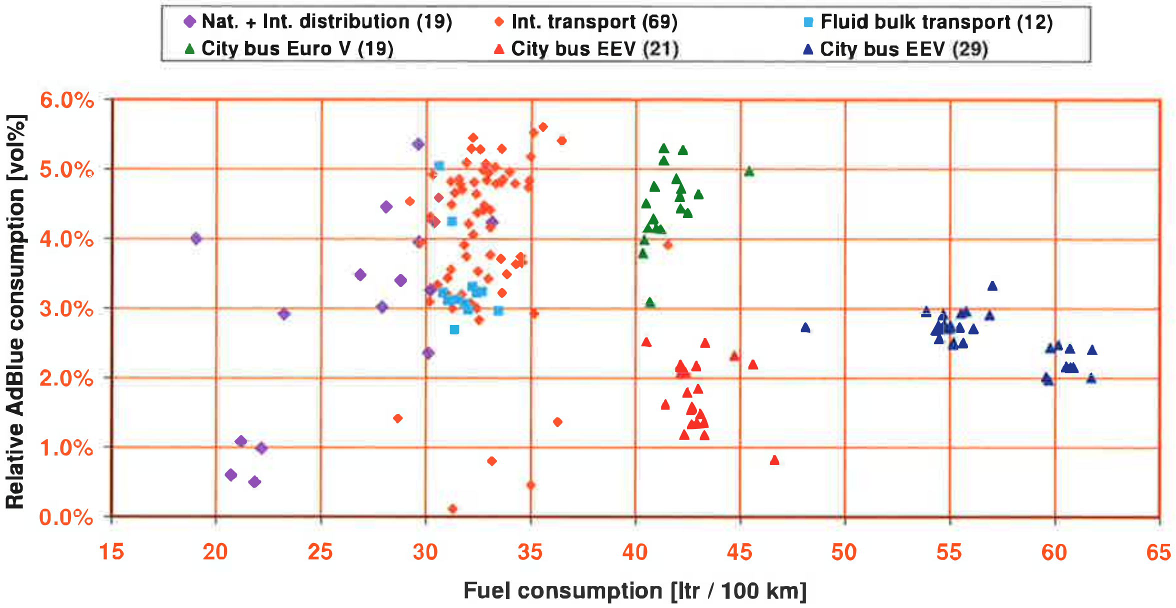


Figure 20: Fuel and AdBlue consumption per fleet (166 vehicles)

Below three figures are presented in order to investigate a possible correlation between AdBlue consumption and the following parameters:

- Specific power in kW per tonne total vehicle weight
- Maximum power (engine rated power)
- Year of first registration

Figure 21 shows the AdBlue consumption for the different truck and bus applications as a function of specific power in kW per tonne of total vehicle weight. In general there is no clear relationship between AdBlue consumption and specific power.

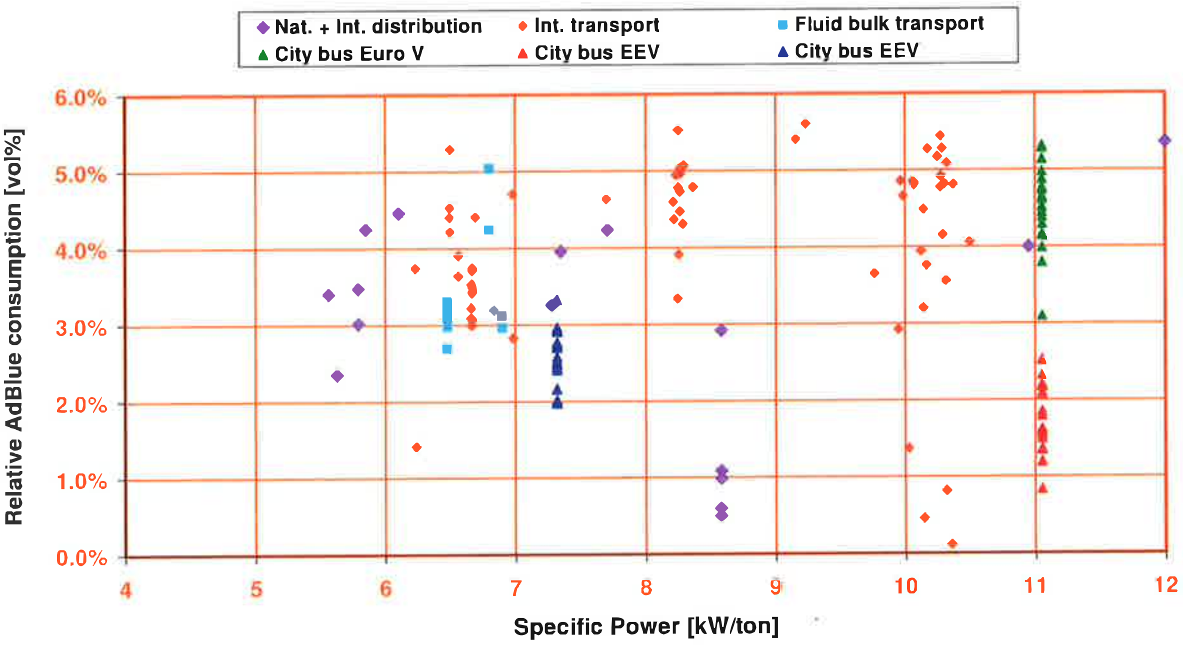


Figure 21: AdBlue consumption as a function of specific power in kW per tonne total vehicle weight

Figure 22 shows the AdBlue consumption as a function of maximum engine power. The AdBlue consumption tends to increase on average with engine power, although there are still some 300 kW vehicles with low AdBlue consumption. Of course heavier powered vehicles (>300 kW) are more often used for international transportation and operate under relatively high load conditions. These conditions are more favourable for an SCR after treatment system. In general there is no clear relationship between AdBlue consumption and power.

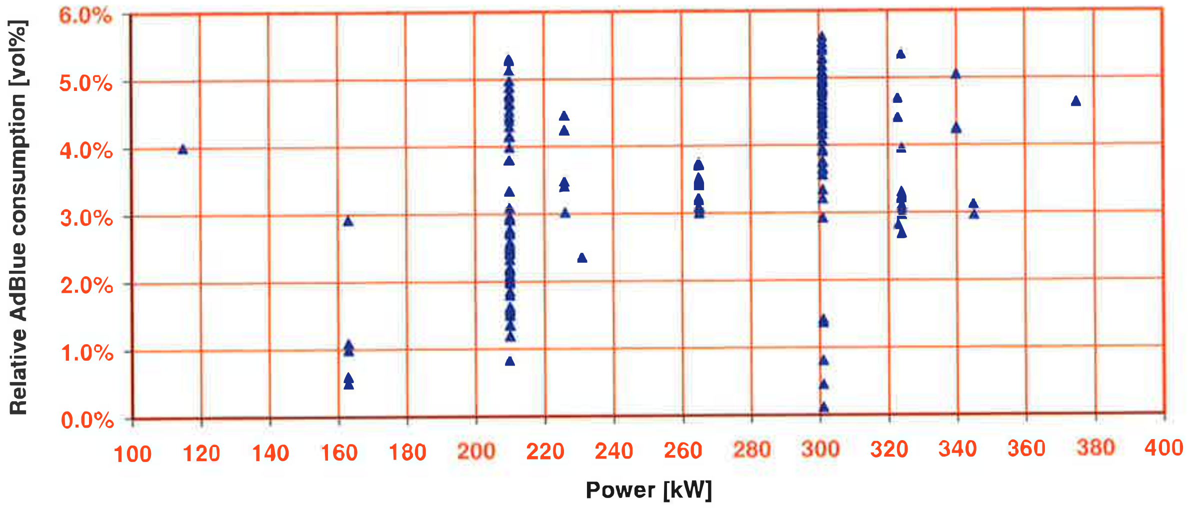


Figure 22: AdBlue consumption as a function of engine power

Figure 23 shows the AdBlue consumption in relation to the age of the vehicles. It can be seen that most of the vehicles are from the years 2007 and 2008 and to a lesser extent 2006. The bus fleets within this were all from 2007 and 2008. From the figure, it can be concluded that for trucks registered in 2009 and 2010 (with all Euro V legal requirements), there are fewer trucks with a very low AdBlue consumption of below 3% than for trucks registered in 2006. However for 2009 and 2010 less data was available.

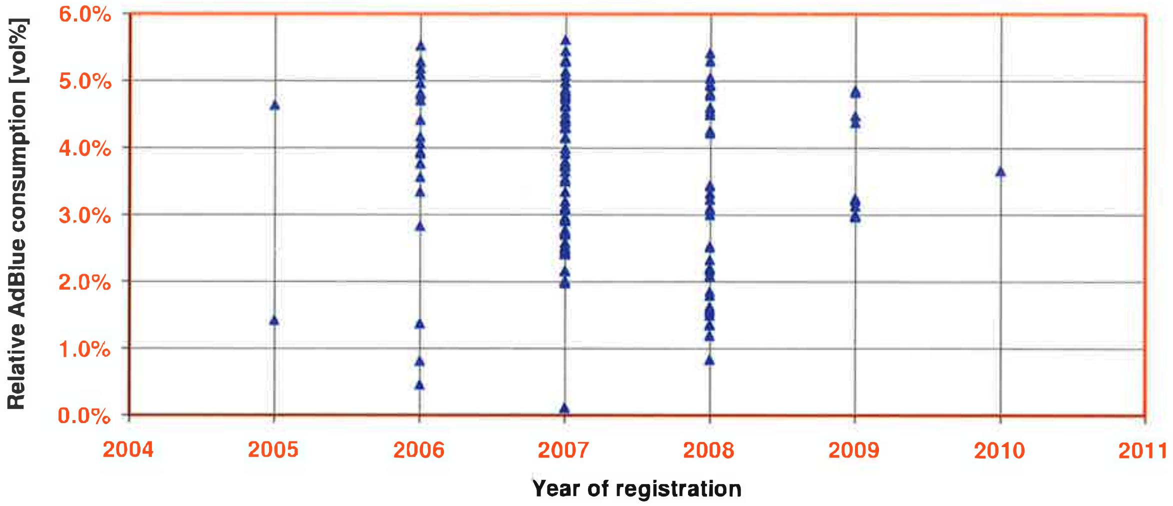


Figure 23: Registration year of the trucks and buses in the investigation

3.4.1 *Estimated NO_x emission*

The average NO_x emission per vehicle fleet is presented in Table 7. This is based on an engine out NO_x level of 9 g/kWh. The estimated NO_x varies from 3 to 4 g/kWh for one of the bus fleets and international transport to about 5 g/kWh for the distribution trucks and about 7 g/kWh for one of the bus fleets. The number of vehicles and fleets per category are however too small to use this as representative numbers for these categories.

Within the figures, for example in Figure 20, sub groups can be distinguished with lower or higher NO_x emissions. For example one of the bus sub groups has an average AdBlue consumption of 1.8% which corresponds to a NO_x level of about 7 g/kWh. Another bus sub group has an average AdBlue consumption of 4.5%, which corresponds to a NO_x level of about 3 g/kWh.

3.5 Discussion

The results demonstrate that the relative AdBlue consumption of the trucks and buses varies strongly from values as low as 0 or 1% to about 5.5% of the fuel consumption. Comparing this range with the range calculated above and also specified by the vehicle manufacturers (5.5% to 7%), it can be concluded that the average real-world NO_x emission is likely to be higher than intended.

Looking at the fleets within this investigation, there seems to be no particular difference with respect to the bandwidth of AdBlue consumption between the truck and the city bus fleets. There are however more buses with a very low consumption (e.g. below 3%) than trucks.

An explanation for the low AdBlue consumption of a number of fleets can be that the average in-use load is rather low. This would lead to rather low exhaust gas and catalyst temperatures during certain periods of use. During these periods the AdBlue consumption might be relatively low or even switched off. This is confirmed by Figure 20. It can be seen that the trucks used for international transport and fluid bulk transport on average consume more AdBlue than trucks used for national and international distribution. Motorway driving and the relatively heavy bulk transport usually leads to higher average engine load and better operation of the SCR system than distribution transport.
The figures however also show that for most applications, there are sub-groups or individual vehicles with a quite reasonable AdBlue consumption of 4% or higher. Consequently the real-world average NO_x emission would be in the order of 4 g/kWh or better.

The correlation of the AdBlue consumption with a number of parameters such as specific power, max engine power and GVW was investigated. From this it appeared that there is a weak correlation with max engine power and GVW. The higher powered and heavier vehicles are more often used for international transport, which would also lead to a higher average load and better operating conditions for the SCR catalyst.

The relation between the age of the vehicle and the AdBlue consumption (Figure 23) shows that between the trucks registered in 2009, there are fewer trucks with a very low AdBlue consumption of below 3% than among the trucks registered in 2006. This may indicate an improvement of the real-world NO_x emissions for newer trucks.

3.6 Conclusions

The AdBlue consumption data of 3 truck fleets and 2 bus fleets were analysed. Most trucks were Euro V vehicles, while the buses were either Euro V or EEV. Based on the AdBlue consumption the real-world NO_x emissions were estimated.

The conclusions with respect to the Euro V and EEV vehicles are:
- The AdBlue consumption varies strongly depending on the particular vehicle from about 0.5% to a maximum of about 5.5%
- The average AdBlue consumption is 30-50% lower than specified by the manufacturer, which indicates a relatively high real-world NO_x emission.

Based on an assumed average engine out NO_x level of 9 g/kWh the following is concluded with respect to the real-world NO_x emission:
- Depending on the vehicle fleet the average NO_x emission varies from about 4 g/kWh for the best performing fleet (international transportation) to nearly 7 g/kWh for one of the city bus fleets.
- Within these fleets there are sub-groups with lower or higher NO_x emissions.
- The large variation of AdBlue consumption between several vehicles indicates that the NO_x reduction of the SCR system is apparently not optimal under certain operating conditions (payload and driving pattern).

This is likely to be influenced by vehicle/engine characteristics (power to weight ratio, cylinder displacement to weight ratio, SCR catalyst type, calibration etc.), although no clear correlation with one of these parameters was found.

4 Discussion

The primary aim of the program was to assess the real-world emissions of Euro V vehicles. This was primarily done by analyzing the results of measurements with a PEMS on 11 Euro V vehicles. In order to have a better statistical base, also the AdBlue consumption data of five fleets with a total of 166 vehicles was analysed.

The measurements with PEMS show that a) the difference in NO_x emissions between the vehicles is very large and b) many trucks have relatively high NO_x emissions at vehicle speeds up to about 60 or 70 km/h. Only three vehicles showed a low NO_x emission across all or most of the vehicle speed range. These trucks demonstrate that it is technically possible to have low NO_x emissions under most driving conditions.

The findings of the AdBlue consumption evaluation confirm the results from the PEMS measurements in the sense that it also showed a large difference in AdBlue consumption depending on the specific vehicle type. The average estimated real-world NO_x emissions varied from about 4 g/kWh for the international truck fleet to about 5 g/kWh for distribution trucks and about 5-7 g/kWh for one of the bus fleets depending on the assumed engine-out NO_x emissions.

Important is the relationship with the year of registration of the vehicles, since the 2006 and 2007 Euro V vehicles were released under a less stringent OBD and additional NO_x control measures regime (paragraph 2.2.1). The AdBlue analysis showed that model year 2009 and 2010 vehicles may have lower NO_x emissions than older vehicles, although the number of vehicles to confirm this is rather small. It can be concluded that on average there might be some improvement with newer vehicle types, although the PEMS measurements show that also some newer vehicles have a rather high NO_x emission.

5 Conclusions

TNO conducted several programs to determine the real-world NO_x emissions of heavy duty vehicles. This consisted of:

- Two measurement programs with a PEMS (Portable Emissions Measuring System). In total 11 trucks and 1 bus were measured.
- Analysis of AdBlue consumption on 5 vehicle fleets with a total of 166 vehicles.

In general, the results show a large variability between trucks, in particular under urban conditions. Some trucks demonstrate the possibility of achieving low emissions under urban conditions, but the results also clearly show that this is not the case for most of the trucks.

The results of the PEMS measurements and the AdBlue consumption analysis support each other, both showing high variability. For all investigated applications which range from typical city transport (buses) to regional distribution and long haulage, there are vehicle types with low and with high real-world NO_x emissions under urban and rural driving conditions. During motorway operation many vehicles perform as expected.

6 References

[Ligterink, 2009]	Ligterink, N., et. al.: On-road NO_x emissions of Euro-V trucks, 2 December 2009, TNO report MON-RPT-033-DTS-2009-03840
[DG ENTR, 2007]	Portable Emission Measurement Systems (PEMS) Heavy-Duty Pilot Programme, Final Project Plan 2007
[DG JRC, 2007]	Bonnel P. et al.: Guide for the Preparation and the Execution of Emissions Road Tests on Heavy-Duty Vehicles - *Draft Version 3 - EU-PEMS Project Pilot Program*
[DG JRC, 2009]	Bonnel P. et al.: Evaluation of Pass-Fail Methods for Heavy-Duty Emissions Compliance Testing based on PEMS *EU-PEMS Project - Task 3 Report*
[DG ENTR, 2010]	F1 7808 PE EURO VI - Draft Commission Regulation (EC) No …/.. of […] implementing and amending Regulation (EC) No 595/2009
[Mueller, 2001]	Mueller and Keefe; Experience with SCR Technology for Diesel, Exhaust Emission Control of Trucks in Asia Europe and North America; http://www.meca.org/galleries/default-file/Mueller.pdf
[Frank, 2003]	Frank et. al., PUREM Technologies; SCR systems for Heavy Duty trucks progress towards meeting Euro 4 emission standards in 2005
[Vermeulen, 2010]	Vermeulen, R.J., et. Al.: Real World Exhaust Gas Emissions of N2 Distribution Trucks, October 2010, TNO report MON-RPT-2010-2396
[Cloudt, 2009]	Cloudt, R, et al.: SCR-only Concept for Heavy-duty Euro VI Applications, MTZ 2009, Vol. 70

7 Glossary

BS	Brake Specific
BSFC	Brake Specific Fuel Consumption
CAN	Controller Area Network (ECU network communication interface and protocol)
CF	Conformity Factor
CO	Carbon monoxide
CO_2	Carbon dioxide
DG ENTR	European Commission Directorate General Enterprise and Industry
DG JRC	EC DG Joint Research Centre
ECU	Electronic Control Unit
EEV	Enhanced Environmentally Friendly Vehicle (HDV emission standard)
ESC	European Steady state engine test Cycle
ETC	European Transient engine test Cycle
FC	Fuel Consumption
GVW	Gross Vehicle Weight
HC	Hydrocarbons
HDV	Heavy Duty Vehicle
ISC	In Service Conformity
IUC	In Use Compliance
MI	Malfunction Indicator
NH_3	Ammonia
NO_x	Nitrogen Oxide
OBD	On-Board Diagnostics
OCE	Off-Cycle Emissions
PEMS	Portable Emissions Measurement System
SCR	Selective Catalytic Reduction
TA	Type Approval
THC	Total Hydrocarbons
VROM	Dutch Ministry of Environment
WbW	Work based Window
WHDC	World-wide harmonised Heavy-Duty Certification
WHSC	World-wide harmonised Heavy-duty Steady state engine test Cycle
WHTC	World-wide harmonised Heavy-duty Transient engine test Cycle

8 Signature

Delft, 11 November 2010

TNO Science and Industry

B. Bos

Dr. B. Bos
Head of department

Ir. R.P. Verbeek
Author