Earth, Life & Social Sciences
Anna van Buerenplein 1
2595 DA Den Haag
P.O. Box 96800
2509 JE The Hague
The Netherlands

www.tno.nl

T +31 88 866 00 00

TNO report

TNO 2017 R11473

NOx emissions of eighteen diesel Light Commercial Vehicles: Results of the Dutch Light-Duty road vehicle emission testing programme 2017

Date	6 December 2017
Author(s)	Gerrit Kadijk Robin Vermeulen Edo Buskermolen Mitch Elstgeest Declan van Heesen Veerle Heijne Norbert Ligterink Peter van der Mark
Copy no	2017-STL-RAP-0100310530
No. of copies	
Number of pages	103
Number of appendices	-
Sponsor	Dutch Ministry of Infrastructure and Water Management PO Box 20901 2500 EX THE HAGUE The Netherlands
Project name	In Use Compliance Light & Heavy Duty Vehicles
Project number	060.04301 and 060.21429

Samenvatting

Dit rapport beschrijft de resultaten van metingen aan de praktijkemissies van Euro 5 en Euro 6/VI dieselbestelauto's en busjes voor personenvervoer. Praktijkemissies zijn emissies zoals deze optreden, rijdend met het voertuig, op de openbare weg. Het project waarbinnen deze metingen zijn verricht wordt door TNO uitgevoerd in opdracht van het Nederlandse Ministerie van Infrastructuur en Waterstaat.
TNO heeft dit soort metingen eerder uitgevoerd aan Euro 6 dieselpersonenauto's en aan Euro 5 dieselbestelauto's [TNO 2016c, TNO 2016d].

Net als bij Euro 6 personenauto's is gebleken dat de NO_x-uitstoot van Euro 6/VI dieselbestelauto's in de praktijk gemiddeld flink hoger is dan de NO_x-uitstoot gemeten tijdens de officiële typekeuringstest op de rollenbank. Voor Euro 6 liggen de NO_x-emissies van bestelauto's in absolute zin wel op een lager niveau dan voor Euro 5. Er blijkt een grote spreiding te zijn in de NO_x-emissies van de geteste voertuigen. Een aantal van de geteste Euro 6/VI bestelauto's liet in de praktijk NO_x-emissies zien die op of onder de voor de typekeuring geldende grenswaarden liggen. Ook de CO_2-uitstoot is gemeten. Gebleken is dat de CO_2-uitstoot in praktijktesten hoger ligt dan de typekeurwaarde.

De verwachting is dat de nieuwe 'Real Driving Emissions' (RDE) test, waarbij voor de typekeuring de emissies met mobiele meetapparatuur op de weg worden gemeten, zal leiden tot een lagere NO_x-uitstoot in de praktijk. Vanaf september 2017 wordt deze test met bijbehorende limietwaarden geleidelijk verplicht. In 2021 moeten alle nieuwe voertuigen aan de uiteindelijke RDE-norm voor de praktijk NO_x-emissies voldoen.

Het meetprogramma
Om negatieve effecten van de uitstoot van luchtverontreinigende stoffen en het broeikasgas CO_2 door het wegverkeer te verminderen, zijn er Europese normen voor de uitlaatgasemissies van wegvoertuigen. Ook is er Nederlands beleid om de toepassing van schone en zuinige voertuigtechnieken te stimuleren. Om de effectiviteit van dit beleid te kunnen beoordelen, voert TNO sinds 1987 in opdracht van het Nederlandse Ministerie van Infrastructuur en Waterstaat emissiemetingen uit aan wegvoertuigen. Daar waar in de beginjaren de aandacht vooral uitging naar controle van de emissies van nieuwe auto's tijdens de officiële typekeuringstest op de rollenbank, is de aandacht het laatste decennium verschoven naar het verzamelen van betrouwbare informatie over de emissies van voertuigen in de praktijk.

De resultaten van deze metingen worden door het Ministerie met de Tweede Kamer gedeeld. TNO legt de testresultaten van individuele geteste voertuigen ter commentaar voor aan de fabrikanten van de geteste voertuigen. Na eventuele bespreking van de testresultaten met de fabrikant, stuurt TNO de gevonden resultaten door naar de RDW. De RDW stuurt de resultaten ter informatie weer door naar de typekeuringsautoriteit van het land dat de emissiegoedkeuring voor het betreffende voertuig heeft afgegeven. Daarnaast worden de meetresultaten verwerkt in emissiefactoren, die worden gebruikt voor het modelleren van de luchtkwaliteit ten behoeve van het Nationaal Samenwerkingsprogramma Luchtkwaliteit (NSL) en voor de nationale emissieregistratie. Tot slot worden de uit

de meetprogramma's verkregen inzichten gebruikt om in Brussel en Genève wetgeving en testprocedures met betrekking tot voertuigemissies te verbeteren.

In het huidige meetprogramma voor personen- en bestelvoertuigen gaat de aandacht vooral uit naar de NO_x-praktijkemissies van voertuigen met een dieselmotor. Gebleken is dat deze emissies veel hoger zijn dan de NO_x-praktijkemissies van moderne voertuigen met benzinemotoren.
In dit rapport wordt verslag gedaan van een meetprogramma voor screening van de NO_x-praktijkemissies van achttien dieselbestelauto's. Hiervoor zijn tien Euro 6b en drie Euro VI bestelvoertuigen, alsook drie Euro 5b bestelvoertuigen getest. Daarnaast zijn nog twee Euro 6b 9-persoons busjes voor personenvervoer getest. Om de metingen te kunnen doen zijn de voertuigen uitgerust met mobiele emissiemeetapparatuur, in dit geval het door TNO ontwikkelde Smart Emission Measurement System (SEMS), en zijn de voertuigen getest tijdens meerdere praktijkritten op de openbare weg.

Praktijkemissies op de weg, de samengevatte resultaten

a) *Algemeen*

De gemiddelde NO_x-uitstoot van de op de weg geteste Euro 6/VI dieselbestelvoertuigen ligt in de praktijk één tot acht maal hoger dan de op de typekeuringstest geldende Euro 6 limietwaarde van 105 of 125 mg/km. De gemeten NO_x-emissie van deze voertuigen in stadsverkeer varieert in de praktijk van 130 tot 850 mg/km. Eerder werd gerapporteerd dat de uitstoot van Euro 5 bestelauto's in de stad 650 tot 2300 mg/km is [TNO 2016d].

b) *Effect van beladingsgraad en rijgedrag op emissies.*

Acht voertuigen zijn in RDE-testen met verschillende beladingen en rijstijlen getest. De CO_2-emissies blijken 25 tot 35% toe te nemen bij toenemende belading en meer dynamische rijstijlen. De bijbehorende NO_x-emissies blijken echter niet eenduidig van belading en dynamiek af te hangen. Sommige voertuigen hebben een stabiel NO_x-emissiegedrag, maar bij andere voertuigen blijkt de NO_x-emissie t.g.v. verschillende beladingsgraden en rijstijlen wel een factor 4 tot 6 te variëren. Bij hogere beladingen in combinatie met een sportieve rijstijl kan de NO_x-emissie wel 800 tot 1000 mg/km zijn.

c) *Vergelijking van de* NO_x*-emissies van zware bestelbussen met een LD of HD typegoedkeuring*

Voor bestelwagens in de zware categorie (klasse III) met een referentiemassa tussen 2380 en 2840 kg mogen fabrikanten kiezen welke typegoedkeuringsregime wordt gevolgd: light-duty (LD) of heavy-duty (HD). Omdat beide wetgevingen van elkaar verschillen in normstelling en testeisen, is het de vraag hoe bestelbussen van beide categorieën ten opzichte van elkaar presteren op het gebied van NO_x-emissies. Om die vraag te beantwoorden zijn zowel voertuigen met een Euro 6 (LD) typegoedkeuring als met een Euro VI (HD) typegoedkeuring getest over dezelfde ritten. Ter referentie zijn testen uitgevoerd aan vergelijkbare voertuigen met een Euro 5b (LD) typegoedkeuring.

Uit de vergelijking van de NO_x-emissies van voertuigen met een Euro 6 LD en Euro VI HD typegoedkeuring blijkt dat er gemiddeld geen significant verschil is tussen de NO_x-emissies in de praktijk van voertuigen van beide typegoedkeuringsregimes. Wel is er verschil in de spreiding van testresultaten binnen de beide voertuigcategorieën. De voertuigen met een HD keuring hadden consistent lage NO_x-emissies terwijl de Euro 6 voertuigen meer spreiding lieten zien. Mogelijk wordt de lagere spreiding onder praktijktestcondities van de HD gekeurde typen veroorzaakt door de praktijktest die voor deze categorie al vanaf 2014 verplicht is.

Voor één model bleek dat zowel de Euro 6 als de Euro VI variant een NO_x-emissie had in het bereik van 30 tot 90 mg/km. Een ander Euro 6 voertuig vertoonde ook dergelijk lage NO_x-emissies. Dit geeft aan dat een laag emissieniveau beneden dat van de typegoedkeuringslimiet (125 mg/km) haalbaar is in praktijktesten.

d) *SCR en LNT technologieën*
De gemeten hogere NO_x-praktijkemissies lijken niet toegeschreven te kunnen worden aan de keuze voor een bepaalde uitlaatgasnabehandelingstechnologie. Zowel voertuigen met LNT- als SCR-technologie blijken in de praktijk NO_x-emissies te hebben die tot wel een factor vier kunnen variëren.

e) Koude start emissies
Van de huidige Euro 6 dieselvoertuigen (modeljaar 2016) blijken de NO_x-emissies bij de koude start gerelateerd te zijn aan de toegepaste voertuigtechnologie. De opwarmfase bij koude start in de voor het meetprogramma uitgevoerde RDE testen duurt voor voertuigen met een SCR-katalysator gemiddeld 600 seconde. De geteste voertuigen met SCR-katalysator hebben gemiddeld een 400 milligram hogere NO_x-uitstoot in de opwarmfase dan de gemiddelde emissies in een vergelijkbare test met een warme start. De voertuigen met LNT-katalysator stoten gemiddeld in hun RDE-opwarmfase van 300 seconde 50 milligram extra NO_x uit. Dit verschil kan worden verklaard uit het feit dat LNT-katalysatoren NO_x-gas absorberen boven een werktemperatuur van 80-100°C terwijl SCR-katalysatoren pas boven een temperatuur van 150-200°C actief worden

f) Trends in emissiegedrag moderne dieselvoertuigen
Het emissieonderzoek aan deze voertuigen bevestigt resultaten gevonden in eerdere studies: dieselauto’s kunnen in het laboratorium aan de typekeuringsnorm voldoen maar in de praktijk ligt de NO_x-uitstoot vaak fors hoger. Onderzoek naar de oorzaak hiervan valt buiten de scope van het hier gerapporteerde emissiemeetprogramma. Tegelijkertijd laten resultaten voor sommige geteste voertuigen zien dat lage praktijkemissies, op of onder de voor de labtest geldende limietwaarde, wel mogelijk zijn met bestaande technologie.

Al jaren laten onderzoeken van TNO zien dat de beoogde reducties van de NO_x-emissies van dieselpersonenauto’s en dieselbestelauto’s, op basis van de aanscherping van de emissielimieten, in de praktijk niet worden gehaald. Uit de in dit rapport gepresenteerde resultaten wordt duidelijk dat het verschil tussen norm- en praktijkemissies ook bij Euro 6/VI voor veel voertuigen hoog blijft.

Ontwikkelingen van de EU emissiewetgeving
De verwachting is dat een aanpassing van de testcyclus voor de rollenbank, zoals in de nieuwe WLTP (Worldwide harmonized Light vehicles Test Procedures), weinig soelaas biedt voor dit probleem. Het op de weg meten en monitoren van voertuigen met mobiele meetapparatuur en eisen stellen aan de uitkomsten van dergelijke metingen, is cruciaal om de praktijkemissies onder controle te brengen. Metingen op de weg zijn onderdeel van de nieuwe RDE (Real Driving Emissions) wetgeving, die in Brussel is ontwikkeld en per 1 september 2017 voor nieuwe typekeuringen

van personen- en N1 klasse I en II bestelwagens is ingevoerd en twee jaar later in 2019 voor alle nieuwe voertuigen van deze categorie verplicht wordt.

Emissiefactoren
Naar aanleiding van de in dit rapport gepresenteerde meetresultaten zal de Taakgroep Verkeer en Vervoer van de Nationale Emissieregistratie de NO_x-emissiefactoren voor Euro 6 dieselpersonenwagens in 2018 opnieuw bepalen. Emissiefactoren zijn op basis van meetgegevens berekende gemiddelde emissies voor specifieke voertuigcategorieën onder specifieke gemiddelde verkeerscondities. Deze worden o.a. gebruikt voor luchtkwaliteitsberekeningen in Nederland.

Summary

This report describes the results of real-world emission measurements of Euro 5 and Euro 6/VI diesel light commercial vehicles and passenger vans. Real-world emissions are emissions derived from driving with a vehicle on public roads. TNO is ccommissioned by the Dutch Ministry of Infrastructure and Water Management to carry out the real-world emission measurements. Such measurements have been performed before on Euro 6 diesel passenger cars and Euro 5 diesel light commercial vehicles [TNO 2016c, TNO 2016d].

In line with the results of the Euro 6 passenger cars, the NO_x emissions of most Euro 6/VI diesel light commercial vehicles (LCVs) are much higher in real-world driving on the road than on the official type-approval tests performed on a dynamometer. However, the NO_x values of Euro 6 LCVs are lower than the Euro 5 results. It appears there is a large spread in the NO_x emission results of the tested vehicles. In real-world driving, some of the Euro 6/VI vehicles performed at or below the type-approval limits, others showing up to eight times higher results. The CO_2 emissions were measured as well, revealing higher real-world CO_2 emissions than the type-approval values.

It is expected that the new Real Driving Emissions (RDE) test, which requires on-road type-approval testing with mobile measurement equipment, will lead to lower real-world NO_x emissions. This test and the associated limit values are introduced gradually, starting in September 2017 with type-approvals for new models. In 2021, all newly registered light duty vehicles will have to comply with the RDE test and limits for on-road NO_x emissions.

The measurement programme
In order to reduce the negative impacts of the pollutant and greenhouse gas emissions of road transport, the European Commission has implemented emission regulations that set limits for various pollutant components (and targets for CO_2) in the exhaust emissions of road vehicles. In addition, Dutch policies are implemented with the aim to promote the application of clean and energy-efficient vehicle technologies. To enable evaluation of the effectiveness of these policies, the Dutch Ministry of Infrastructure and Water Management has commissioned TNO to carry out road vehicle emission tests. These test programmes have been executed since 1987. In the early years, the focus was on validation of the emissions of new road vehicles on the type-approval test. In the last decades, however, the focus has shifted towards obtaining reliable information on the emission performance of vehicles in real-world operation on the road.

The Ministry regularly shares results of these measurements with the Dutch Parliament. Since 2015 TNO also sends test results of individual vehicles to the vehicle manufacturer for comments and after that to the Dutch type-approval authority RDW (Rijksdienst voor het Wegverkeer). These test results are forwarded by the RDW to the granting type-approval authority that is responsible for the Whole Vehicle Type Approval of that particular vehicle. Furthermore, the results are used to determine national vehicle emission factors, that are used for air quality modelling and the national emission registration. Insights derived from the

measurement are used in Brussels and Geneva to improve emission legislation and emission test procedures.

The current measurement programme for passenger cars and light commercial vehicles focuses on vehicles with diesel engines, as their real-world NO_x emissions are found to be significantly higher than those of petrol engines.

This report describes real-world emission test results of eighteen diesel vehicles. Ten Euro 6b and three Euro VI light commercial vehicles, two Euro 6b passenger vans and three Euro 5b LCVs were tested. The vehicles were equipped with TNO's Smart Emission Measurement System (SEMS) and their emission performance was screened while driving representative routes on public roads.

Real-world emissions, summarised results

a) General

The tested Euro 6/VI vehicles showed NO_x emission levels that are 1 to 8 times higher than the type-approval emission limit values of 105 and 125 mg/km, depending on vehicle reference mass: their average NO_x emissions in urban traffic ranged from 130-850 mg/km. In an earlier study on Euro 5 LCV's the NOx emissions in urban traffic were reported ranging from 650-2300 mg/km [TNO 2016d].

b) The effect of different payloads and driving styles on emissions

Eight vehicles were tested in RDE tests with different payloads in combination with three different driving styles. The main trend of the CO_2 emission per vehicle is related to more demanding conditions of the RDE tests. Higher payloads and a dynamic driving style result for most vehicles in a CO_2 increase up to 25-35%. However, the NO_x trends corresponding to different driving styles and payloads are more diverse. Some vehicles have very stable NO_x emissions, but others vary widely (up to a factor 4 to 6) between test trips. With high payloads and a sportive driving style these NO_x emissions can be 800 to 1000 mg/km.

c) Comparison of NO_x emissions of class III LCVs with a type-approval according the LD or the HD regime

For LCVs in the heavy class (III) with a reference mass between 2380 and 2840 kg manufacturers may choose for either the Euro 6 LD (vehicle certified) or the Euro VI HD (engine certified) regime for the emissions type-approval. Both regimes differ with regard to emission limits and test procedures. The question is, therefore, how vehicles type-approved according to the two regimes compare in terms of NO_x emissions levels. To answer this question, vehicles of both regimes were selected and tested over the same trips. As a reference, vehicles that were type-approved according to the Euro 5 LD requirements were tested as well.

With regard to the comparison of the real-world NO_x emissions of vehicles with a Euro 6 and Euro VI type-approval, the average of the two regimes showed no significant difference. However, the Euro 6 vehicles clearly show a large spread in the NO_x emissions, whereas the NO_x emissions of Euro VI vehicles are more consistently low. The larger consistency of low NO_x emissions of the Euro VI vehicles may be attributed to the on-road In-Service Conformity test that is a mandatory as of 2014 for Euro VI engines and vehicles.

Low NO_x emissions in the range of 30-90 mg/km were measured for both the Euro 6 and the VI variant of a particular vehicle model. Another Euro 6 vehicle showed similar low values. This indicates that low emission levels, below the type-approval limit value of 125 g/km, can be achieved in real-world tests.

d) *SCR and LNT technologies and emission controls*

Higher real-world NO_x emissions appear not to be correlated with the applied exhaust after treatment technologies: the ranges of NO_x emissions of the two groups of vehicles (SCR or LNT technology) both span a factor 4 between the best and the worst emission performance.

e) *Cold start emissions*

For current Euro 6 diesel vehicles (models from 2016) the amount of additional NO_x emissions during a cold start is found to be related to the applied after-treatment technology. The tested SCR vehicles have a cold start period that lasts on average about 600 seconds in the performed RDE trips. The SCR vehicles emit on average 400 mg extra NO_x, compared to the expected emissions under the same conditions with a hot start. In the first 300 seconds of the urban part of RDE trips with a cold start the three tested vehicles with a LNT have an average NO_x emission of 50 mg. This may be explained by the fact that the NO_x absorption of an LNT typically starts at 80-100 °C, while the light-off temperature of SCR catalysts is 150-200 °C.

f) *Trends in NO_x emissions of modern diesel cars*

These test results confirm the results of earlier studies: Diesel cars can comply with type-approval emission limits in the standardized laboratory test, but real-world NO_x emissions of many vehicles are far higher. In this project, the causes for this difference in NO_x emissions have not been investigated as this would require another type of research. At the same time, the results of some tested vehicles show that on-road emission values at or below the type-approval limit values are already possible with existing technologies.

Developments of EU emission legislation

It is expected that a modification of the test cycle, like in the WLTP (Worldwide harmonized Light vehicles Test Procedures), will not resolve the issue of high real-world NO_x emissions. The upcoming Real Driving Emission (RDE) legislation, which prescribes emissions testing with portable emission measurement systems during normal on-road driving, is crucial for closing the gap between the type-approval pollutant emission limits and the real-world values. The RDE legislation developed by the European Commission is mandatory for new types of passenger and class I and II light commercial vehicles since 1 September 2017 and will become so two years later, in 2019, for all new vehicles of these categories.

Emission factors

The new emission data presented in this report will be used in 2018 by TNO to update the Dutch emission factors for Euro 6 diesel light commercial vehicles. These emission factors are used to feed Dutch air quality models. Since no Euro 6 light commercial vehicles were available before 2016, the emission factors of Euro 6 LCVs were based on the emission performance of Euro 5 LCVs and the difference of Euro 6 passenger car emission results compared to Euro 5 passenger cars. Hence, the new 2018 emission factors for Euro 6 LCVs will give the first insight in the actual performance of these vehicles.

Contents

1 Introduction

This document contains results from emission tests carried out by TNO in the period autumn 2016 until summer 2017. The focus is on NO_x emissions of Euro 6 light commercial vehicles (LCVs). The emission tests were carried out as part of a project for the Dutch Ministry of Infrastructure and Water Management.

This report presents a detailed overview of test results for the individual vehicles. With this report TNO intends to provide clarity and understanding on the measured data and what the results do and do not imply. TNO and the Dutch Ministry of Infrastructure and Water Management aspire to provide maximum transparency on the information that feeds into policy decisions regarding air quality and emission legislation. The results presented in this report are consistent with results presented in previous reports.

1.1 Context

To minimize air pollutant emissions of light-duty vehicles, in 1992 the European Commission introduced the Euro emission standards. In the course of time, these standards have become more stringent. Currently-produced light commercial vehicles of category N1 must comply with the Euro 6b standard. The Euro 6d standard, that further limits the emissions of light-duty vehicles, has become mandatory from September 2017.

The standards apply to vehicles with spark ignition engines and to vehicles with compression ignition engines and cover the following gaseous and particulate emissions:

- CO (carbon monoxide);
- THC (total hydrocarbons);
- NO_x (nitrogen oxides);
- PM (particulate mass), and;
- PN (particulate number).

As a result of the Euro emission standards, the pollutant emissions of light-duty vehicles as observed in type-approval tests have reduced significantly over the past decades. However, under real driving conditions some emissions substantially exceed the type-approval values. The real driving emissions of nitrogen oxides, or NO_x, from diesel vehicles are currently the most important issue with regard to pollutant emissions, as many cities fail to satisfy the European NO_2 air-quality standards mainly through the poor real-world performance of diesel cars. As NO_x represents the sum of NO and NO_2 emitted, and much of the NO is converted to NO_2 in ambient conditions, reducing NO_x emissions of vehicles is important for bringing down the ambient NO_2 concentration in cities. In the Netherlands, the ambient NO_2 concentration still exceeds European limits at a limited number urban road-side locations[1].

---

[1] http://www.atlasleefomgeving.nl/en/meer-weten/lucht/stikstofdioxide

Commissioned by the Dutch Ministry of Infrastructure and Water Management, TNO regularly performs emission measurements within the “in-use compliance programme for light-duty vehicles”. In the early years, i.e. from 1987 to 2000, the focus was on performing a number of standard type-approval tests on a large number of vehicles in the lab. In recent years, however, the emphasis has shifted towards gathering emission data under conditions that are more representative for real-world driving, by using various non-standard, i.e. real-world, driving cycles in the lab and by increasingly testing cars on the road with mobile emission measurement equipment.

All real-world investigations considered, urban emission factors derived for the NO_x emissions of Euro 3, 4 and 5 diesel light commercial vehicles are a lot higher than the legislative emission limit values, as illustrated in Figure 1-1.

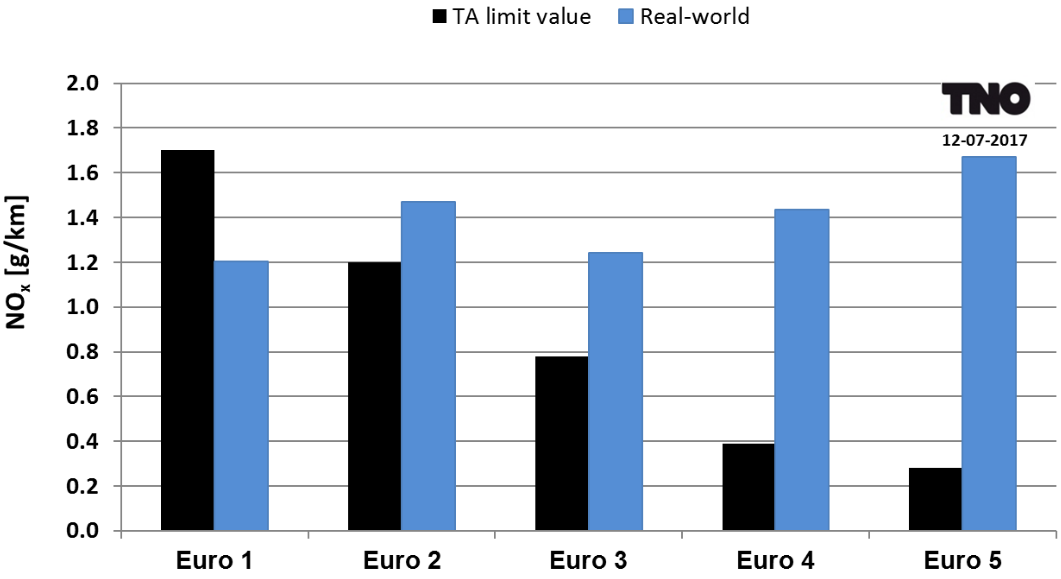


Figure 1-1: Emission limits and 2016 real-world emission factors in urban traffic for N1 class III diesel light commercial vehicles.

TNO has performed real-world tests on multiple Euro 6 diesel vehicles over the years. In recent years common production models with Euro 6 type-approval have entered the market and emissions of those vehicles have been determined and reported [TNO 2016c].

In this report the test results of eighteen Euro 5, 6 and VI light commercial vehicles (model year 2015 to 2017) are presented and discussed. For all N1 class I vehicles the Euro 6b emission limit values entered into force in September 2015 and one year later the N1 class II and III vehicles followed. The Euro VI limit for heavy duty vehicles applies since 31 December 2013.

From September 2016, vans under the N1 class III Euro 6 legislation became generally available for most brands and models. Several laboratories and commercial parties started testing these vehicles. Among the laboratories that test for emission factors and emission inventories, the preliminary findings indicate that the results are in most cases similar across the laboratories, for the same vehicle models that have been tested more than once. In general, on-road testing includes an RDE test. The results of different RDE tests are not necessarily the same because of the variation in on-road test conditions, such as ambient temperature, and test execution, including driving styles. However, the RDE test emission results are generally very similar, also among the different laboratories in the European collaboration network of ERMES.

On the contrary the emission results from other, commercial parties (such as the Emissions Analytics EQUA index, http://equaindex.com/equa-air-quality-index/) are often deviating. It is not possible to trace back the cause of these differences, as little information is supplied by these parties on the test execution, the details of the executed test trips and vehicle condition. The LCV testing at TNO includes the determination of the variations of vehicle emissions with the variation in on-road test execution. This span is typically much larger than a factor two. Hence, it makes no sense to report the emission result of on-road testing without reporting, or agreeing on, the test execution and test conditions. It is therefore not surprising that deviating results are reported. Within the bounds of RDE testing, the variation in emission results is much smaller. In the case of RDE tests, it seems that results can often be compared with the limitations described above.

Based on the performed emission measurements, TNO develops, and annually updates, vehicle emission factors that represent the average real-world emissions for various specific vehicle categories under different driving / traffic conditions. Vehicle emission factors are used for emission inventories, air quality monitoring and air-quality studies. TNO is one of the few institutes in Europe that perform independent emission tests. Dutch generic emission factors are based on these tests. The emission factors, and the underlying test results, are one of the few independent sources of evidence for the growing difference between legislative emission limits and real-world emission performance of cars.

1.2 Aim and approach

The project, of which the results are presented in this report, is one in a long sequence of projects, carried out by TNO for the Dutch government, to investigate the emission behaviour of road vehicles. The primary purpose of these projects is to gain an understanding of the emissions of road vehicles in real-world situations under varying operating conditions. The results provide input for the process of establishing generic emission factors which are used in the Netherlands for policies at the national, regional and municipal level related to air quality and overall emissions of air-polluting substances.

Furthermore, the insights obtained in the project serve as input for the activities of the Dutch government and the RDW in the context of regulation and legislative processes in Brussels (European Commission) and Geneva (GRPE) to improve emission legislation and the associated test procedures for light and heavy duty vehicles, all with the aim to reduce real-world emissions and improve air quality.

The aim of the research, presented in this report, was to assess the real-world emission performance of Euro 6 light commercial vehicles and to provide input for generating emission factors for this vehicle category. This was done by performing emission measurements on the road with TNO's Smart Emission Measurement System (SEMS). Although less accurate than laboratory measurements on a chassis dynamometer or measurements with well-known Portable Emission Measurement Systems (PEMS), SEMS allows for a quick and low-cost assessment, or screening, of the emission performance of vehicles and for determining deviations in emission performance with sufficient accuracy. Moreover, the SEMS equipment allows operation in normal use, as no special operator or protocol for the test equipment is required to perform emission tests. Hence, vehicles can be tested for thousands of kilometres in normal operation. The SEMS equipment is calibrated and validated to achieve optimal accuracy.

A second aim of this test programme, of which results are reported here, was to build up further experience with RDE test practices. The legislative requirements for a valid RDE test are more limited than the complete spectrum of driving characteristics occurring in normal use. Therefore, tests are frequently invalid according to one or more of the RDE boundary conditions. On the other hand, RDE legislation does allows for variation in test execution. It is therefore relevant to uncover the range of valid testing within RDE boundaries.

This study involves SEMS measurements on eighteen Euro 5, 6 and VI light commercial vehicles. Most vehicles were tested in a three-day test programme encompassing 20 different trips over 780 km. This relatively large number of vehicles and trips provides a sufficient basis to observe trends in their emission behaviour and to generate representative average emission factors for this vehicle category for the most relevant traffic situations.

1.3 TNO policy with respect to publication of data

TNO takes the utmost care in generating data and in communication on the findings of its studies, taking into account the interests of the various stakeholders. In the projects, of which the work presented in this document is a part, importers and manufacturers of tested vehicles are informed of the test results of their vehicles before publication, and are given the opportunity to reflect on them. This is beneficial to ensure that no errors are made in the testing and to address possible technical problems, that might affect the test results, in an early stage.

In the evaluation and interpretation of test results on individual vehicles the llowing considerations need to be taken into account:

- The tests performed by TNO are intended to determine the levels and trends of emissions of various categories of vehicles. The tests are not intended for enforcement, and they are not suitable for identifying or claiming fraud or other vehicle-related irregularities in a scientifically and legally watertight way.
- For each make or model, only a single vehicle or a small number of vehicles is/are tested a limited number of times. This means that the results correlate to the specific condition of the tested vehicles or to specific test conditions. The latter is especially the case in road-world testing on the road in which a large number of conditions, that have a strong influence on test results, vary from trip to trip.

In publications about the emission test results on light duty vehicles TNO has up to March 2016, for reasons as indicated above, chosen to present test results in a way that does not allow makes and models to be identified. In case results of individual vehicles were reported, these were always anonymized.

As part of TNO's constructive contribution to the on-going public debate about the real-world NO_x emissions of diesel cars, TNO has decided in 2016 to present test results with references to makes and models. This decision also meets a desire expressed by the Dutch Ministry of Infrastructure and Water Management. By presenting results from the complete sample of vehicle models tested, covering a wide range of makes and models, and by providing the necessary background information on test procedures and test conditions as well as caveats with respect to what can be concluded from these data, the test results on individual vehicle models are presented in a context that allows a well-balanced interpretation of the meaning of the results.

Finally, TNO would like to emphasize that as an independent knowledge institute, TNO is, has been, and will be open to constructive dialogue with industry and governments. This is part of TNO's efforts to work together with relevant stakeholders in finding and supporting the implementation of effective solutions to reduce real-world emissions of harmful substances from vehicles, as well to determine and demonstrate the effects of implemented measures in an objective way.

1.4 Remark on RDE legislation and subsequent validity of test results

In 2017 RDE legislation has entered into force in Europe. While this legislation was being prepared, TNO already started to build up experience and knowledge of RDE test practices and data evaluation tools. The on-road test results in this report are primarily meant to determine emission factors and they are not fully RDE-compliant. Although the trips on which the RDE measurements have been performed are often RDE-compliant, the SEMS measurement method is not.

All test results and information about test conditions are reported to the Dutch type-approval authority RDW (Rijksdienst voor het Wegverkeer). It is the responsibility of RDW to assess whether the information provides indications of possible non-compliance of vehicles and to decide about forwarding of the test results to other Type-approval Authorities.

1.5 Structure of the report

Chapter 2 first describes the characteristics of the sample of tested vehicles and the applied test trips. Then, in Chapter 3, the test results are reported. In Chapter 4 the topic of cold start effects is investigated and in Chapter 5 RDE test trip parameters are analysed. After a discussion of various issues related to the reported results in Chapter 6, conclusions are presented in Chapter 7.

2 Test programme

This chapter presents the most important characteristics of the test programme as performed. The measurement methods are described in more detail in the TNO methodology report [TNO2016a].

2.1 Tested vehicles

2.1.1 Vehicle selection

The Euro 6 diesel engines in LCVs of the different manufacturer groups were identified based on engine volume and power, using Dutch new car sales data up to January 2017. For these engines, the vehicle models with the highest sales volumes were identified. A limited sample of vehicles was selected, to represent the largest representation of Euro 6 engines, and the largest representation of vehicles in which these engines are used. Most selected test vehicles of Table 2-1 belong to the group of the highest sales vehicles. Three N1 class III vehicle types were tested in a LD and HD variant. It is expected that the same engine in another vehicle model or vehicle brand will perform similarly. For this reason, it is expected that current test results are representative for the current Dutch Euro 6 LCV fleet.

2.1.2 Vehicle specifications

In Table 2-1 some basic data of the vehicles are specified, including the applied after treatment technologies (AT).

Table 2-1: Sixteen tested Euro 5/6/VI light commercial vehicles and two Euro 6 M1 vans.

No	Brand	Model	Category N1 class	Euro Class	Power [kW]	Aftertreatment	Odometer [km]	Test mass empty [kg]
1	Peugeot	Partner	II	6b	73	Oxicat+DPF+ SCR	21,263	1,460
2	Renault	Trafic	III	6b	92	Oxicat+DPF+SCR	3,200	2,065
3	Ford	Transit Connect	II	6b	74	Oxicat+DPF+LNT+pSCR	15,353	1,596
4	Volkswagen	Caddy	II	6b	55	Oxicat+DPF+SCR	4,498	1,486
5	Volkswagen	Kombi Transporter	M1	6b	62	Oxicat+DPF+SCR	20,004	1,894
6	Mercedes-Benz	Citan	II	6b	55	Oxicat+DPF+LNT	17	1,448
7	Mercedes-Benz	Vito	M1	6b	100	Oxicat+DPF+SCR	44,875	2,477
8	Peugeot	Expert	III	6b	90	Oxicat+DPF+SCR	12,878	1,817
9	Ford	Transit	III	5b	74	Oxicat+DPF	56,356	2,167
10	Ford	Transit	III	6b	96	Oxicat+DPF+SCR	11,751	2,383
11	Ford	Transit	III	VI	114	Oxicat+DPF+SCR	37152	3181
12	Mercedes-Benz	Sprinter	III	5b	95	Oxicat+DPF	23,878	2,535
13	Mercedes-Benz	Sprinter	III	6b	105	Oxicat+DPF+SCR	12,770	2,695
14	Mercedes-Benz	Sprinter	III	VI	120	Oxicat+DPF+SCR	30,734	2,960
15	Volkswagen	Crafter	III	5b	100	Oxicat+DPF	60,544	2,146
16	Volkswagen	Crafter	III	6b	80	Oxicat+DPF+SCR	2,694	2,158
17	Volkswagen	Crafter	III	VI	120	Oxicat+DPF+SCR	70,780	2,146
18	Iveco	New Daily	III	6b	114	Oxicat+DPF+SCR	4,488	2,366

2.2 On-road test trips

Eighteen vehicles were tested based on a standard trip schedule with a total length of more than 800 km. Some information of the test trips of this 3-day test programme is presented in Table 2-2. The average velocity of the trips varies between 12 – 83 km/h and the length of the trips varies between 4 – 123 km. Some vehicles were subjected to a more restricted test programme. The Euro 5 and Euro VI vehicles were not subjected to the full measurement progrmame, but only to a limited number of trips, enough to compare their results with the Euro 6 variants.

All trips were carried out with a ‘normal’ driving style except for trip 1, which was carried out with the driving style ‘economy’, and trip 8, which was performed with a ‘sportive’ driving style. The details of the applied driving styles are presented in Table 2-3. To test vehicles in congested traffic, the trips 4 and 5 were started during evening and morning traffic at motorways. Most RDE trips were carried out in the region of The Hague (RDE_H). The In-Service Conformity (ISC) trip is defined along the heavy duty official in-service conformity test protocol.

Table 2-2: On-road test trips in the three-days test programme in the region of The Hague

No.	Trip Name	Road Type(s)	Start condition	Test Day	Payload [%]	Driving style	Distance [km]	Average velocity [km/h]
1	RDE_C	Urban / rural / motorway	Cold start	1	28	Economic	74.7	43
2	Motorway	Motorway	Hot start	1	28	Regular	89.5	79
3	RDE_H	Urban / rural / motorway	Hot start	1	28	Regular	74.7	43
4	Congest_H	Motorway, evening traffic	Hot start	1	28	Regular	84.3	56
5	Congest_C	Motorway, morning traffic	Cold start	2	95	Dynamic	85.3	83
6	City	Urban	Hot start	2	95	Regular	27.8	21
7	Rural	Rural	Hot start	2	95	Regular	64.5	50
8	RDE_H	Urban / rural / motorway	Hot start	2	55	Regular	74.7	43
9	City to City	Urban / rural / motorway	Hot start	2	95	Regular	21.2	36
10	RDE_C	Urban / rural / motorway	Cold start	3	95	Dynamic	74.7	43
11	Short trip	Urban/rural	Hot start	3	55	Regular	4.3	28
12	Delivery trip	Urban	Hot start	3	55	Regular	17.4	12
13	ISC_H	Urban / rural / motorway	Hot start	3	55	Regular	122.7	57
14	City to City	Urban / rural / motorway	Hot start	3	55	Regular	21.2	36
1-14	Total						837.1	

One initial vehicle, the Peugeot Partner, was used to investigate RDE boundaries and the effect of the EMROAD evaluation tool that is part of the RDE procedures. The test programme with this vehicle was more extensive, and the results were used in discussions with stakeholders about RDE and the EMROAD tool.

Table 2-3: Parameters of the three applied driving styles.

Driving style		**Economy**	**Normal**	**Sportive**
Driving behaviour		careful	regular	dynamic
Gearshift engine speed	[rpm]	2000	2500	3500
Distance to target at start of braking	[m]	90	60	30
Delay time speed to brake pedal	[s]	30	3	0
Start-stop system active		Yes	Yes	No
Vehicle stops of 120-180 s		0	0	2
Maximum position speed pedal	[%]	80	90	100
Speed pedal activation speed		slow	normal	fast
Maximum speed on the motorway	[km/h]	110	120	140

2.3 Measurement equipment

Emission measurements on the road were performed using a sensor-based Smart Emission Measurement System (SEMS). The NO_x and O_2 measuring signals of the sensors as well as the Mass Air Flow sensors of the vehicles were calibrated (except for two cases). All test results were corrected using these calibrations.

To assess the accuracy of the SEMS equipment, SEMS measurements have been carried out on a roller bench, simultaneously recording the readings of the SEMS and of the regular laboratory equipment. A first impression of the performance of a SEMS system in four different chassis dynamometer tests in comparison with the type-approval method (CVS – bags) is given in Figure 2-1 and Figure 2-2. In four different tests the CO_2 emission measurements of SEMS deviate from the standard lab measurements by -2.4 to +0.8 g/km (-1.6% to +0.3%). For NO_x emissions, the deviation is -0.7 to +54.7 mg/km (-0.1 to +8.8%). The accuracy of the SEMS equipment relies on the accuracy of the calibrated concentration measurements, the exhaust flow accuracy and the engine signals used.

For further information on the measurement methods used by TNO, the reader is referred to the TNO methodology report [TNO2016a].

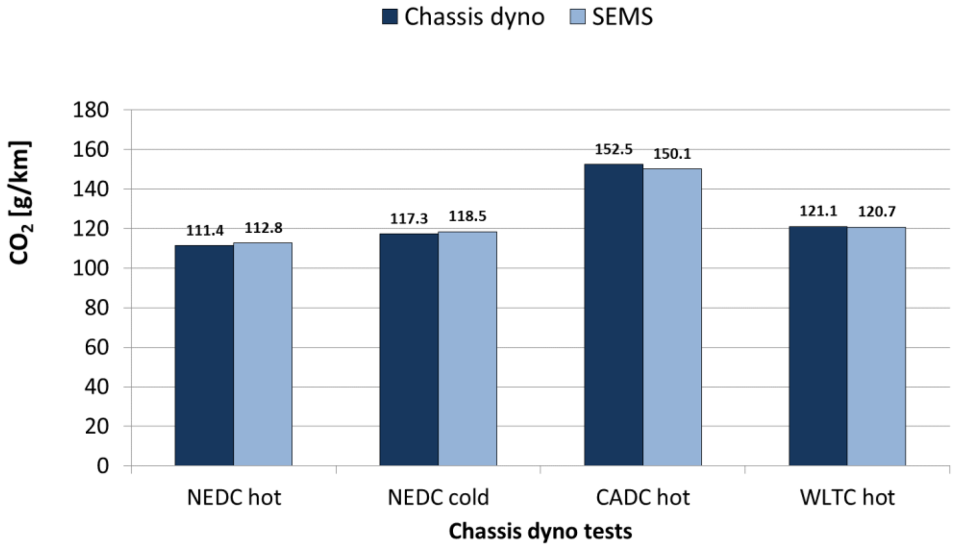


Figure 2-1: CO_2 emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS.

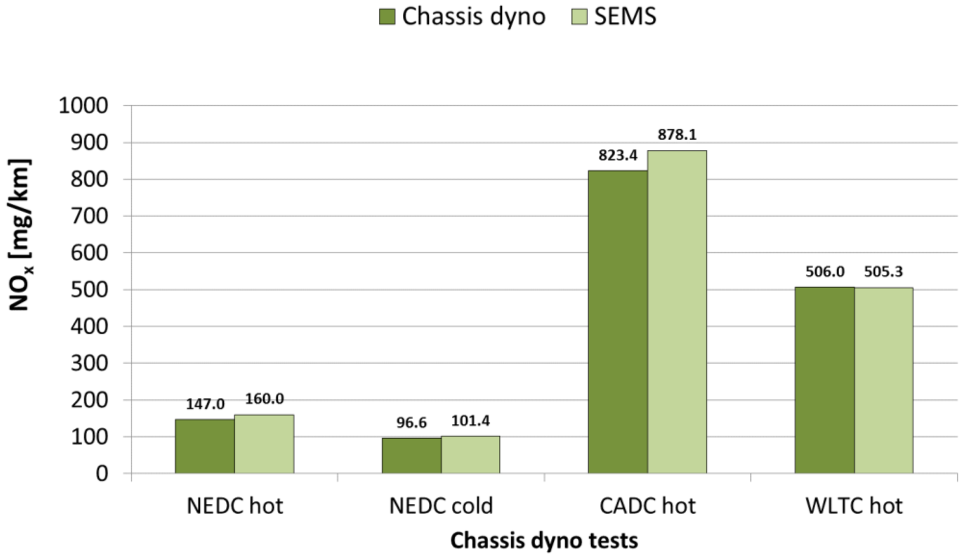


Figure 2-2: NO_x emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS.

3 Emission test results

This chapter provides the test results per vehicle. For each vehicle, the following data are reported:

1. Executed test trips
2. Binned on-road NO_x emissions per trip
3. NO_x emission map of the engine plus exhaust after treatment system

Furthermore, several overviews with results of all tested vehicles are given in sections 3.2 to 3.4.

3.1 Emission test results per vehicle

The emission test results for each tested vehicle are summarized in the following paragraphs. First, the emission results per trip are summarized in a table, along with the average of all measurement data, weighted with the trip time. The results per trip can vary due to the traffic conditions, such as congestion, and ambient conditions. In addition, three graphs per vehicle are reported with average emissions per velocity bin, the amount of data per bin and the average emissions as function of velocity and acceleration.

Emissions per velocity bin

Emissions are measured second by second, simultaneously with vehicle speed. In order to compare the different vehicles, the data of all trips per vehicle is grouped into velocity bins of 10 km/h each. An important quantity is the spread of the emission results within a velocity bin. This is indicated by the error bars, which represent +/- one standard deviation from the median NO_x value. If for a given speed bin both very high and very low emissions occur, the error bars are far apart, indicating a large spread. If all the NO_x emissions in one velocity bin are close together, the spread is small. For example, the bin at 110-120 km/h in Figure 3-7 has a large spread, so both very high and low emissions occurred at this velocity.

Amount of data per velocity bin

For a correct interpretation of the binned results, it is important to keep in mind that not all velocity bins are filled with the same amount of data. For some bins in Figure 3-1 for example, at velocities over 120 km/h, a limited amount of data is available. This is illustrated by the blue bars in Figure 3-2, that represent the number of seconds the vehicle is driving in that specific velocity regime. In this figure, most data are collected in the bin 100-110 km/h. The amount of data is an indication of the reliability of the average NO_x emission value.

Emissions as function of velocity and acceleration

An even better illustration of the emission behaviour of the vehicle can be given by not only grouping the data into bins of similar velocity, but into bins of similar velocity and acceleration, as shown in Figure 3-3. This requires a large amount of data, as is collected in the multiple-day test programme. The emissions typically increase with higher velocities, and with higher accelerations. The combination of both high velocity and high acceleration yields the largest increase in emissions. By comparing these figures for different vehicles, the emission behaviour of the vehicles as function of speed and acceleration can be compared. To read the scale in these plots it helps to note that an emission rate of 10 mg/s (green colour in the plots) results in 720 mg/km at 50 km/h and 360 mg/km at 100 km/h.

3.1.1 *Peugeot Partner (73 kW)*

Table 3-1: Vehicle specifications of the Peugeot Partner.

Trade Mark	[-]	Peugeot
Type	[-]	Partner
Body	[-]	B9/FRG/BHY/M5/B13
Vehicle Category	[-]	N1 Class II
Fuel	[-]	Diesel
Engine Code	[-]	DV6FD 9810543080
Swept Volume	[cm3]	1560
Max. Power	[kW]	73
Euro Class	[-]	Euro 6b
Type Approval Authority	[-]	France
Type Approval Number	[-]	e2*715/2007*2015/45X*14247*02
Vehicle Empty Mass	[kg]	1292
Declared CO_2 emission	[g/km]	110
Vehicle Identification Number	[-]	VF3 7BBHY6 FJ663981
Vehicle Test Mass	[kg]	1482 - 1936
Odometer	[km]	21263
Registration Date	[dd-mm-yy]	31-08-15

Table 3-2: Emission results per trip of a Peugeot Partner Euro 6 diesel.

No.	Trip ID + payload%	Date	Start time	Duration	Distance	Average velocity	Ambient temperature Avg/min/max			CO_2	NO_x	NH_3
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2016-12-1	9:23	6487	75.2	47.3	8	7	8	130.4	274.5	0.7
2	Motorway 28%	2016-12-1	12:57	4384	103.1	86.3	10	9	10	116.1	268.1	0.9
3	RDE_H 28%	2016-12-1	11:18	5795	70.3	45.4	9	8	10	146.2	389.5	2.6
4	Congest_H 28%	2016-12-1	15:38	3287	57.3	64.3	10	10	10	109.2	168.4	0.7
5	Congest_C 95%	2016-12-2	7:50	4019	83.6	76.6	5	4	6	113.4	230.3	0.8
6	City 95%	2016-12-2	9:00	4611	22.4	18.8	6	6	7	206.8	618.4	0.7
7	Rural 95%	2016-12-2	10:22	6371	83.9	50.2	8	7	9	137.8	376.6	0.5
8	RDE_H 95%	2016-12-2	13:03	6110	72.6	45	10	9	10	134.2	364.8	0.5
9	City to City 95%	-	-	-	-	-	-	-	-	-	-	-
10	RDE_C 55%	-	-	-	-	-	-	-	-	-	-	-
11	Short trip 55%	-	-	-	-	-	-	-	-	-	-	-
12	Delivery trip 55%	-	-	-	-	-	-	-	-	-	-	-
13	ISC_H 55%	-	-	-	-	-	-	-	-	-	-	-
14	City to City 55%	-	-	-	-	-	-	-	-	-	-	-
Total					568					137	336	1.0

Remarks:

- RDE trips 1, 3 and 8 comply with the boundary conditions and trip dynamics criteria.
- Regeneration of the DPF took place at trip 3.
- In this test programme of 600 km (incl. commissioning) the fuel consumption of the vehicle was 5.35 l/100 km and the AdBlue consumption 5.21 l/10,000 km.

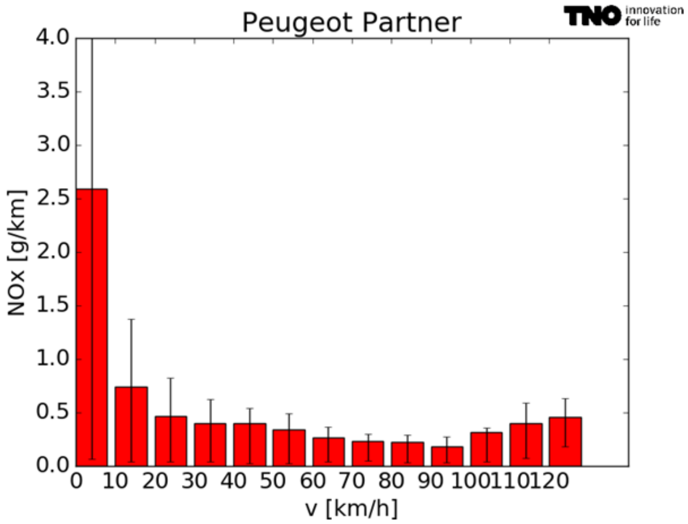


Figure 3-1: Average NO_x emissions of a Peugeot Partner Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

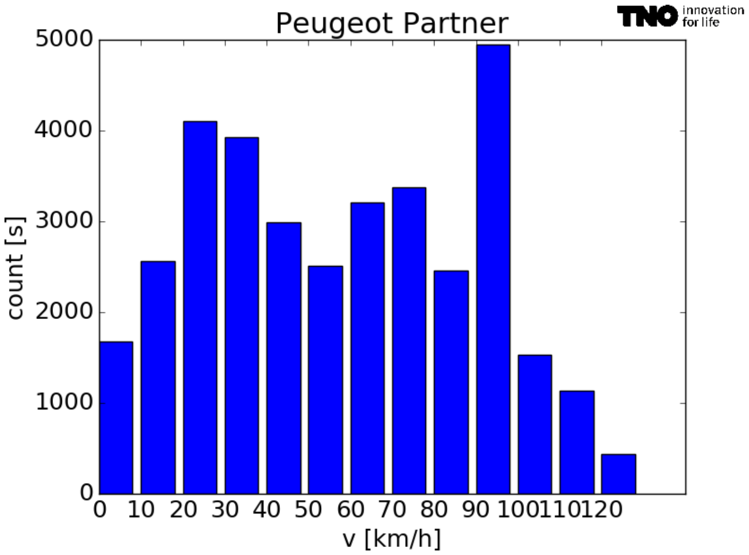


Figure 3-2: Number of seconds per velocity bin, over all trips. Idling is excluded.

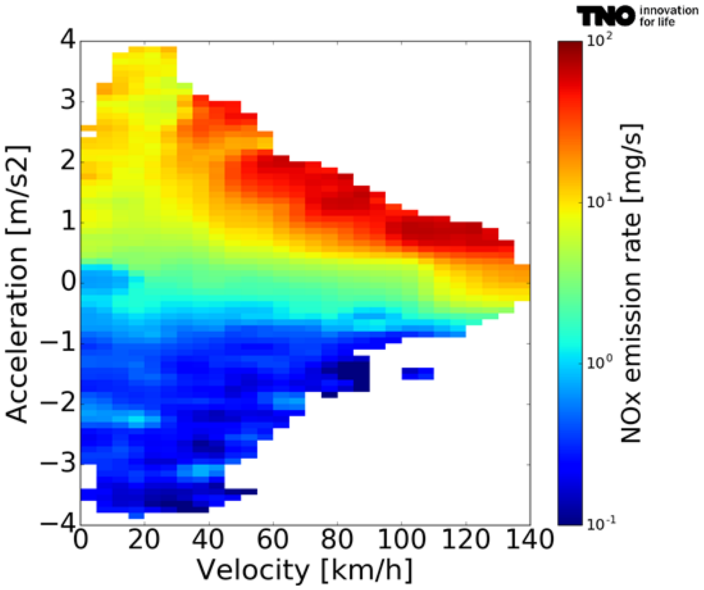


Figure 3-3: NO_x emission rate [mg/s] of a Peugeot Partner Euro 6 diesel in bins of velocity and acceleration.

3.1.2 *Renault Trafic (92 kW)*

Table 3-3: Vehicle specifications of the Renault Trafic.

Trade Mark	[-]	Renault
Type	[-]	Trafic
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1598
Max. Power	[kW]	92
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	1835
Declared CO_2 emission	[g/km]	159
Vehicle Identification Number	[-]	VF1FL000456216521
Vehicle Test Mass	[kg]	2320-2990
Odometer	[km]	3078
Registration Date	[dd-mm-yy]	30/09/16

Table 3-4: Emission results per trip of a Renault Trafic Euro 6 diesel.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg**	**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]	[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2016-12-13	9:07	6453	69.1	38.6	7	211	266	-
2	Short4 28%	2016-12-13	10:57	680	4.2	22.2	7	265	477	-
3	RDE_H 28%	2016-12-13	11:21	5619	69.9	44.8	7	203	294	-
4	Motorway 28%	2016-12-13	12:59	4561	103.0	81.3	7	173	131	-
5	Congest_H 28%	2016-12-13	15:26	4274	57.1	48.1	8	177	199	-
6	ISC_H 95%	2016-12-14	13:06	8191	121.8	53.5	10	188	245	2.4
7	Short4 95%	2016-12-14	15:27	369	4.1	40.5	10	216	305	2.0
8	Delivery trip 95%	2016-12-14	15:36	3118	15.5	17.9	10	263	375	3.5
9	Congest_C 55%	2016-12-15	7:51	5312	83.0	56.3	6	190	207	0.9
10	City 55%	2016-12-15	9:21	4132	20.7	18.1	6	294	497	2.6
11	Rural 55%	2016-12-15	10:30	6321	84.0	47.9	6	207	211	0.9
12	RDE_H 55%	2016-12-15	12:31	5626	69.8	44.6	7	225	377	7.4
13	Short5 55%	2016-12-15	14:07	899	5.4	21.6	7	274	484	0.5
Total					707.6			201	249	2.7

Remarks:

- RDE trips 1, 3 and 12 comply with the boundary conditions.
- RDE trip 1 complies with the trip dynamics criteria.
- RDE trips 3 and 12 comply not with the trip dynamics criteria because the motorway part has a too static speed profile.
- Regeneration of the DPF took place during trip 12.
- In this test programme of 825 km (incl. commissioning) the fuel consumption of the vehicle was 7.98 l/100 km and the AdBlue consumption was not measured.

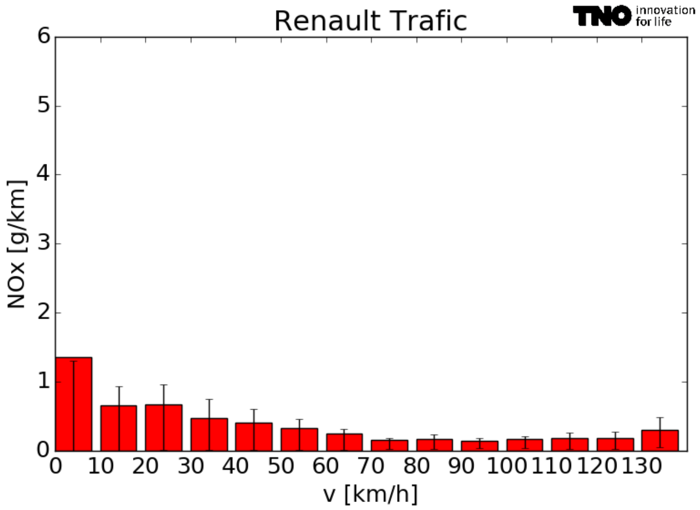


Figure 3-4: Average NO_x emissions of a Renault Trafic Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

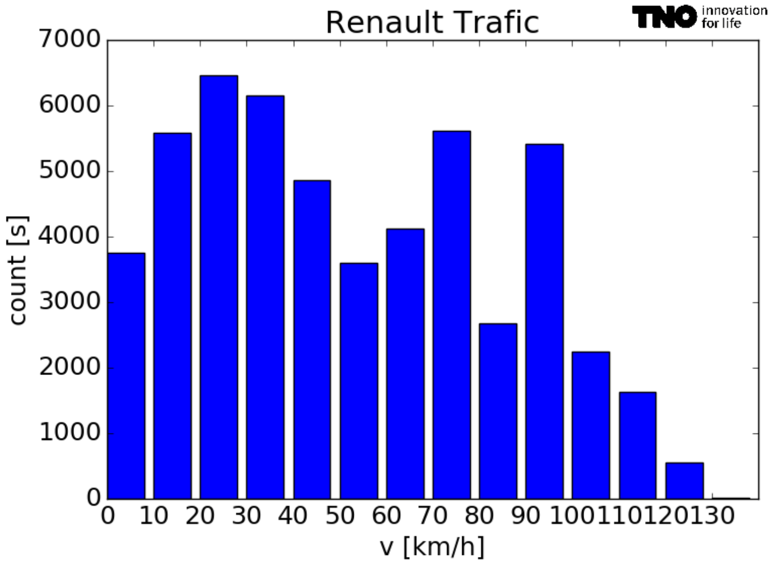


Figure 3-5: Number of seconds per velocity bin, over all trips. Idling is excluded.

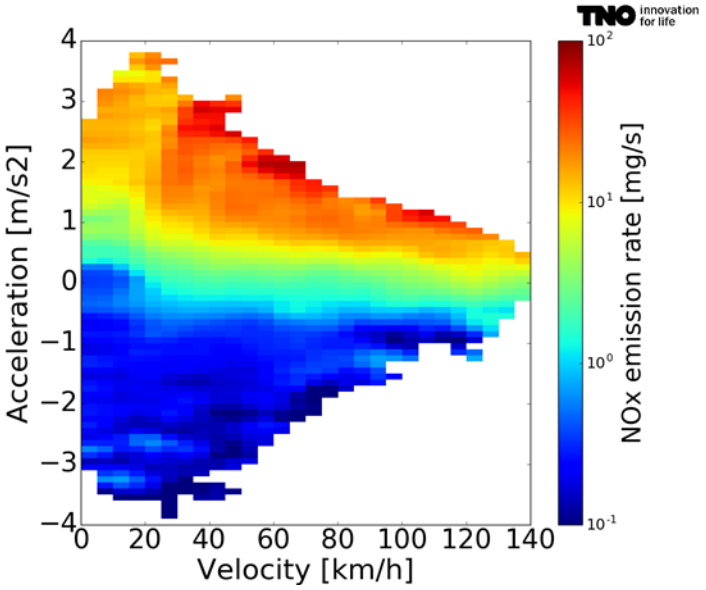


Figure 3-6: NO_x emission rate [mg/s] of a Renault Trafic Euro 6 diesel in bins of velocity and acceleration.

3.1.3 Ford Transit Connect (74.2 kW)

Table 3-5: Vehicle specifications of the Ford Transit Connect.

Trade Mark	[-]	Ford
Type	[-]	Transit Connect
Body	[-]	Light Commercial vehicle
Vehicle Category	[-]	N1 Class 2
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1499
Max. Power	[kW]	74.2
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	1596
Declared CO_2 emission	[g/km]	124
Vehicle Identification Number	[-]	WF0SXXWPGSGC06510
Vehicle Test Euro	[kg]	1747-2131
Odometer	[km]	15353
Registration Date	[dd-mm-yy]	28/07/16

Table 3-6: Emission results per trip of a Ford Transit Connect Euro 6 diesel.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
			hh:ss	[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2017-5-5	12:53	6317	72.4	41.3	12	10	13	155	432	-
2	Motorway 28%	2017-5-3	9:39	4153	89.9	77.9	10	9	11	154	358	-
3	RDE_H 28%	2017-5-3	10:57	5728	72.3	45.4	11	10	15	160	504	-
4	Congest_H 28%	2017-5-3	13:39	4774	86.1	64.9	14	12	18	135	274	-
5	Congest_C 95%	2017-5-4	8:01	3965	83.0	75.3	11	9	13	164	504	-
6	City 95%	2017-5-4	9:11	4235	24.3	20.7	12	10	15	215	533	-
7	Rural 95%	2017-5-4	10:24	4653	65.0	50.3	13	11	16	147	588	-
8	RDE_H 95%	2017-5-4	11:52	6204	72.3	42.0	15	13	17	209	1038	-
9	City to City 95%	2017-5-4	13:38	2090	21.1	36.4	15	14	16	176	588	-
10	RDE_C 55%	2017-5-8	8:17	6596	72.2	39.4	10	9	12	175	572	-
11	Short trip 55%	2017-5-8	10:13	594	4.5	27.5	11	10	12	192	842	-
12	Delivery trip 55%	2017-5-8	10:25	4700	16.1	12.3	12	10	14	246	576	-
13	ISC_H 55%	2017-5-8	11:44	7133	112.3	56.7	14	11	17	150	448	-
14	City to City 55%	2017-5-8	13:45	2445	20.9	30.7	16	13	19	172	419	-
Total					812.4					164	514	-

Remarks:

- RDE trips 1, 3, 8 and 10 comply with the boundary conditions.
- RDE trips 1,3 comply with the trip dynamics criteria.
- RDE trip 8 does not comply with the trip dynamics criteria because the v*a(pos) value in the urban part is too high.
- RDE trip 10 does not comply with the trip criteria because the idling time in the urban part is too long (traffic jam).
- Start/stop not functional during trip 1 to 7
- Regeneration of the DPF took place at trip 8.
- In this test programme of 1107 km (incl. commissioning) the fuel consumption of the vehicle was 6.38 l/100 km.

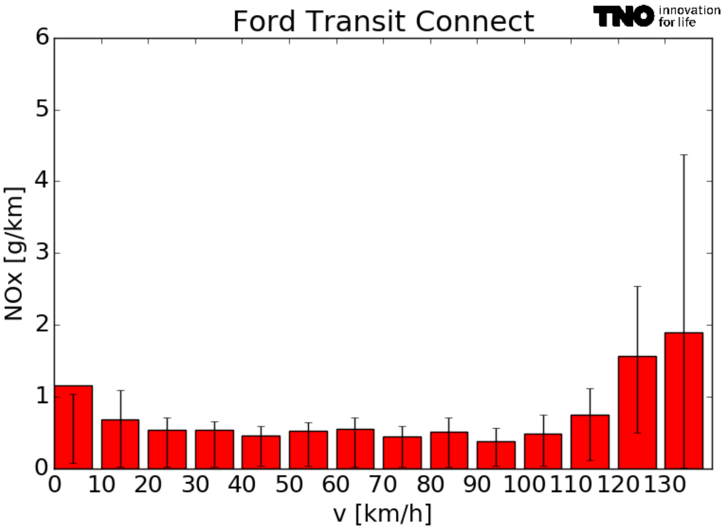


Figure 3-7: Average NO_x emissions of a Ford Transit Connect Euro 6 diesel per velocity bin for all trips.The error bars represent +/- one standard deviation from the median. Idling is excluded.

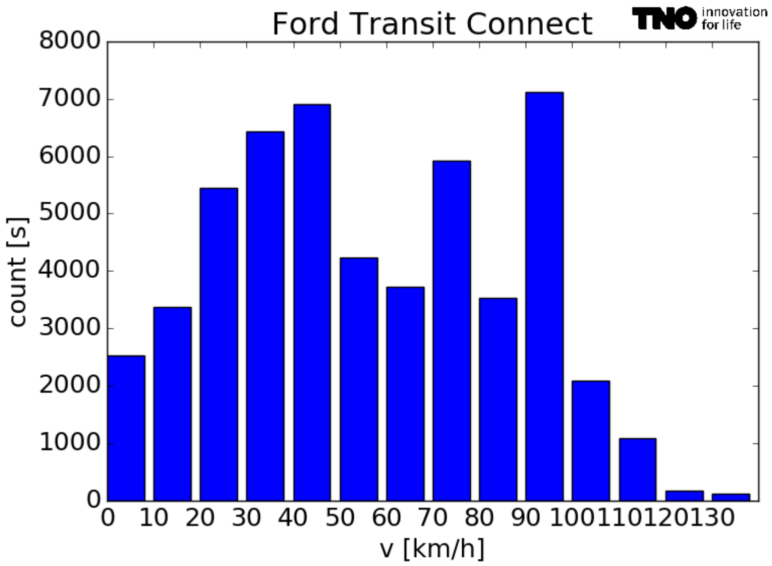


Figure 3-8: Number of seconds per velocity bin, over all trips. Idling is excluded.

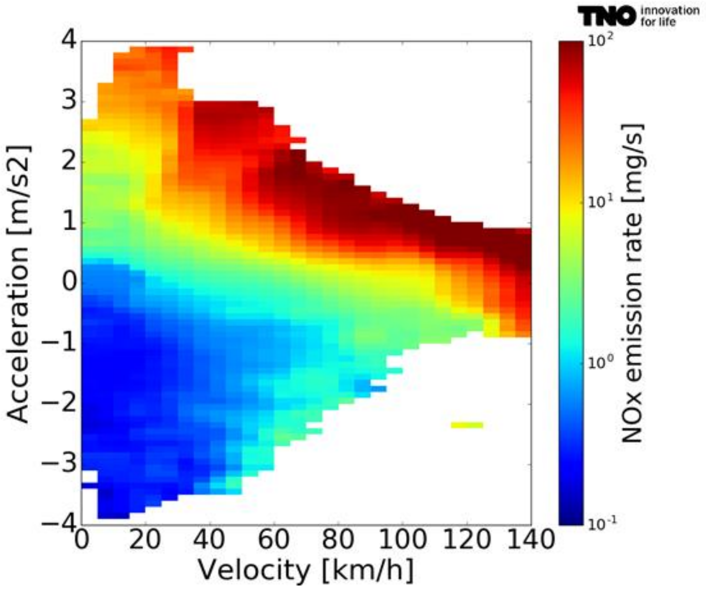


Figure 3-9: NO_x emission rate [mg/s] of a Ford Transit Connect Euro 6 diesel in bins of velocity and acceleration.

3.1.4 Volkswagen Caddy (55 kW)

Table 3-7: Vehicle specifications of the Volkswagen Caddy.

Trade Mark	[-]	Volkswagen
Type	[-]	Caddy
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 2
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1968
Max. Power	[kW]	55
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	1473
Declared CO_2 emission	[g/km]	117
Vehicle Identification Number	[-]	WV1ZZZ2KZHX070008
Vehicle Test Euro	[kg]	1678-2136
Odometer	[km]	4498
Registration Date	[dd-mm-yy]	10/03/17

Table 3-8: Emission results per trip of a Volkswagen Caddy Euro 6 diesel.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2017-5-11	8:25	5998	73.0	43.8	16	13	18	115	39	0.6
2	Motorway 28%	2017-5-8	10:49	3800	87.4	82.8	12	10	16	110	38	0.1
3	RDE_H 28%	2017-5-8	12:51	5690	72.7	46.0	15	14	17	120	57	0.2
4	Congest_H 28%	2017-5-8	15:01	6153	85.0	49.7	16	13	20	113	52	0.2
5	Congest_C 95%	2017-5-9	7:43	5736	82.9	52.0	12	9	13	113	48	0.2
6	City 95%	2017-5-9	9:28	4871	28.5	21.1	12	11	14	157	96	0.6
7	Rural 95%	2017-5-9	11:14	4813	64.6	48.3	13	12	15	113	45	0.3
8	RDE_H 95%	2017-5-9	12:56	6276	70.6	40.5	14	12	17	172	217	0.9
9	City to City 95%	2017-5-9	14:46	2672	21.5	28.9	15	13	18	140	101	2.4
10	RDE_C 55%	2017-5-10	7:54	6000	72.6	43.5	10	9	12	133*	70	1.1
11	Short trip 55%	2017-5-10	9:45	424	4.2	35.5	12	11	15	136	100	1.0
12	Delivery trip 55%	2017-5-10	10:05	1943	13.4	18.2	12	11	14	169	128	1.2
13	ISC_H 55%	2017-5-10	11:33	8107	121.0	53.7	15	13	20	114	38	0.4
14	City to City 55%	2017-5-10	13:53	2668	21.5	28.9	15	13	17	135	88	0.5
Total					818.9					127	70	0.5

Remarks:

- RDE trips 1, 3, 8 and 10 comply with the boundary conditions.
- RDE trip 1 and 3 comply not with the trip dynamics criteria because the RPA value in the motorway part is too low.
- RDE trip 8 does not comply with the trip dynamics criteria because the v*a(pos) value in the urban part is too high.
- RDE trip 10 does not comply with the trip criteria because the number of accelerations in the motorway part are too low.
- Regeneration of the DPF took place during trip 8.
- In this test programme of 1054 km (incl. commissioning) the fuel consumption of the vehicle was 5.71 l/100 km and the AdBlue consumption 7.00 l/10,000 km.

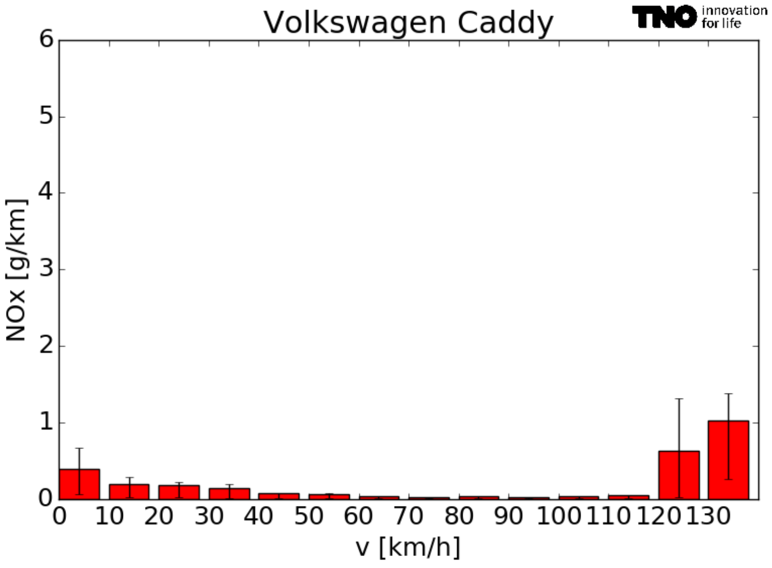


Figure 3-10: Average NO_x emissions of a Volkswagen Caddy Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

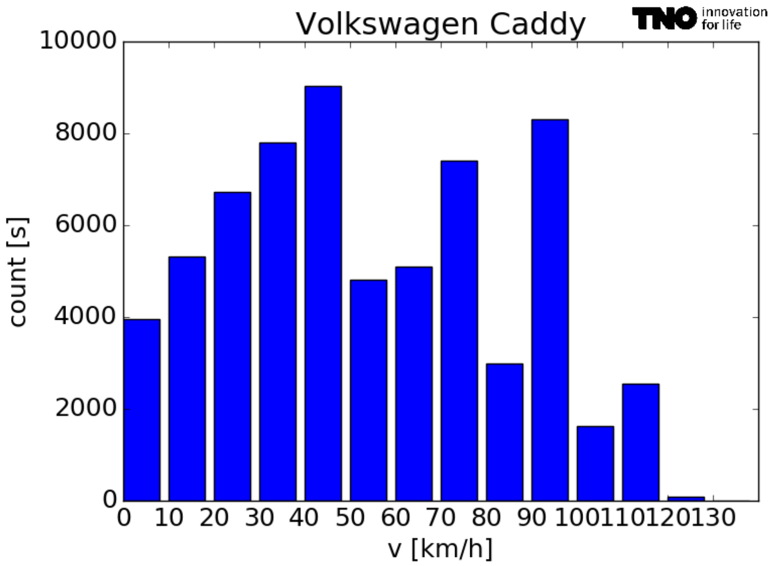


Figure 3-11: Number of seconds per velocity bin, over all trips. Idling is excluded.

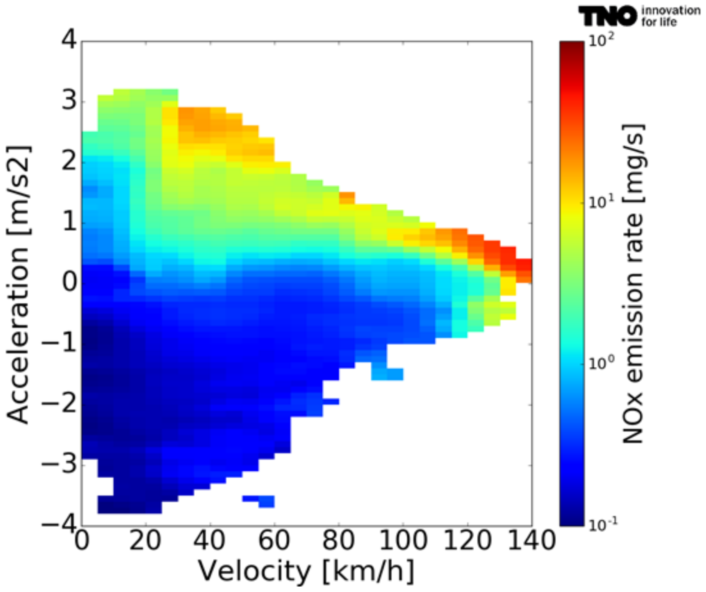


Figure 3-12: NO_x emission rate [mg/s] of a Volkswagen Caddy Euro 6 diesel in bins of velocity and acceleration.

3.1.5 Volkswagen Kombi Transporter (62 kW)

Table 3-9: Vehicle specifications of the Volkswagen Kombi Transporter.

Trade Mark	[-]	Volkswagen
Type	[-]	Kombi Transporter
Body	[-]	Passenger Vehicle
Vehicle Category	[-]	M1
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1968
Max. Power	[kW]	62
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	1894
Declared CO_2 emission	[g/km]	155
Vehicle Identification Number	[-]	WV2ZZZ7HZHH042010
Vehicle Test Euro	[kg]	2413-2959
Odometer	[km]	20,004
Registration Date	[dd-mm-yy]	16/11/16

Table 3-10: Emission results per trip of a Volkswagen Kombi Transporter Euro 6 diesel.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2017-5-9	8:26	5943	73.4	44.4	12	10	14	157	84	2.6
2	Motorway 28%	2017-5-9	10:09	4071	90.3	79.8	13	11	14	178*	293	22.4
3	RDE_H 28%	2017-5-9	11:37	5645	73.9	47.1	14	12	15	162	111	1.8
4	Congest_H 28%	2017-5-9	14:15	4817	85.7	64.1	14	12	16	151	72	1.2
5	Congest_C 95%	2017-5-10	8:09	4372	83.1	68.4	10	8	12	157	116	2.3
6	City 95%	2017-5-10	9:26	4407	25.7	20.9	11	9	13	264*	425	5.1
7	Rural 95%	2017-5-10	10:57	4709	64.8	49.5	12	9	14	155	85	1.3
8	RDE_H 95%	2017-5-10	12:27	5971	71.9	43.4	15	12	18	195	113	3.9
9	City to City 95%	2017-5-10	14:09	1543	23.7	55.3	15	12	17	159	64	1.3
10	RDE_C 55%	2017-5-11	8:03	5906	73.3	44.7	14	11	18	200*	270	3.8
11	Short trip 55%	2017-5-11	9:44	627	4.7	26.8	17	17	17	223	232	2.5
12	Delivery trip 55%	2017-5-11	9:57	4381	17.0	14.0	17	16	19	236	180	2.4
13	ISC_H 55%	2017-5-11	11:11	7455	120.6	58.3	21	16	24	168	70	1.6
14	City to City 55%	2017-5-11	13:17	2607	25.1	34.6	22	16	24	183	104	1.2
Total					833.2					178	151	4.4

Remarks:

- RDE trips 1, 3, 8 and 10 comply with the boundary conditions.
- RDE trips 3, 8 and 10 comply with the trip dynamics criteria.
- RDE trip 1 does not comply with the trip criteria because the number of accelerations in the motorway part are too low.
- Regeneration of the DPF took place during trip 2, 6 and 10.
- In this test programme of 900 km (incl. commissioning) the fuel consumption of the vehicle was 7.69 l/100 km and the AdBlue consumption 16.75 l/10,000 km.

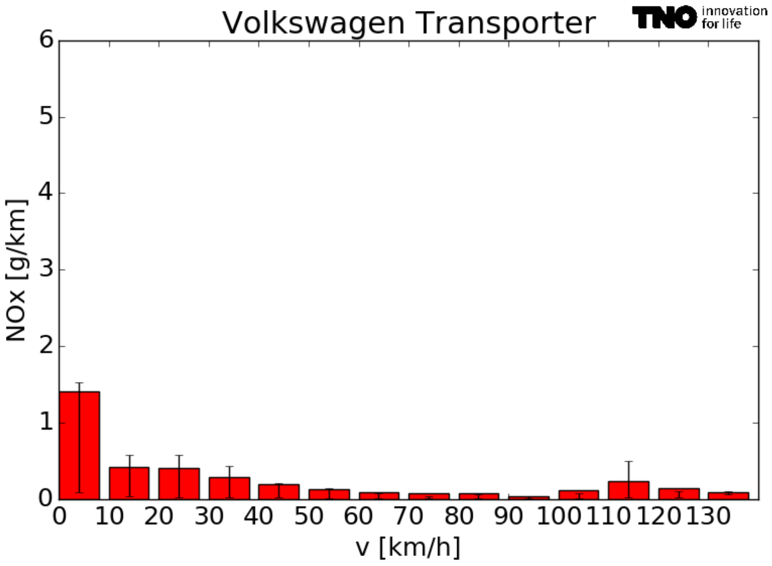


Figure 3-13: Average NOx emissions of a Volkswagen Kombi Transporter Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

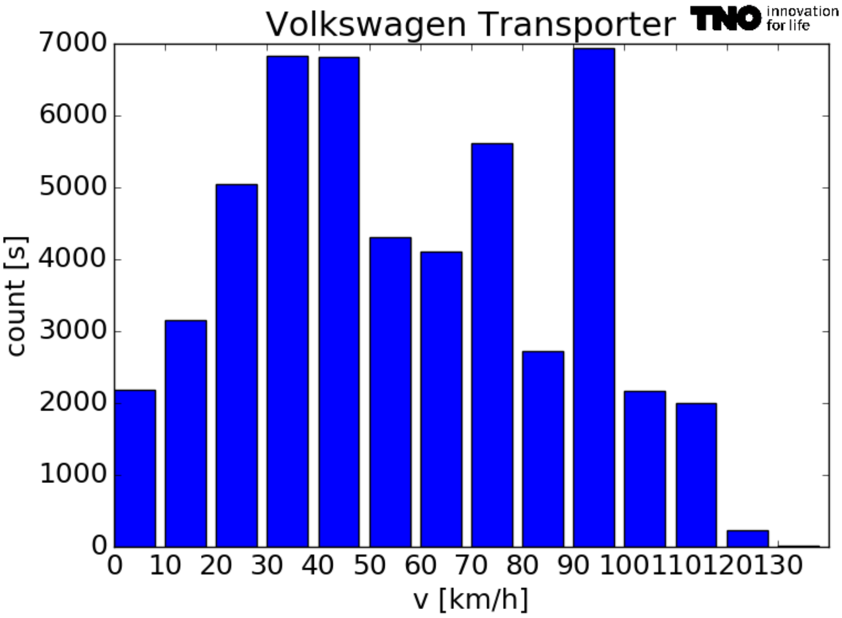


Figure 3-14: Number of seconds per velocity bin, over all trips. Idling is excluded.

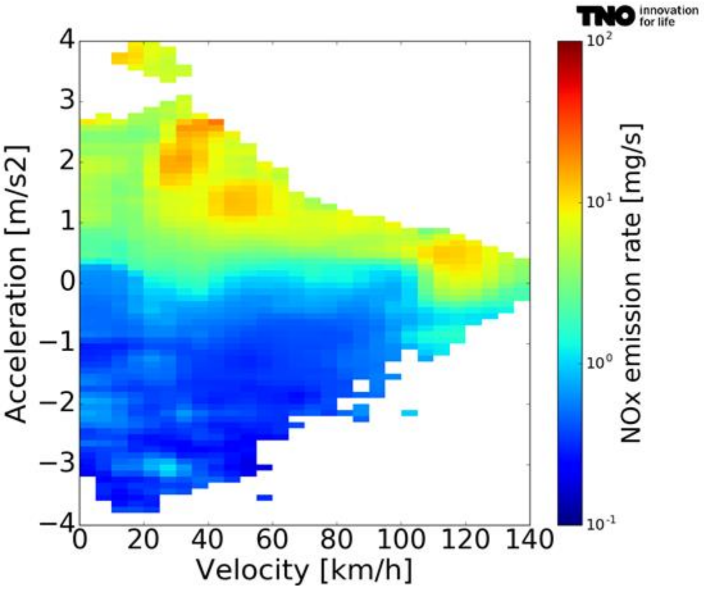


Figure 3-15: NOx emission rate [mg/s] of a Volkswagen Kombi Transporter Euro 6 diesel in bins of velocity and acceleration.

3.1.6 *Mercedes-Benz Citan (55 kW)*

Table 3-11: Vehicle specifications of the Mercedes Citan.

Trade Mark	[-]	Mercedes-Benz
Type	[-]	Citan
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 2
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1461
Max. Power	[kW]	55
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	1330
Declared CO_2 emission	[g/km]	112
Vehicle Identification Number	[-]	WDF4156031U212577
Vehicle Test Euro	[kg]	1589-1925
Odometer	[km]	17
Registration Date	[dd-mm-yy]	05/05/17

Table 3-12: Emission results per trip of a Mercedes Citan Euro 6 diesel.

No.	Trip ID + payload%	Date	Start time	Duration	Distance	Average velocity	Ambient temperature Avg/min/max			CO_2	NO_x	NH_3
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2017-5-12	8:47	6206	72.7	42.2	12	11	13	134	302	-
2	Motorway 28%	2017-5-12	10:46	4080	89.5	79.0	14	13	16	129	108	-
3	RDE_H 28%	2017-5-12	12:25	6386	72.3	40.8	17	16	18	135*	407	-
4	Congest_H 28%	2017-5-12	14:45	5204	85.3	59.0	20	18	21	111	129	-
5	Congest_C 95%	2017-5-17	7:23	5685	82.2	52.0	21	19	23	129	206	-
6	City 95%	2017-5-17	9:07	4322	26.8	22.4	23	21	24	153	883	-
7	Rural 95%	2017-5-17	10:34	4853	64.4	47.8	26	23	29	122	394	-
8	RDE_H 95%	2017-5-17	12:17	5888	71.8	43.9	29	26	31	174*	959	-
9	City to City 95%	2017-5-17	13:59	2774	21.3	27.6	31	29	33	156	458	-
10	RDE_C 55%	2017-5-16	7:52	6149	72.2	42.3	20	19	21	144	502	-
11	Short trip 55%	2017-5-16	9:40	466	4.2	32.3	22	21	23	157	389	-
12	Delivery trip 55%	2017-5-16	9:51	4181	15.3	13.1	23	21	26	165	838	-
13	ISC_H 55%	2017-5-16	11:15	7323	121.2	59.6	25	23	29	131*	387	-
14	City to City 55%	2017-5-16	13:24	2733	21.4	28.2	27	25	30	147	349	-
Total					844.7					137	412	-

Remarks:

- RDE trips 1, 3, 8 and 10 comply with the boundary conditions.
- RDE trips 1,3 and 10 do not comply with the trip criteria because the number of accelerations in the motorway part is too low.
- RDE trip 8 does not comply with the trip criteria because the v*a(pos) value in the urban part is too high.
- Regeneration of the DPF took place during trip 3, 8 and 13.
- In this test programme of 1160 km (incl. commissioning) the fuel consumption of the vehicle was 5.65 l/100 km.

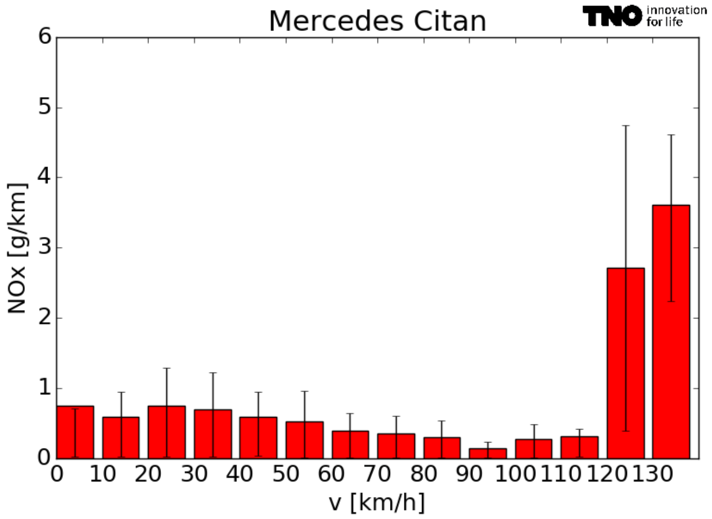


Figure 3-16: Average NO_x emissions of a Mercedes Citan Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

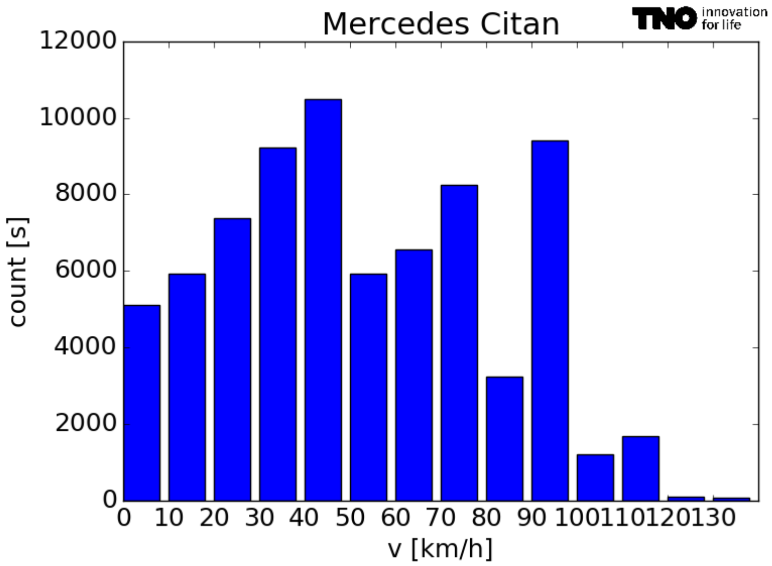


Figure 3-17: Number of seconds per velocity bin, over all trips. Idling is excluded.

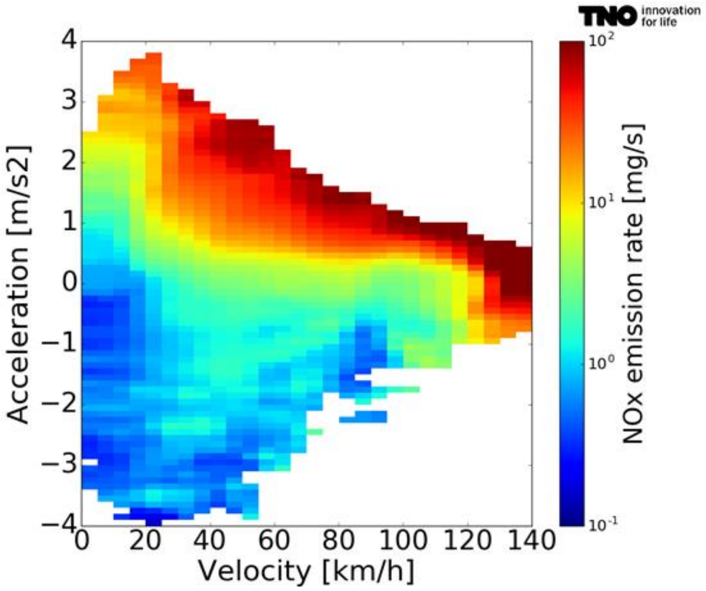


Figure 3-18: NO_x emission rate [mg/s] of a Mercedes Citan Euro 6 diesel in bins of velocity and acceleration.

3.1.7 Mercedes-Benz Vito (100 kW)

Table 3-13: Vehicle specifications of the Mercedes Vito.

Trade Mark	[-]	Mercedes-Benz
Type	[-]	Vito
Body	[-]	Passenger Vehicle
Vehicle Category	[-]	M1
Fuel	[-]	Diesel
Swept Volume	[cm^3]	2143
Max. Power	[kW]	100
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	1910
Declared CO_2 emission	[g/km]	158
Vehicle Identification Number	[-]	WDF44770513102251
Vehicle Test Euro	[kg]	2637-3021
Odometer	[km]	44,875
Registration Date	[dd-mm-yy]	29/04/17

Table 3-14: Emission results per trip of a Mercedes Vito Euro 6 diesel.

No.	Trip ID + payload%	Date	Start time	Duration	Distance	Average velocity	Ambient temperature Avg/min/max			CO_2	NO_x	NH_3
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2017-5-16	8:17	5968	72.2	43.5	20	18	22	167	471	0.4
2	Motorway 28%	2017-5-16	10:00	3859	90.0	84.0	22	20	24	155	232	0.3
3	RDE_H 28%	2017-5-16	11:23	5689	72.2	45.7	24	21	28	179	429	0.3
4	Congest_H 28%	2017-5-16	13:56	4597	86.3	67.6	27	23	30	136	239	0.3
5	Congest_C 95%	2017-5-30	7:05	5652	82.0	52.2	18	16	21	149	171	0.7
6	City 95%	2017-5-30	8:49	4139	26.1	22.7	18	16	22	253*	332	2.7
7	Rural 95%	2017-5-30	10:18	5101	64.1	45.2	17	15	19	180*	273	0.7
8	RDE_H 95%	2017-5-30	12:12	5770	71.5	44.6	18	16	24	217	456	0.3
9	City to City 95%	2017-5-30	13:52	3002	21.0	25.2	21	18	28	202	272	0.6
10	RDE_C 55%	2017-5-31	8:04	5808	72.6	45.0	18	15	23	170	180	0.3
11	Short trip 55%	2017-5-31	9:45	405	4.2	37.0	20	19	24	194	407	0.8
12	Delivery trip 55%	2017-5-31	10:03	4324	14.7	12.2	22	19	29	285	660	1.2
13	ISC_H 55%	2017-5-31	11:16	7628	120.1	56.7	21	19	27	156	236	0.3
14	City to City 55%	2017-5-31	13:27	2614	21.4	29.5	20	17	26	181	295	0.5
Total					851.7					170	294	0.5

Remarks:

- RDE trips 1, 3, 8 and 10 comply with the boundary conditions.
- RDE trips 1,3 and 8 comply with the trip dynamics criteria.
- RDE trip 10 does not comply with the trip criteria because the RPA value in the motorway part is too low.
- Regeneration of the DPF took place during trip 6 and 7.
- In this test programme of 1484 km (incl. commissioning) the fuel consumption of the vehicle was 7.98 l/100 km and the AdBlue consumption 14.43 l/10,000 km.

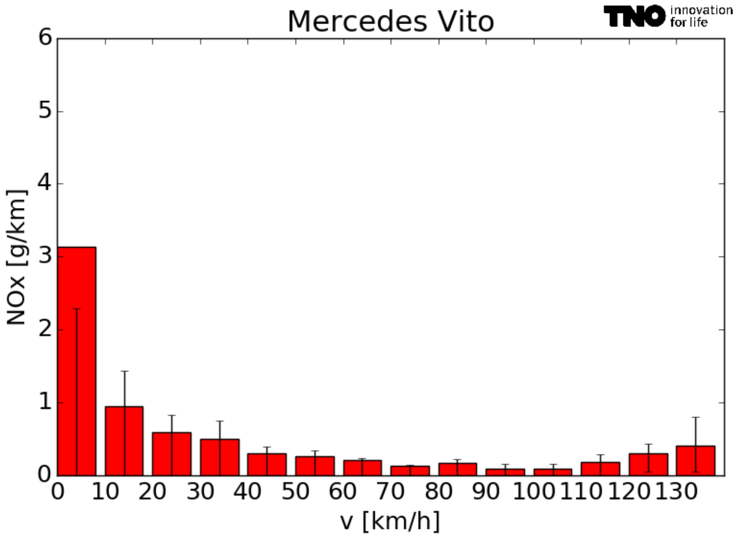


Figure 3-19: Average NO_x emissions of a Mercedes Vito Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

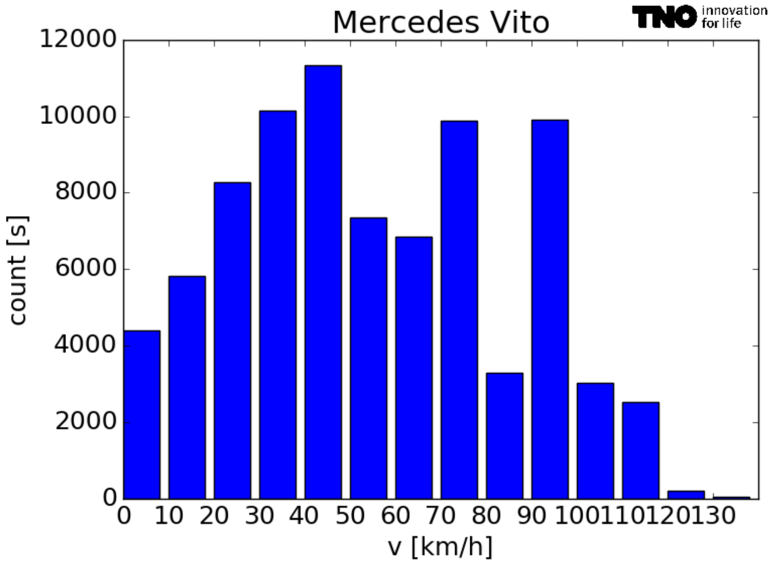


Figure 3-20: Number of seconds per velocity bin, over all trips. Idling is excluded.

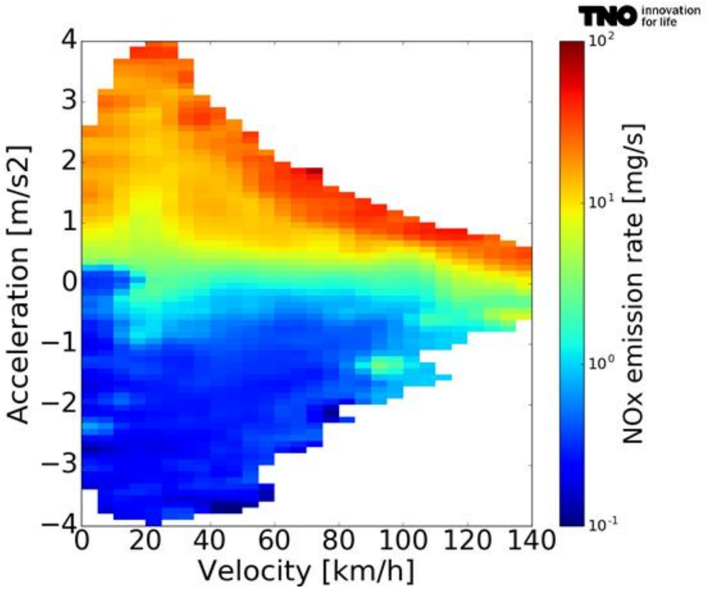


Figure 3-21: NO_x emission rate [mg/s] of a Mercedes Vito Euro 6 diesel in bins of velocity and acceleration.

3.1.8 Peugeot Expert (90 kW)

Table 3-15: Vehicle specifications of the Peugeot Expert.

Trade Mark	[-]	Peugeot
Type	[-]	Expert
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1997
Max. Power	[kW]	90
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	1688
Declared CO_2 emission	[g/km]	139
Vehicle Identification Number	[-]	VF3VFAHKHGZ032078
Vehicle Test Euro	[kg]	2176-2523
Odometer	[km]	12878
Registration Date	[dd-mm-yy]	09/09/16

Table 3-16: Emission results per trip of a Peugeot Expert Euro 6 diesel.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_C 28%	2017-5-19	8:42	6309	72.6	41.5	12	-	15	158	201	2.2
2	Motorway 28%	2017-5-19	10:45	4150	89.6	77.7	14	-	15	154	297	1.5
3	RDE_H 28%	2017-5-19	12:21	6767	71.8	38.2	15	-	16	164	343	1.4
4	Congest_H 28%	2017-5-19	14:45	6755	84.4	45.0	16	-	18	152*	228	4.5
5	Congest_C 95%	2017-5-22	7:42	5126	82.7	58.1	19	-	21	156	247	0.9
6	City 95%	2017-5-22	9:17	4137	26.6	23.1	22	-	23	217	778	0.8
7	Rural 95%	2017-5-22	10:44	4980	64.2	46.4	23	-	25	166	441	0.7
8	RDE_H 95%	2017-5-22	12:44	5563	71.9	46.5	26	-	27	200	878	0.8
9	City to City 95%	2017-5-22	14:25	2918	21.4	26.4	27	-	29	191	641	0.5
10	RDE_C 55%	2017-5-23	7:34	6214	72.7	42.1	17	-	19	174	365	1.0
11	Short trip 55%	2017-5-23	9:20	405	4.2	37.6	19	-	21	188	465	1.1
12	Delivery trip 55%	2017-5-23	9:41	4563	16.0	12.6	18	-	20	217	610	1.2
13	ISC_H 55%	2017-5-23	11:05	7546	121.1	57.8	19	-	21	159	284	1.3
14	City to City 55%	2017-5-23	13:17	3015	21.3	25.5	19	-	24	198	443	0.8
Total					820.5					171	395	1.5

Remarks:

- RDE trips 1, 8 and 10 comply with the boundary conditions.
- RDE trip 3 does not comply with the boundary conditions because the idling time in the urban part is too long.
- RDE trip 10 complies with the trip dynamics criteria.
- RDE trips 1 and 3 do not comply with the trip criteria because the RPA value in the motorway part is too low.
- RDE trip 8 does not comply with the trip criteria because the v*a(pos) value in the urban part is too high.
- Regeneration of the DPF took place during trip 4.
- In this test programme of 978 km (incl. commissioning) the fuel consumption of the vehicle was 6.64 l/100 km and the AdBlue consumption 7.54 l/10,000 km.

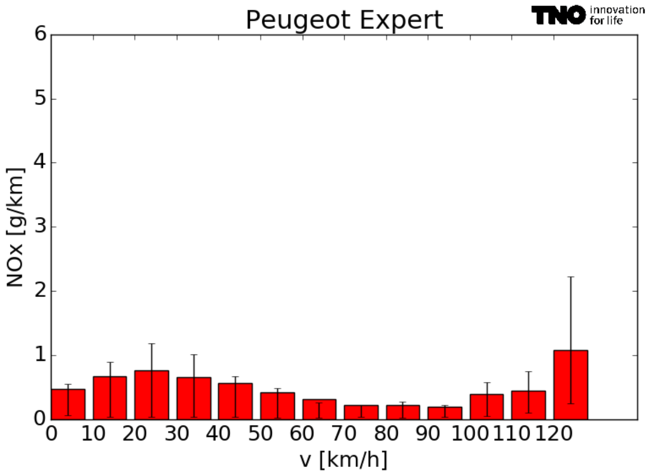


Figure 3-22: Average NO_x emissions of a Peugeot Expert Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

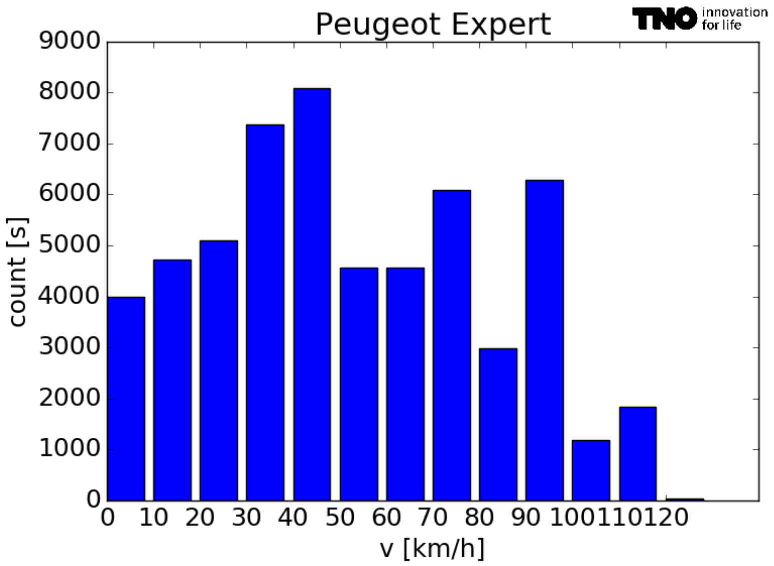


Figure 3-23: Number of seconds per velocity bin, over all trips. Idling is excluded.

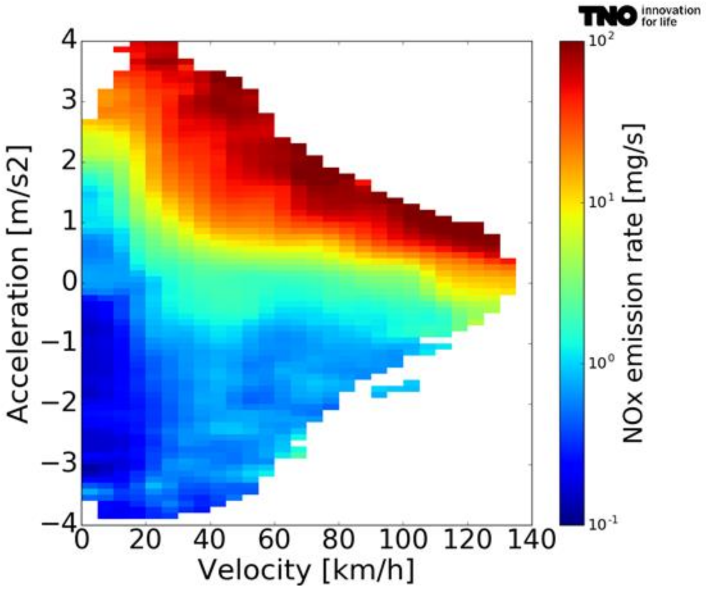


Figure 3-24: NO_x emission rate [mg/s] of a Peugeot Expert Euro 6 diesel in bins of velocity and acceleration.

3.1.9 Ford Transit Euro 5 (74 kW)

Table 3-17: Vehicle specifications of the Ford Transit

Trade Mark	[-]	Ford
Type	[-]	Transit
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	2198
Max. Power	[kW]	74
Euro Class	[-]	Euro 5b
Vehicle Empty Mass	[kg]	2167
Declared CO_2 emission	[g/km]	196
Vehicle Identification Number	[-]	WF0XXXTTGXEG56201
Vehicle Test Euro	[kg]	2620-2945
Odometer	[km]	56,356
Registration Date	[dd-mm-yy]	30-01-15

Table 3-18: Emission results per trip of a Ford Transit Euro 5 diesel. The ambient temperature is not measured at the vehicle, but retrieved from the local weather station database.

No.	Trip ID + payload%	Date	Start time	Duration	Distance	Average velocity	Ambient temperature Avg/min/max			CO_2	NO_x	NH_3
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_16.2%%	13-06-2016	14:36	6335	71.9	40.8	16	-	-	253.8	1279.3	-
13	ISC_42.6%	14-06-2016	9:42	8002	122	58.4	16	-	-	221.2	942.4	-
12	Delivery trip_16.2%	14-06-2016	11:57	3452	21.6	22,5	17	-	-	318.4	1228.4	-
Total				17789	215.5	43.6	-	-	-	241.8	1083.5	-

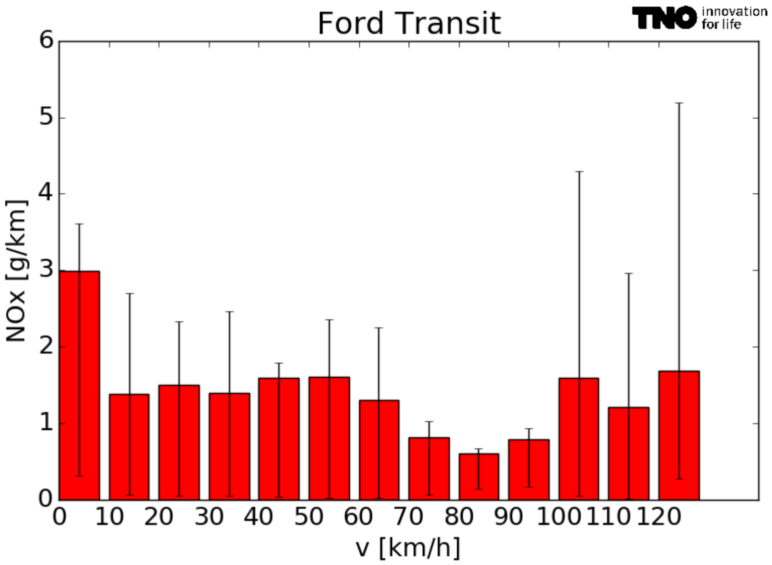


Figure 3-25: Average NO_x emissions of a Ford Transit Euro 5 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

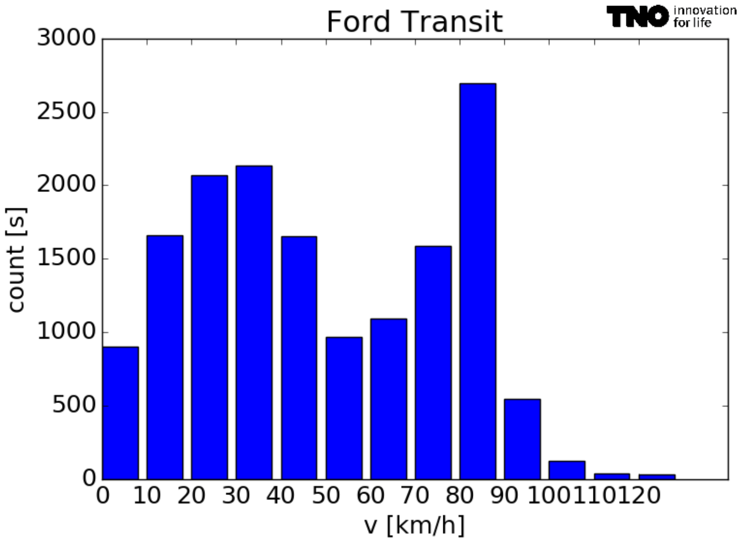


Figure 3-26: Number of seconds per velocity bin, over all trips. Idling is excluded.

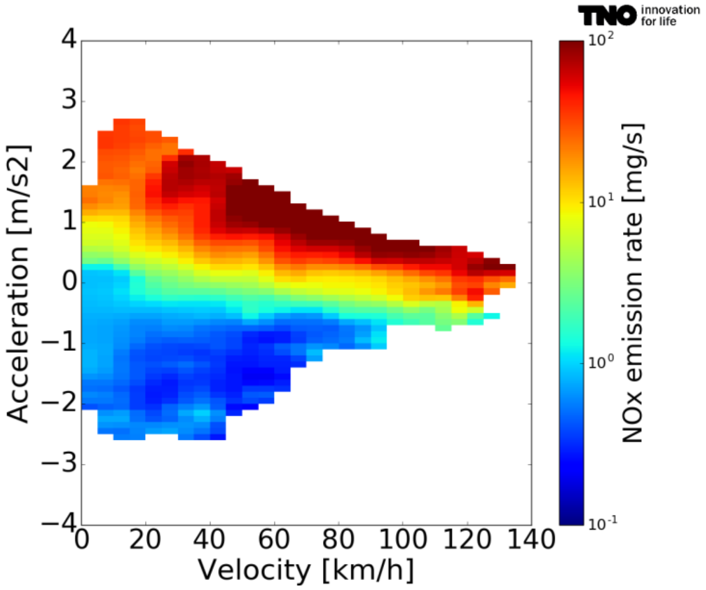


Figure 3-27: NO_x emission rate [mg/s] of a Ford Transit Euro 5 diesel in bins of velocity and acceleration.

3.1.10 *Ford Transit Euro 6 (96 kW)*

Table 3-19: Vehicle specifications of the Ford Transit.

Trade Mark	[-]	Ford
Type	[-]	Transit
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1995
Max. Power	[kW]	96
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	2383
Declared CO_2 emission	[g/km]	187
Vehicle Identification Number	[-]	WF0XXXTTGXGD29962
Vehicle Test Euro	[kg]	2768-3042
Odometer	[km]	11,751
Registration Date	[dd-mm-yy]	29-09-16

Table 3-20: Emission results per trip of a Ford Transit Euro 6 diesel. The ambient temperature is not measured at the vehicle, but retrieved from the local weather station database.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_28%	16-03-2017	12:19	5794	71.6	44.5	15	-	-	237.8	533.6	1.5
12	Delivery trip_28%	16-03-2017	14:18	3021	16.99	20.2	16	-	-	244.6	569.8	2.3
13	ISC_55%	17-03-2017	09:30	8106	121.1	53.8	8	-	-	211.9*	287.6	2.5
Total				16921	209.7	44.6	-	-	-	223.4	394.4	2.1

Remarks:

- Regeneration of the DPF took place during trip 13.

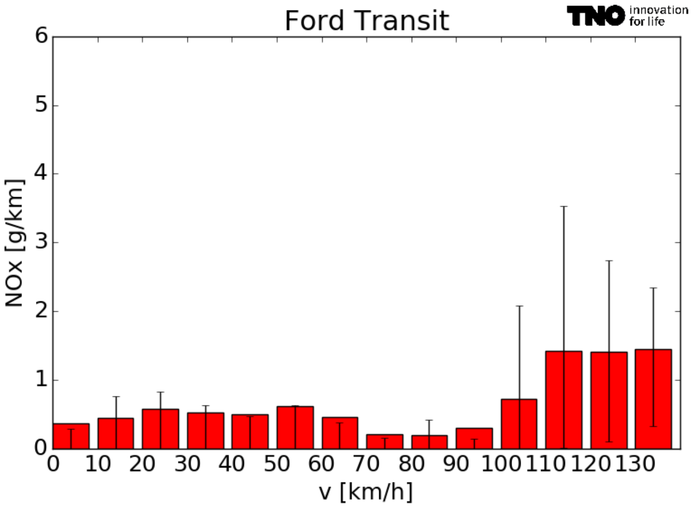


Figure 3-28: Average NO_x emissions of a Ford Transit Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

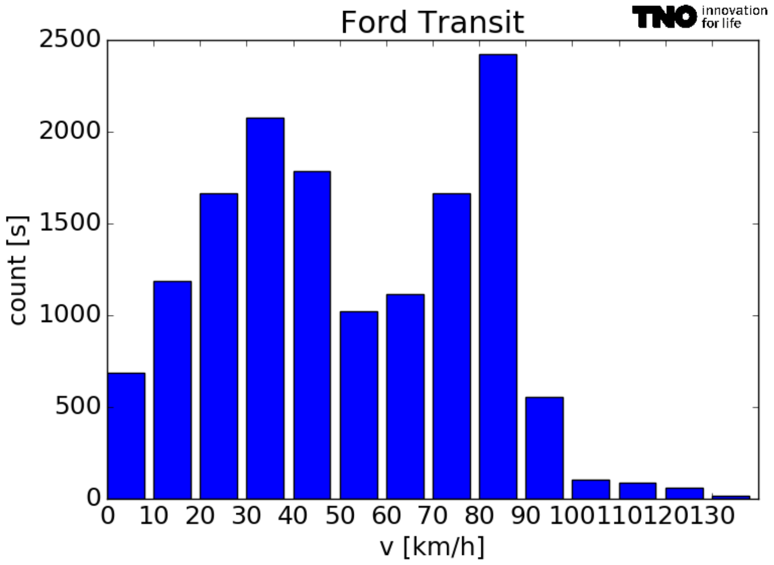


Figure 3-29: Number of seconds per velocity bin, over all trips. Idling is excluded.

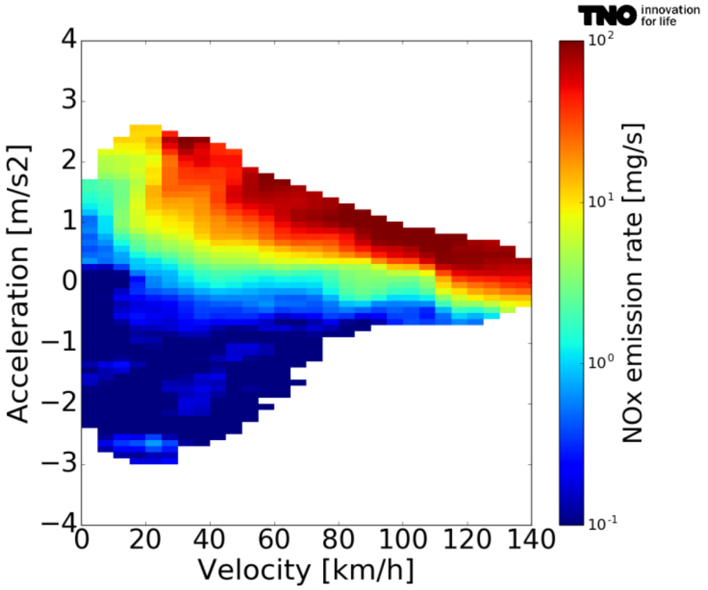


Figure 3-30: NO_x emission rate [mg/s] of a Ford Transit Euro 6 diesel in bins of velocity and acceleration.

3.1.11 Ford Transit Euro VI (114 kW)

Table 3-21: Vehicle specifications of the Ford Transit

Trade Mark	[-]	Ford
Type	[-]	Transit
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1995
Max. Power	[kW]	114
Euro Class	[-]	Euro VI
Vehicle Empty Mass	[kg]	3181
Declared CO_2 emission	[g/km]	n.a.
Vehicle Identification Number	[-]	WF0HXXTTGHGS10833
Vehicle Test Euro	[kg]	3281
Odometer	[km]	36624
Registration Date	[dd-mm-yy]	13-01-2017

Table 3-22: Emission results per trip of a Ford Transit Euro VI diesel. The ambient temperature is not measured at the vehicle, but retrieved from the local weather station database.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_28%	9-8-2017	10:56	5647	72	45.9	18	-	-	292	220	-
12	Delivery trip_28%	9-8-2017	12:47	2708	17	22.6	19	-	-	317	413	-
13	ISC_55%	10-8-2017	9:29	7978	121	54.6	18	-	-	250	112	-
Total				18133	210	46	-	-	-	276	199	-

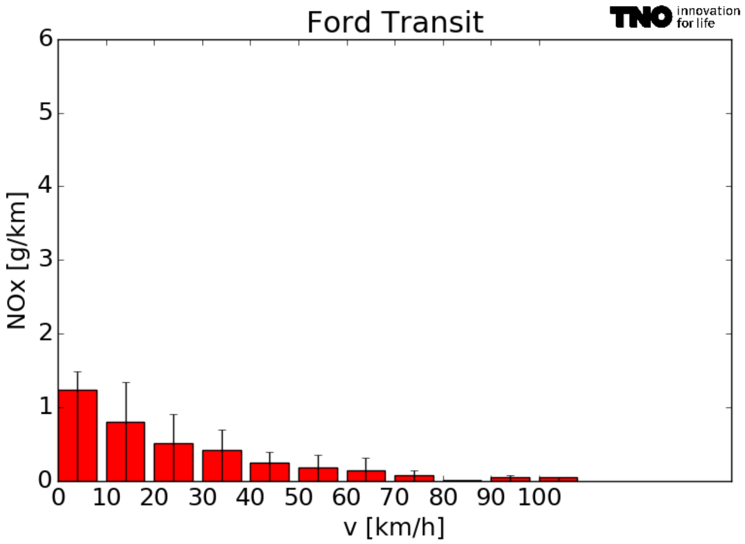


Figure 3-31: Average NO_x emissions of a Ford Transit Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

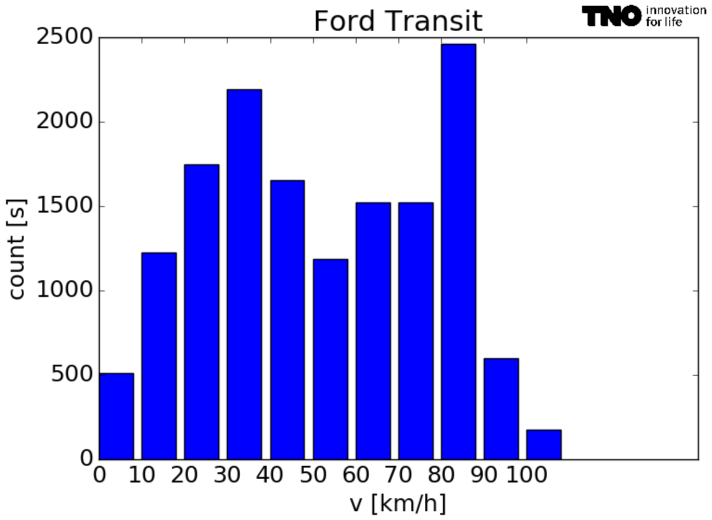


Figure 3-32: Number of seconds per velocity bin, over all trips. Idling is excluded

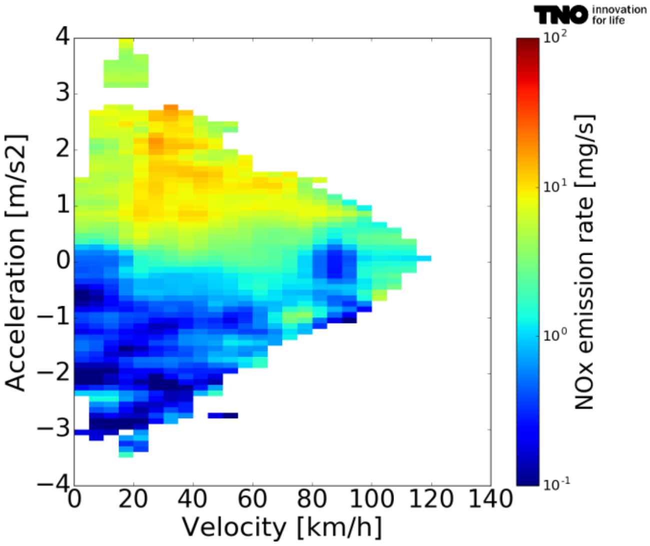


Figure 3-33: NO_x emission rate [mg/s] of a Ford Transit Euro 6 diesel in bins of velocity and acceleration.

3.1.12 Mercedes-Benz Sprinter Euro 5 (95 kW)

Table 3-23: Vehicle specifications of the Mercedes-Benz Sprinter.

Trade Mark	[-]	Mercedes-Benz
Type	[-]	Sprinter
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	2143
Max. Power	[kW]	95
Euro Class	[-]	Euro 5b
Vehicle Empty Mass	[kg]	2535
Declared CO_2 emission	[g/km]	195
Vehicle Identification Number	[-]	WDB9061351N658359
Vehicle Test Euro	[kg]	2900-3125
Odometer	[km]	23,878
Registration Date	[dd-mm-yy]	18-3-16

Table 3-24: Emission results per trip of a Mercedes-Benz Sprinter Euro 5 diesel. In some cases the minimum temperature is unknow due to read-out errors in the sensor resulting in temperature 0.

No.	Trip ID + payload%	Date	Start time	Duration	Distance	Average velocity	Ambient temperature Avg/min/max			CO_2	NO_x	NH_3
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
12	Delivery trip_28%	05-09-2016	10:11	2910	16.6	20.5	20.1	-	28	358.1	1834.3	-
1	RDE_28%	05-09-2016	11:33	6000	71.6	43	21.6	-	26	353.6	1563.2	-
13	ISC_55%	06-09-2016	19:16	7861	121.6	55.7	22.2	-	23	315.5	1276.8	-
Total				16771	209.9	45	21.7	-	26	331.9	1418.6	-

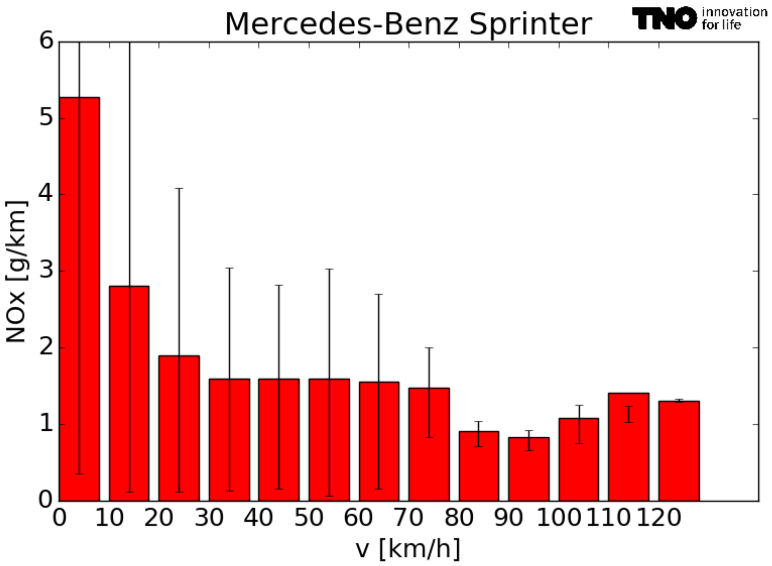


Figure 3-34: Average NO_x emissions of a Mercedes-Benz Sprinter Euro 5 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

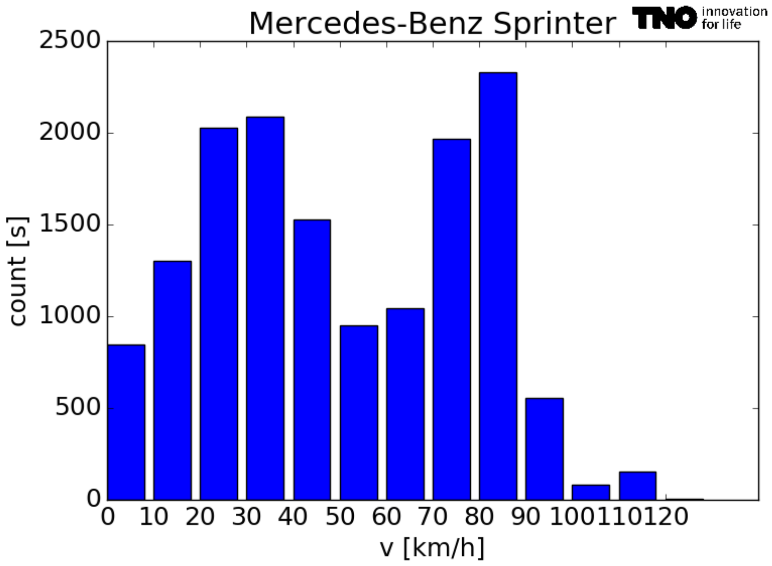


Figure 3-35: Number of seconds per velocity bin, over all trips. Idling is excluded.

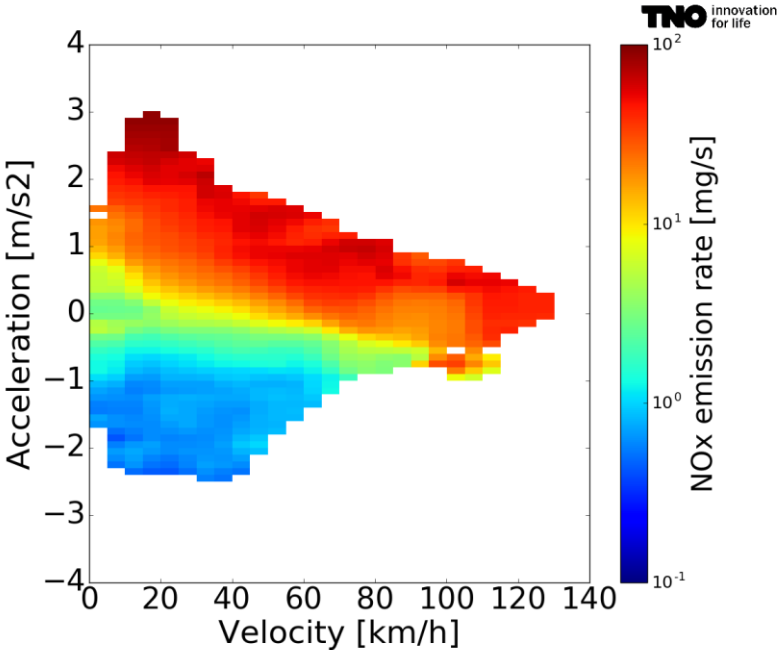


Figure 3-36: NO_x emission rate [mg/s] of a Mercedes-Benz Sprinter Euro 5 diesel in bins of velocity and acceleration.

3.1.13 Mercedes-Benz Sprinter Euro 6 (105 kW)

Table 3-25: Vehicle specifications of the Mercedes-Benz Sprinter.

Trade Mark	[-]	Mercedes-Benz
Type	[-]	Sprinter
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	2143
Max. Power	[kW]	105
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	2695
Declared CO_2 emission	[g/km]	192
Vehicle Identification Number	[-]	WDB9061351N694522
Vehicle Test Euro	[kg]	2992-3183
Odometer	[km]	12,770
Registration Date	[dd-mm-yy]	09-11-16

Table 3-26: Emission results per trip of a Mercedes-Benz Sprinter Euro 6 diesel.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
13	ISC_55%	03-02-2017	09:26	7631	119.5	56.4	9.5	9	14	289.3	266.7	1.1
12	Delivery trip_28%	06-02-2017	10:12	2697	16.7	22.3	7.1	-	14	359.7	401.9	5.5
1	RDE_28%	06-02-2017	11:33	5660	71.4	45.4	7.1	6	11	331.3	261.8	4.3
Total				15988	207.6	46.8	8.2	-	14	309.4*	275.9	2.6

Remarks:

- Regeneration of the DPF took place during trip 1.

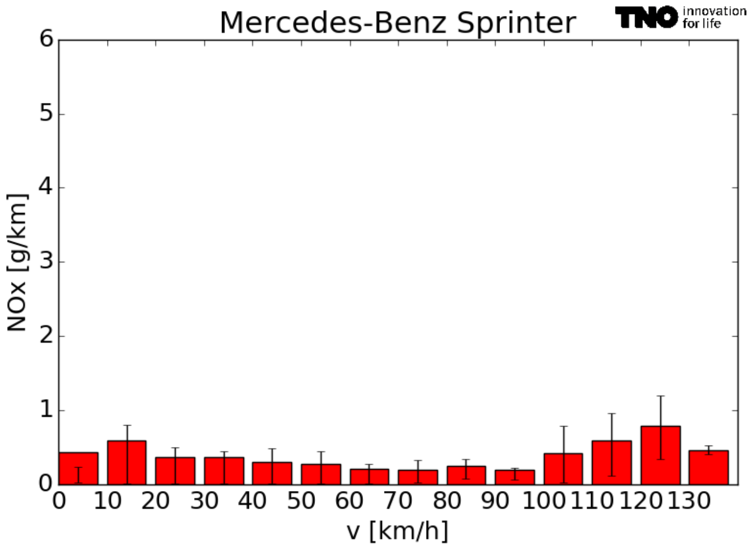


Figure 3-37: Average NO_x emissions of a Mercedes-Benz Sprinter Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

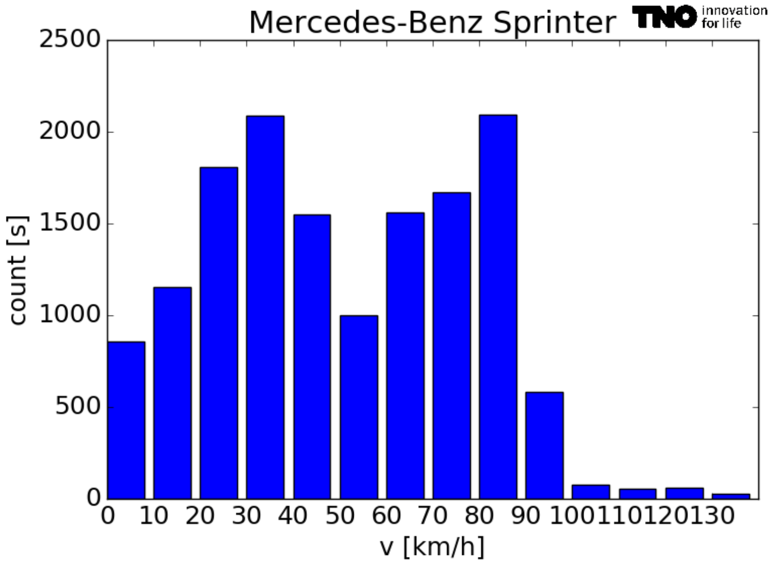


Figure 3-38: Number of seconds per velocity bin, over all trips. Idling is excluded.

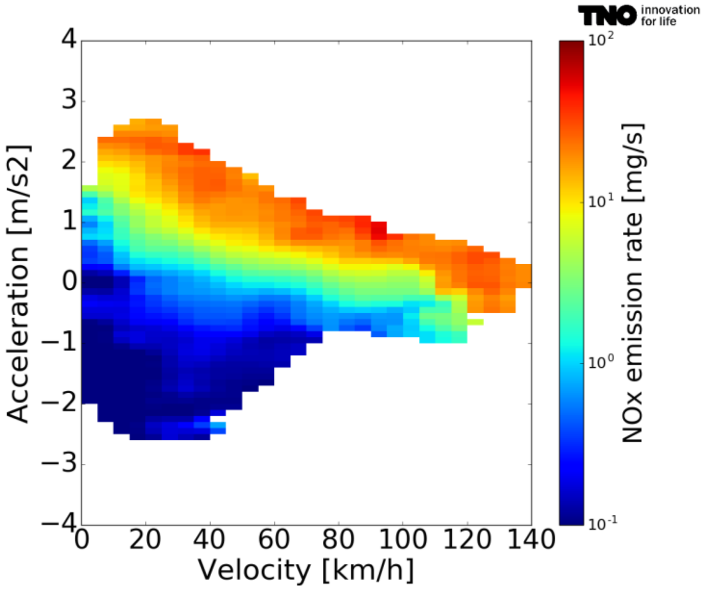


Figure 3-39: NO_x emission rate [mg/s] of a Mercedes-Benz Sprinter Euro 6 diesel in bins of velocity and acceleration.

3.1.14 Mercedes-Benz Sprinter Euro VI (120 kW)

Table 3-27: Vehicle specifications of the Mercedes-Benz Sprinter

Trade Mark	[-]	Mercedes-Benz
Type	[-]	Sprinter
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	2143
Max. Power	[kW]	120
Euro Class	[-]	Euro VI
Vehicle Empty Mass	[kg]	2960
Declared CO_2 emission	[g/km]	212
Vehicle Identification Number	[-]	WDB9061551N641849
Vehicle Test Euro	[kg]	3185-3310
Odometer	[km]	30,734
Registration Date	[dd-mm-yy]	06-11-16

Table 3-28: Emission results per trip of a Mercedes-Benz Sprinter Euro VI diesel

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
12	Delivery trip_28%	24-08-2016	10:16	2875	17	21.2	29	-	34	311.9	648.5	1.5
1	RDE_28%	24-08-2016	11:50	6171	71.5	41.7	32	29	34	331.6	224	3.1
13	ISC_55%	26-08-2016	09:24	8504	121	51.2	26	22	30	289.4	103.1	1.5
Total				17550	209.4	42.9	28	-	34	305.6	188.5	2

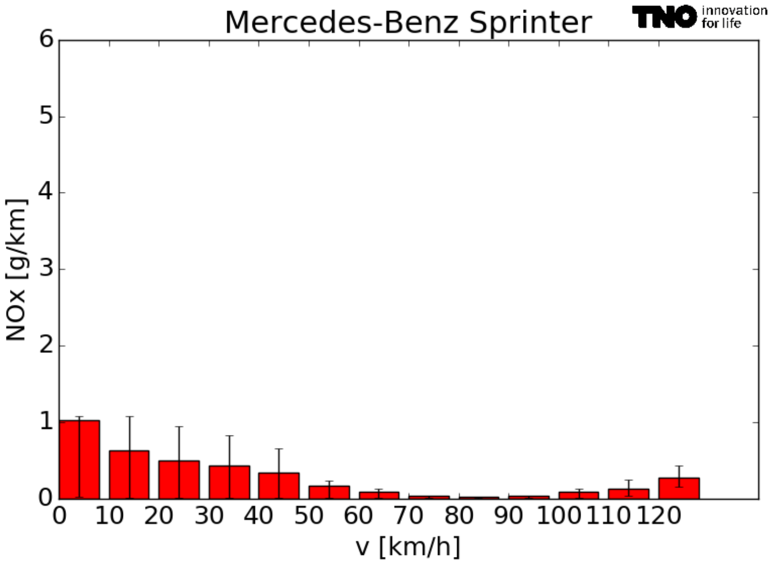


Figure 3-40: Average NO_x emissions of a Mercedes-Benz Sprinter Euro VI diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

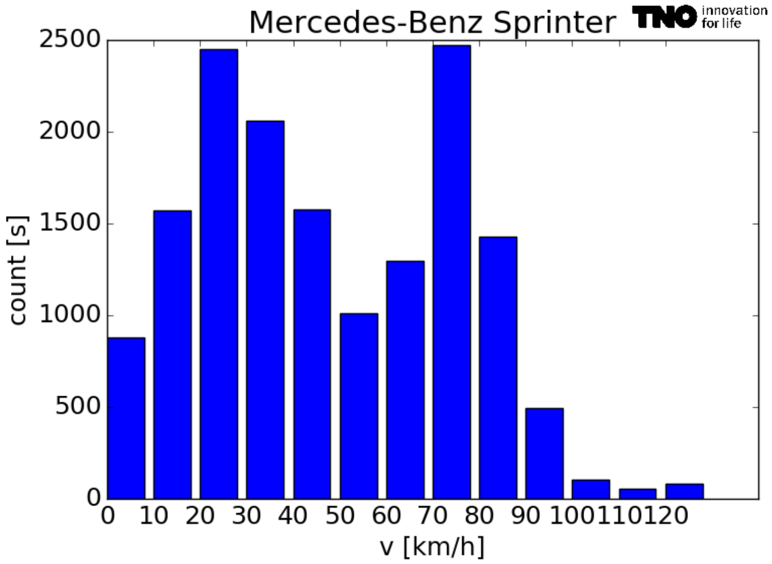


Figure 3-41: Number of seconds per velocity bin, over all trips. Idling is excluded.

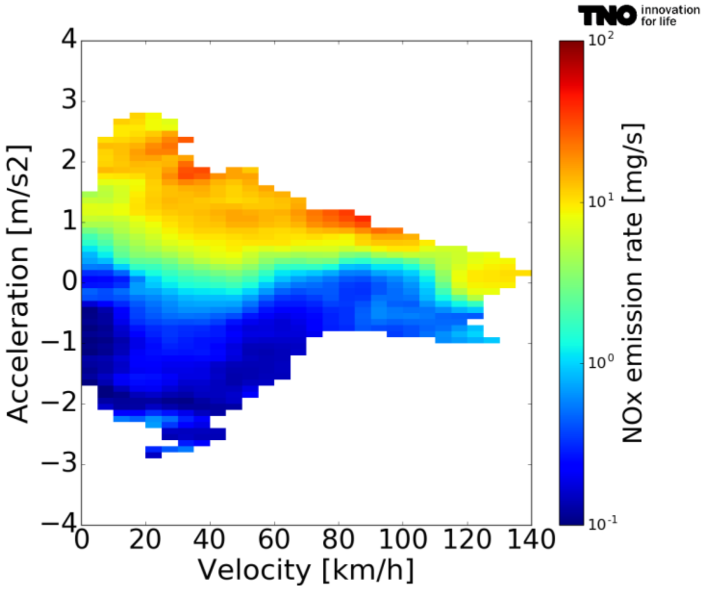


Figure 3-42: NO_x emission rate [mg/s] of a Mercedes-Benz Sprinter Euro VI diesel in bins of velocity and acceleration.

3.1.15 Volkswagen Crafter Euro 5 (100 kW)

Table 3-29: Vehicle specifications of the Volkswagen Crafter

Trade Mark	[-]	Volkswagen
Type	[-]	Crafter
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1968
Max. Power	[kW]	100
Euro Class	[-]	Euro 5b
Vehicle Empty Mass	[kg]	2146
Declared CO_2 emission	[g/km]	229
Vehicle Identification Number	[-]	WV1ZZZ2EZE601214
Vehicle Test Euro	[kg]	2860-2935
Odometer	[km]	60,544
Registration Date	[dd-mm-yy]	20-01-14

Table 3-30: Emission results per trip of a Volkswagen Crafter Euro 5 diesel. The ambient temperature is not measured at the vehicle, but retrieved from the local weather station database.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
1	RDE_28%	13-06-2016	11:02	5714	72.4	45.6	17	-	-	257.3	1022.7	-
12	Delivery trip_28%	13-06-2016	12:38	3157	20.2	23	18	-	-	254.7	860.2	-
13	ISC_55%	14-06-2016	13:51	8340	121.3	52.4	19	-	-	197.6	524.4	-
Total				17211	213.9	44.7	19	-	-	223.2	724.7	-

Remarks:

- Regeneration of the DPF took place during trip 1.

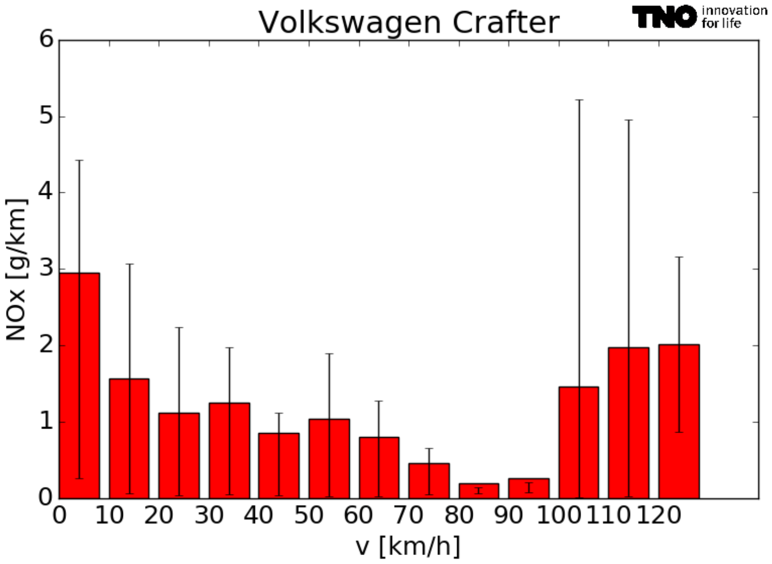


Figure 3-43: Average NO_x emissions of a Volkswagen Crafter Euro 5 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

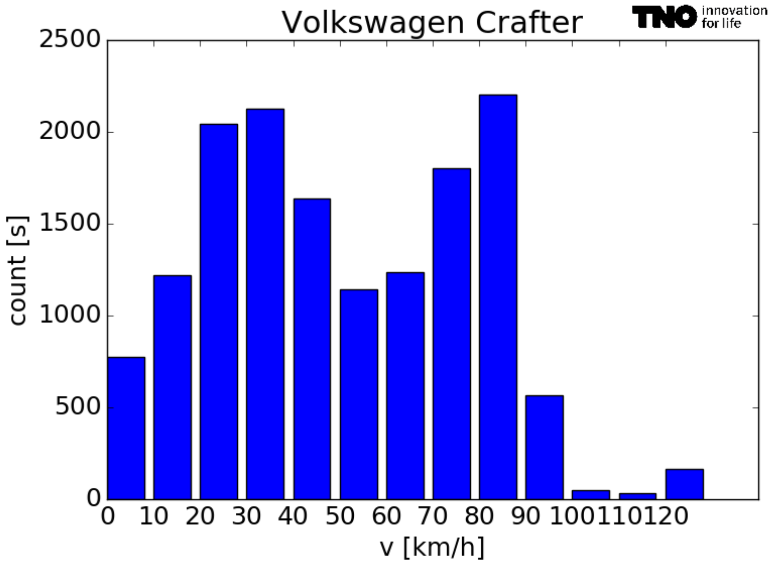


Figure 3-44: Number of seconds per velocity bin, over all trips. Idling is excluded.

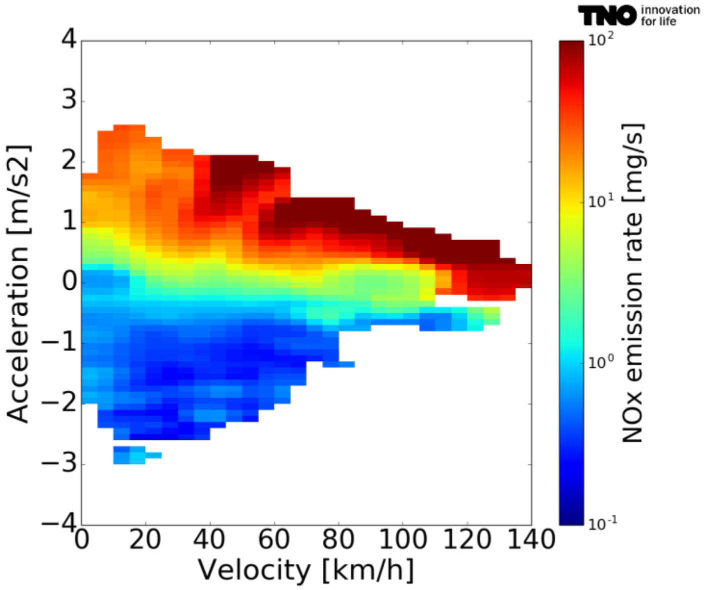


Figure 3-45: NO_x emission rate [mg/s] of a Volkswagen Crafter Euro 5 diesel in bins of velocity and acceleration.

3.1.16 Volkswagen Crafter Euro 6 (80 kW)

Table 3-31: Vehicle specifications of the Volkswagen Crafter

Trade Mark	[-]	Volkswagen
Type	[-]	Crafter
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1968
Max. Power	[kW]	80
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	2158
Declared CO_2 emission	[g/km]	220
Vehicle Identification Number	[-]	WV1ZZZ2EZG6050989
Vehicle Test Euro	[kg]	2522-2773
Odometer	[km]	2,694
Registration Date	[dd-mm-yy]	23-02-17

Table 3-32: Emission results per trip of a Volkswagen Crafter Euro 6 diesel

No.	Trip ID + payload%	Date	Start time	Duration	Distance	Average velocity	Ambient temperature Avg/min/max			CO_2	NO_x	NH_3
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
13	ISC_55%	30-03-2017	10:16	8115	121.4	53.9	18.8	17	21	202.9	28.8	0.9
12	Delivery trip_28%	31-03-2017	8:19	2741	16.9	22.2	15.8	-	17	267.4	129.1	1.7
1	RDE_28%	31-03-2017	11:39	5666	72.1	45.8	20.8	-	23	225.9	35.8	1.3
Total				16522	210.5	45.9	19	-	23	216	39.3	1.1

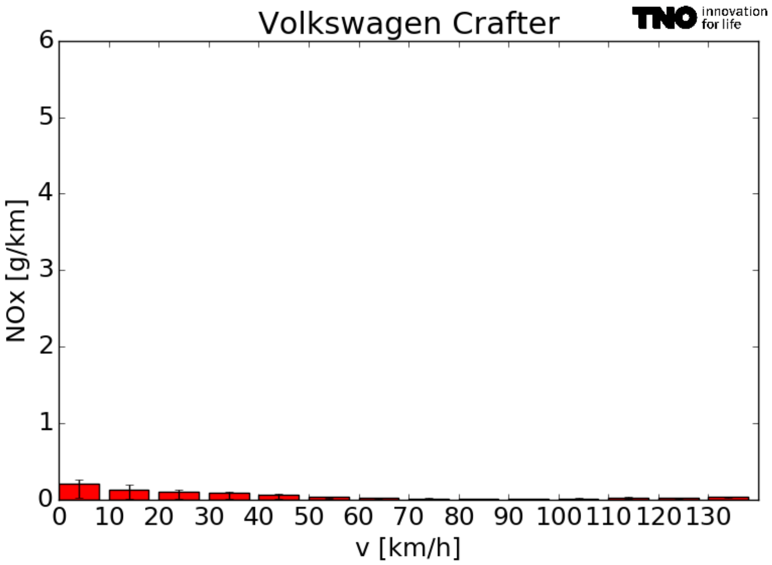


Figure 3-46: Average NO_x emissions of a Volkswagen Crafter Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

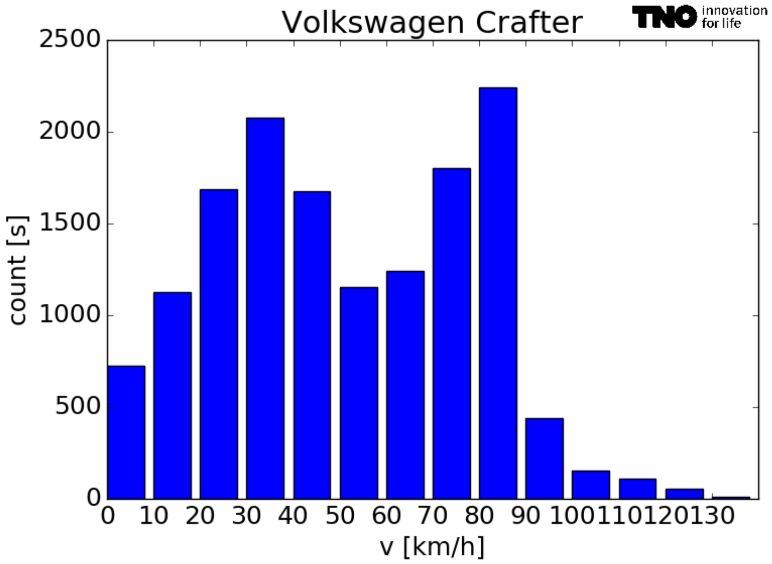


Figure 3-47: Number of seconds per velocity bin, over all trips. Idling is excluded.

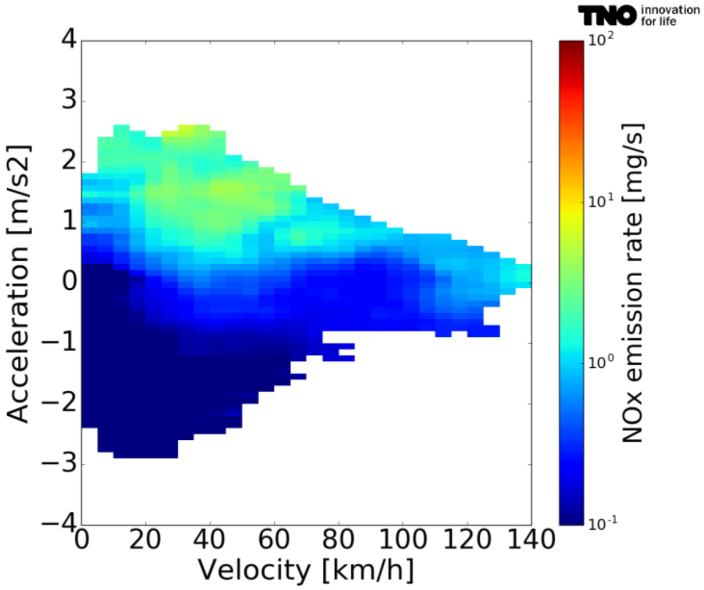


Figure 3-48: NO_x emission rate [mg/s] of a Volkswagen Crafter Euro 6 diesel in bins of velocity and acceleration.

3.1.17 *Volkswagen Crafter Euro VI (120 kW)*

Table 3-33: Vehicle specifications of the Volkswagen Crafter

Trade Mark	[-]	Volkswagen
Type	[-]	Crafter
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	1968
Max. Power	[kW]	120
Euro Class	[-]	Euro VI
Vehicle Empty Mass	[kg]	2146
Declared CO_2 emission	[g/km]	205
Vehicle Identification Number	[-]	WV1ZZZ2FZE7005629
Vehicle Test Euro	[kg]	3068-3230
Odometer	[km]	70,780
Registration Date	[dd-mm-yy]	17-11-14

Table 3-34: Emission results per trip of a Volkswagen Crafter Euro VI diesel. The ambient temperature is not measured at the vehicle, but retrieved from the local weather station database.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
13	ISC_55%	01-03-2017	09:22	7779	121.4	56.2	6	-	-	246.8	89.9	3
12	Delivery trip_28%	01-03-2017	14:12	2761	16.7	21.8	8	-	-	284.7	446.6	2.9
1	RDE_28%	02-03-2017	11:13	5575	72.2	46.6	8	-	-	289.2	146.7	7
Total				16115	210.3	47	7	-	-	264.4	137.7	4.4

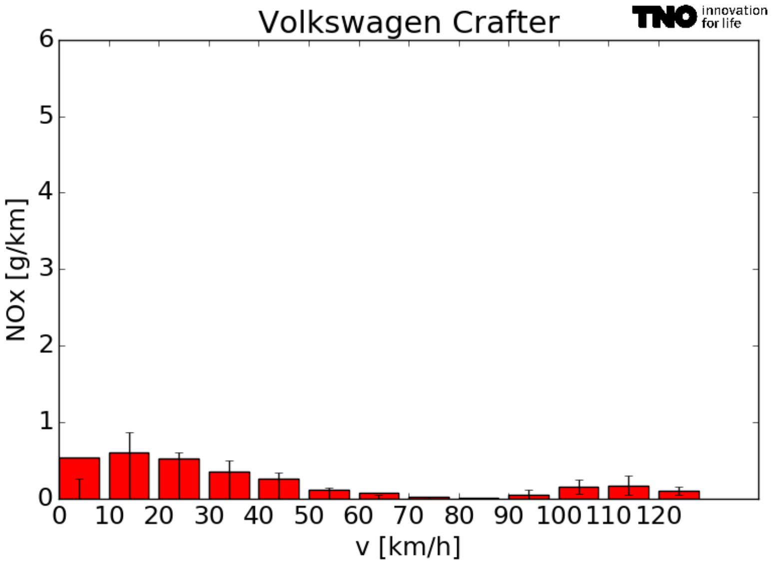


Figure 3-49: Average NO_x emissions of a Volkswagen Crafter Euro VI diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

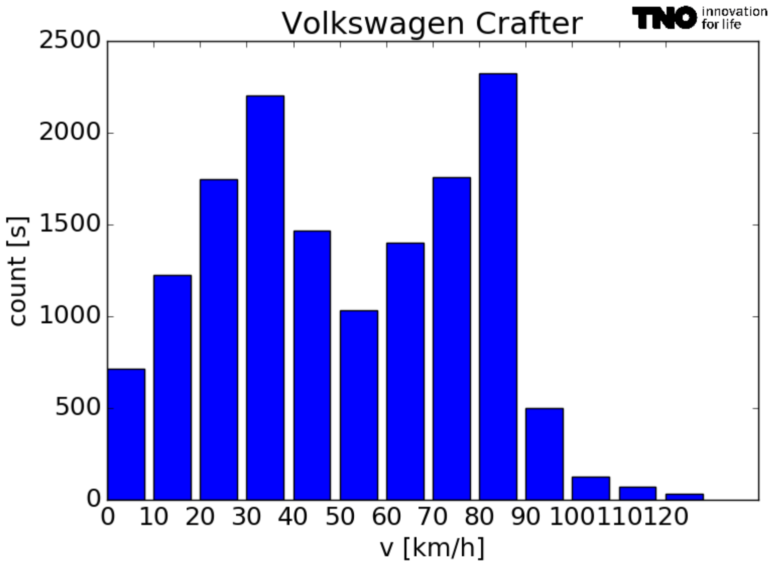


Figure 3-50: Number of seconds per velocity bin, over all trips. Idling is excluded.

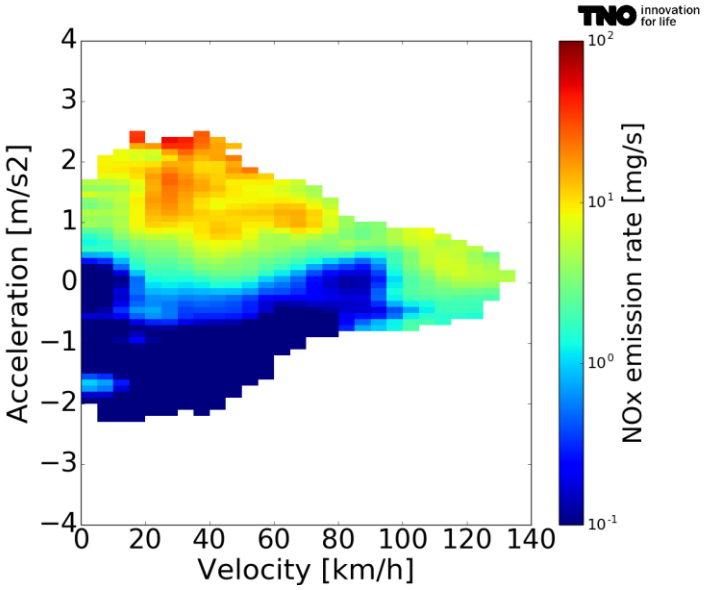


Figure 3-51: NO_x emission rate [mg/s] of a Volkswagen Crafter Euro VI diesel in bins of velocity and acceleration.

3.1.18 Iveco New Daily 35S16 (114 kW)

Table 3-35: Vehicle specifications of the Iveco New Daily 35S16.

Trade Mark	[-]	Iveco
Type	[-]	New Daily 35S16
Body	[-]	Light Commercial Vehicle
Vehicle Category	[-]	N1 Class 3
Fuel	[-]	Diesel
Swept Volume	[cm^3]	2287
Max. Power	[kW]	114
Euro Class	[-]	Euro 6b
Vehicle Empty Mass	[kg]	2366
Declared CO_2 emission	[g/km]	202
Vehicle Identification Number	[-]	ZCFC135B405139372
Vehicle Test Euro	[kg]	2756-3035
Odometer	[km]	4,488
Registration Date	[dd-mm-yy]	15/03/17

Table 3-36: Emission results per trip of an Iveco New Daily Euro 6 diesel. The ambient temperature is not measured at the vehicle, but retrieved from the local weather station database.

No.	**Trip ID + payload%**	**Date**	**Start time**	**Duration**	**Distance**	**Average velocity**	**Ambient temperature Avg/min/max**			**CO_2**	**NO_x**	**NH_3**
				[s]	[km]	[km/h]	[°C]			[g/km]	[mg/km]	[mg/km]
13	ISC_55%	22-06-2017	8:09	7322	138.7	21.4	27	-	-	248.8	190.1	0.8
1	RDE_28%	22-06-2017	11:52	5486	70.9	46.6	27	-	-	297.4	520.5	0.7
12	Delivery trip_28%	22-06-2017	13:48	2944	17.5	68.2	20	-	-	376.7	644.5	0.5
Total				15749	227.2	51.9	-	-	-	273.9	328.4	0.7

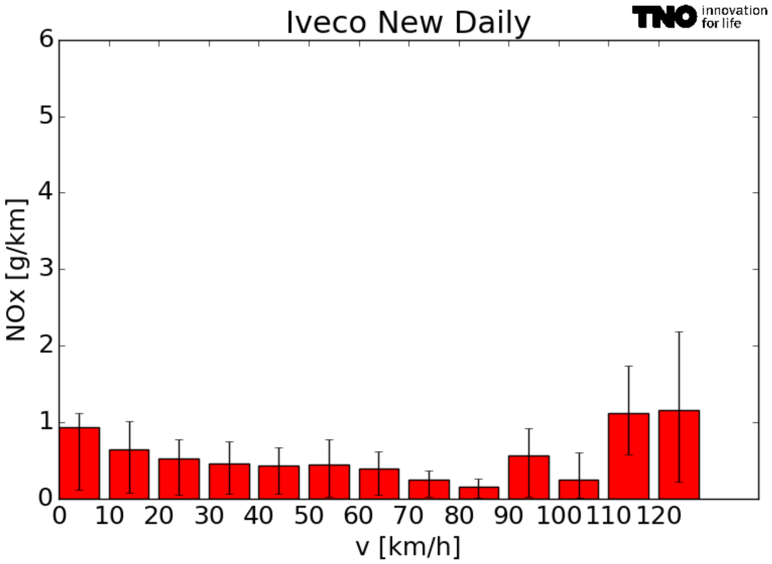


Figure 3-52: Average NO_x emissions of an Iveco New Daily Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

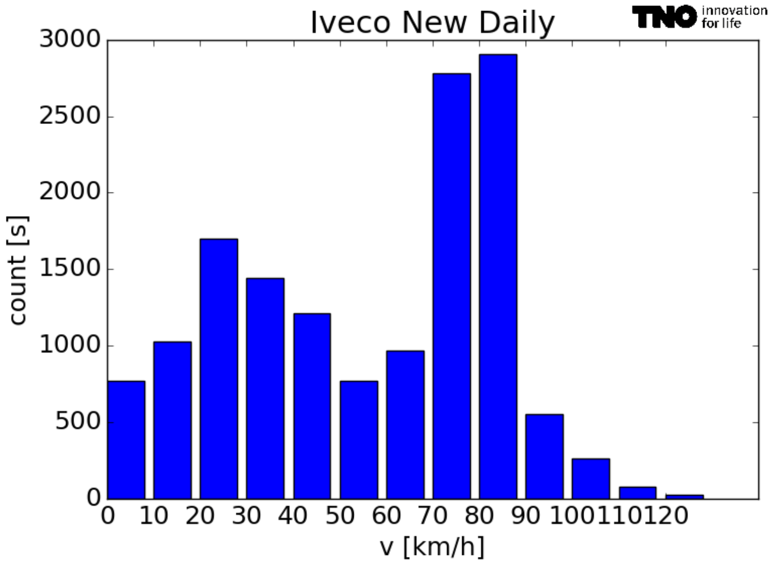


Figure 3-53: Number of seconds per velocity bin, over all trips. Idling is excluded.

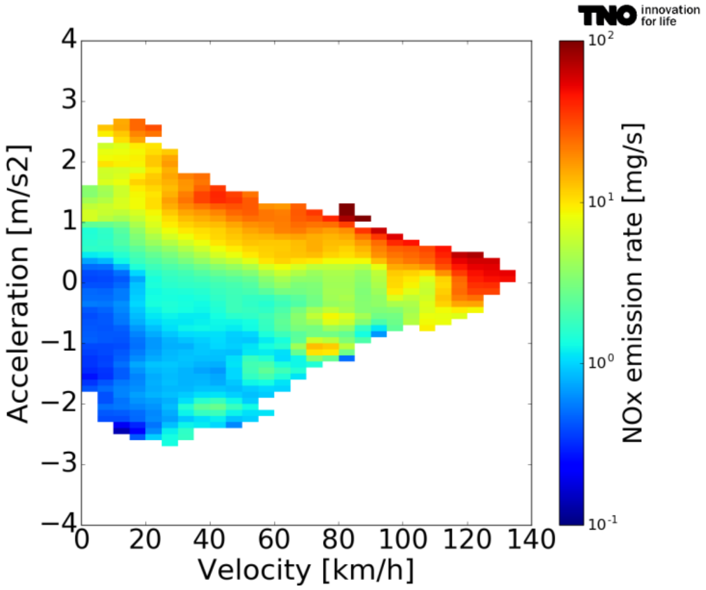


Figure 3-54: NO_x emission rate [mg/s] of a Iveco New Daily Euro 6 diesel in bins of velocity and acceleration.

3.2 Overview of test results for all 18 vehicles

In Figure 3-55 and Figure 3-56 the NO_x and CO_2 emissions of RDE tests with a warm start and 28% payload of all vehicles are shown. The NO_x emissions of Euro 6/VI vehicles on this trip are in the range of approximately 40 to 500 mg/km and have no direct relationship with the size of these vehicles; The performance of the applied emission control systems seems to be more decisive for the NO_x emissions. The Euro 5 vehicles have NO_x emissions in the range of 1000 to 1600 mg/km.

In Figure 3-57 and Figure 3-58 the NO_x and CO_2 emissions of In Service Conformity tests (along the heavy duty testing protocol) with a warm start and 55% payload of all vehicles are shown for all tested vehicles. For this test the NO_x emissions of Euro 6/VI vehicles are in the range of 30 to 450 mg/km and seem not to be related to the vehicle size. The two Euro 6 vehicles with LNT (Citan and Transit Connekt) have relatively high NO_x emissions (387 and 448 mg/km) while the NO_x emission of the vehicles with SCR are in the range of 29 to 288 mg/km. All NO_x emissions of Euro 6/VI vehicles are substantially lower than of the Euro 5 variants, which are in the range of 500 to 1300 mg/km.

In Figure 3-59 and Figure 3-60 the NO_x and CO_2 emissions of delivery trips with a warm start and 55% payload are shown for all vehicles. The NO_x emissions of Euro 6/VI vehicles on these trips are in the range of 100 to 800 mg/km and seem not to be related to the vehicle size. All NO_x emissions of Euro 6/VI vehicles are lower than of the Euro 5 variants, which are in the range of 900 to 1800 mg/km.

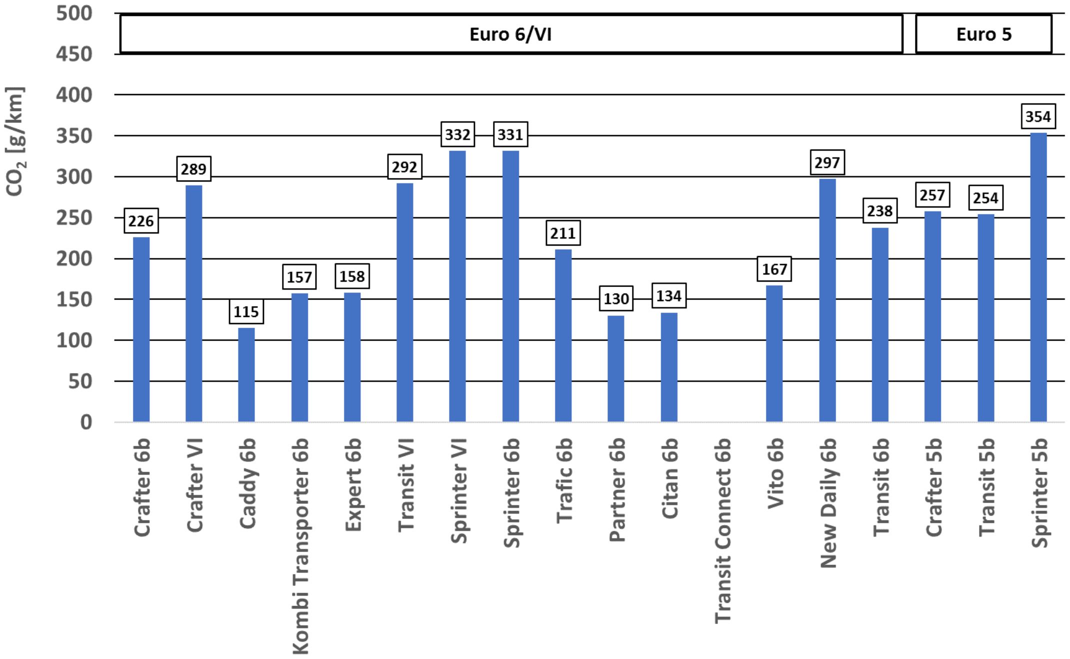


Figure 3-55: CO_2 emissions of RDE tests (74.7 km) of 18 vehicles with 28% payload. The vehicles are ordered by increasing NO_x emissions on this trip.

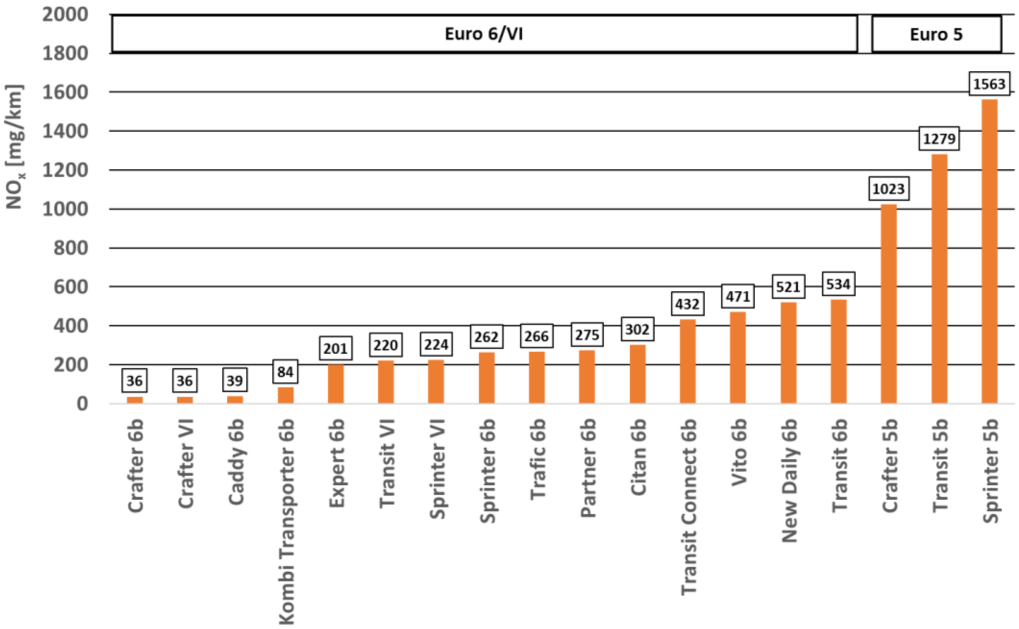


Figure 3-56: NO_x emissions of RDE tests (74.7 km) of 18 vehicles with 28% payload

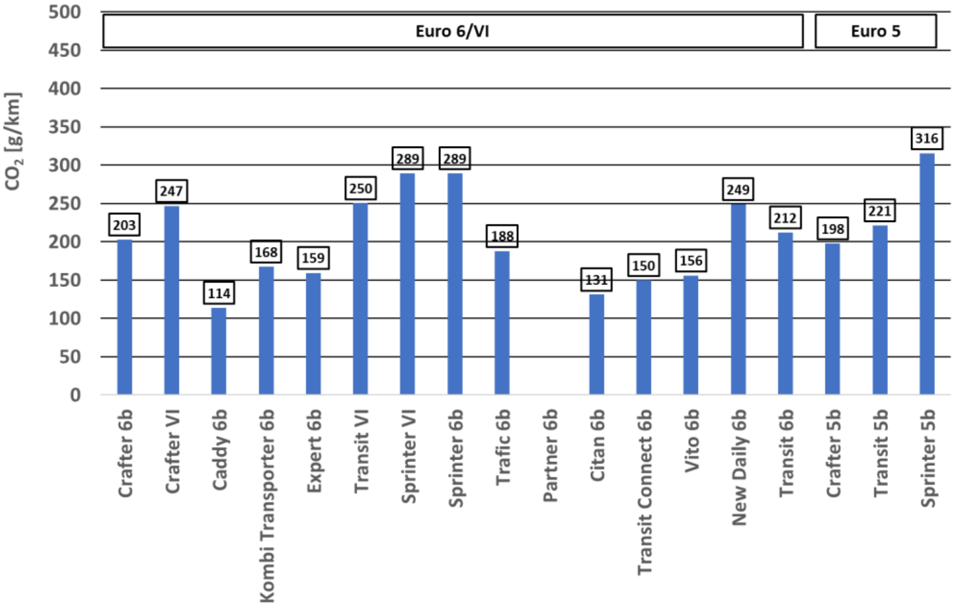


Figure 3-57: CO$_2$ emissions of ISC tests (122.7 km) of 18 vehicles with 55% payload

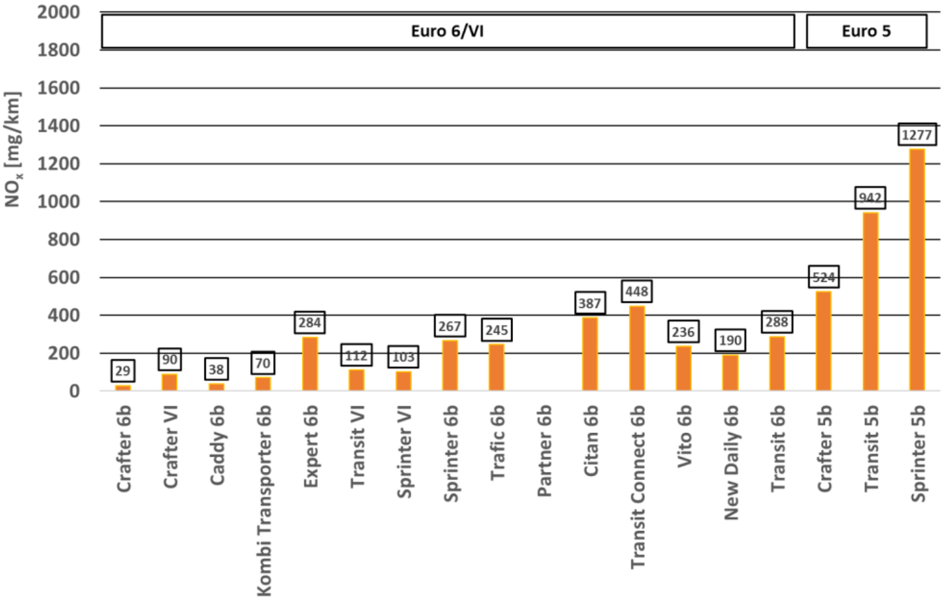


Figure 3-58: NO$_x$ emissions of ISC tests (122.7 km) of 18 vehicles with 55% payload

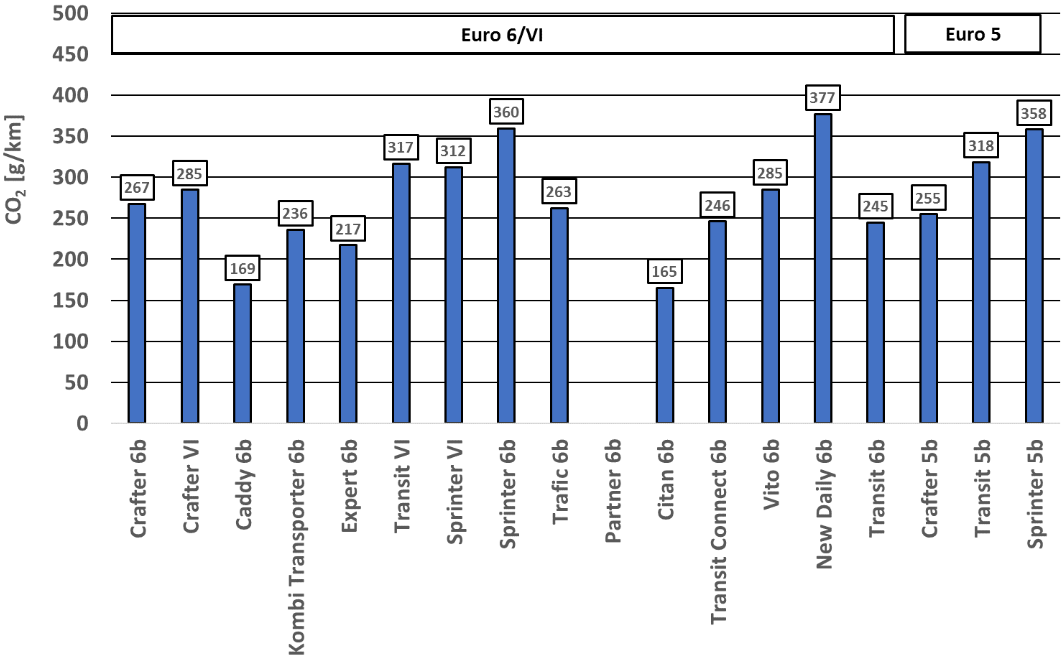


Figure 3-59: CO_2 emissions of delivery trips (17.4 km) of 18 vehicles with 55% payload

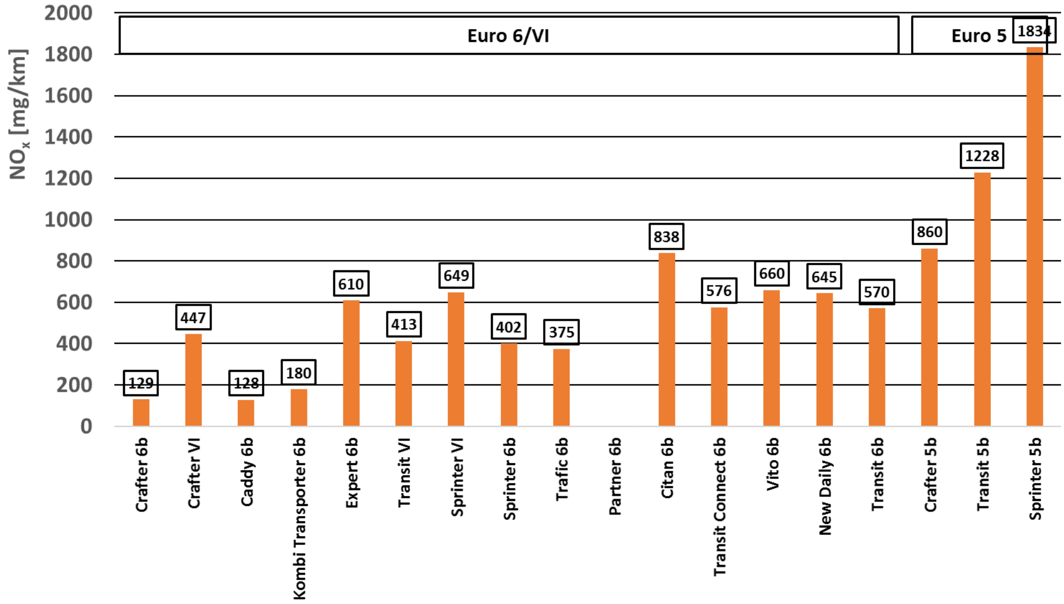


Figure 3-60: NO_x emissions of delivery trips (17.4 km) of 18 vehicles with 55% payload

3.3 Overview of RDE test results with different payloads and driving styles

In Figure 3-61 and Figure 3-62 the CO_2 and NO_x results of different RDE tests per vehicle are shown. Variations were set in payloads (28%, 55% and 95%) and three different driving styles were executed (economic, normal and sportive). The main target of these variations was to cover the whole RDE operating range with respect to payload, driving style and vehicle speeds. Although the driver instructions in terms of driving style and maximum vehicle speeds were strict, due to traffic situations the actual execution of the RDE test may deviate.

CO_2 emission per vehicle tend to increase with more demanding test conditions on the RDE trips. Higher payloads and a dynamic driving style result for most vehicles in a CO_2 increase of 25 to 35%, see Figure 3-61. However the corresponding NO_x trends in Figure 3-62 are more diverse. Some vehicles have very stable NO_x emissions but other vehicles vary widely (up to a factor 4 to 6) depending on test conditions. With high payloads and a sportive driving style NO_x emissions can be 800 to 1000 mg/km. It must be noted that the emissions of these vehicles are optimized for fixed chassis dynamometer tests and not for on-road tests.

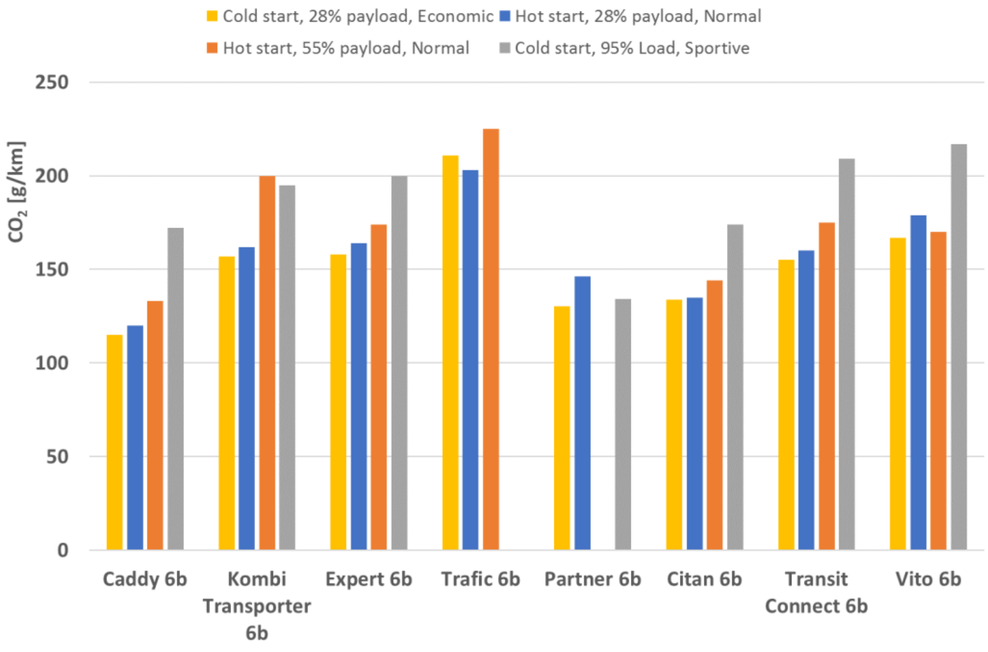


Figure 3-61: CO_2 emissions of RDE trips with different payloads and driving styles of 8 vehicles

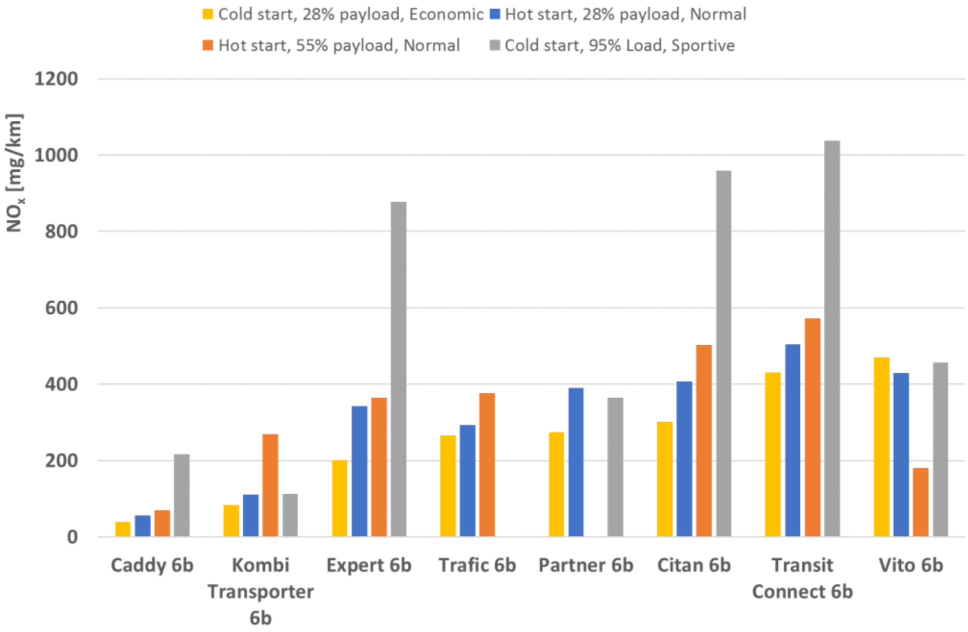


Figure 3-62: NO_x emissions of RDE trips with different payloads and driving styles of 8 vehicles

3.4 Comparison of NO_x emissions levels of Euro 6 and VI LCVs

For LCVs in the heavy class (III) with a reference mass between 2380 and 2840 kg, manufacturers may choose for either the Euro 6 LD or the Euro VI HD regime for the emissions type-approval. Both regimes differ with regard to emission limits and test procedures. The question is therefore, how vehicles type-approved according the two regimes compare in terms of real-world NO_x emissions levels. To answer this question, vehicles of both regimes were selected and tested driving the same trips. Euro 5 LD vehicles have been tested as reference.

Three of the best sold vehicle types in the heavy-class (III) were selected. For each type, three comparable vehicles were sought with a Euro 5 LD, Euro 6 LD and Euro VI HD type-approval. All nine vehicles had to drive a set of three trips, being an LD RDE trip an HD in-service conformity trip and a real-world trip in which parcel delivery is simulated by five stops during the trip with engine off.

Overall, the vehicles with Euro 6 and VI type-approvals have substantially lower NO_x emissions than the ones with a Euro 5 LD type-approval. For the Euro 5 vehicles, NO_x emissions levels vary from vehicle to vehicle and from trip to trip in the range of 500 mg/km to 1800 mg/km. The emissions levels of NO_x for Euro 6 and VI are in the range of 30 to 650 mg/km which shows that the NO_x emissions of the Euro 6 and VI vehicles are not consistently low. On average the NO_x emissions of Euro 6 and VI vehicles are lower than for Euro 5, but they also vary from vehicle to vehicle and trip to trip. For one vehicle model, both the Euro 6 and the Euro VI variant manage to obtain comparably low NO_x emissions over most trips. For another vehicle model, the NO_x emission of the Euro VI variant is lower than of the Euro 6 LD variant over all trips. In general, the delivery trip with a low average speed and regular ‘stops’, with engine off to simulate parcel delivery, is the most severe with regard to NO_x emissions. For all Euro 5, 6 and VI vehicles the NO_x emissions are higher over this trip than over the RDE (LD) and ISC (HD) trips.

4 Cold start effects

The resultant effect of driving behaviour, vehicle preconditioning, and ambient conditions comes to expression in the tailpipe emissions measured during an RDE test trip. Therefore, a more complex analysis is needed to separate the individual effect of the cold start from other effects. Here it is shown that the cold start effect is substantial in magnitude and duration in most SCR-equipped vehicles, while the effect is limited in LNT-equipped vehicles.

For the larger part, primary emissions are still the result of the instantaneous driving behaviour: the velocity and acceleration of the vehicle and the required power demand from the engine. Emission models and emission legislation rely somewhat on this basic assumption. Nowadays different emission control strategies and buffering of emissions have become more important in determining the secondary (tailpipe) emissions, sometimes causing unexpected variations. Consequently, the emissions are less directly related to the velocity or acceleration of the vehicle. The cold start emissions are a well-known effect of catalytic after-treatment technologies and is only weakly related to the driving behaviour. For example, for petrol vehicles with a three-way catalyst, the cold start is dominant in the total emissions in normal use. Hence, a complex situation arises where emission control strategies can vary not only with the catalyst temperature but also with many other physical parameters. In this chapter an attempt is made to quantify the variation of emissions for the tested diesel LCVs in case of cold start conditions, keeping the driving behaviour constant. The generic emission behaviour of the vehicle is guiding in this analysis.

Cold starts are an integral part of normal driving and, therefore, they are an integral part of the RDE test. The cold start should constitute an appropriate part to the total result, as compared to normal vehicle usage. In order to investigate the relative contribution of the cold start in the RDE test, its impact must be specified in the results. This separation of the cold start contribution is done by performing a residual analysis of the results, i.e. the variation in emissions on top of the variation due to driving behaviour.

To evaluate the impact of cold starts, the cold start effects need to be distinguished from the normal emission behaviour, averaged over all measurement data. The latter can be determined by parametrizing the NO_x emissions in terms of velocity and CO_2 using all the emission data, in order to account for different velocity profiles, driving behaviour and payload. Figure 4-1 shows the resulting instantaneous NO_x emissions as a function of velocity (x-axis) and CO_2 (y-axis). The emission behaviour differs between the different generations of vehicles. The Euro 5 vehicle has high emissions for all high load situations, whereas the Euro 6 and VI vehicles clearly perform better at high load when the velocity is also high.

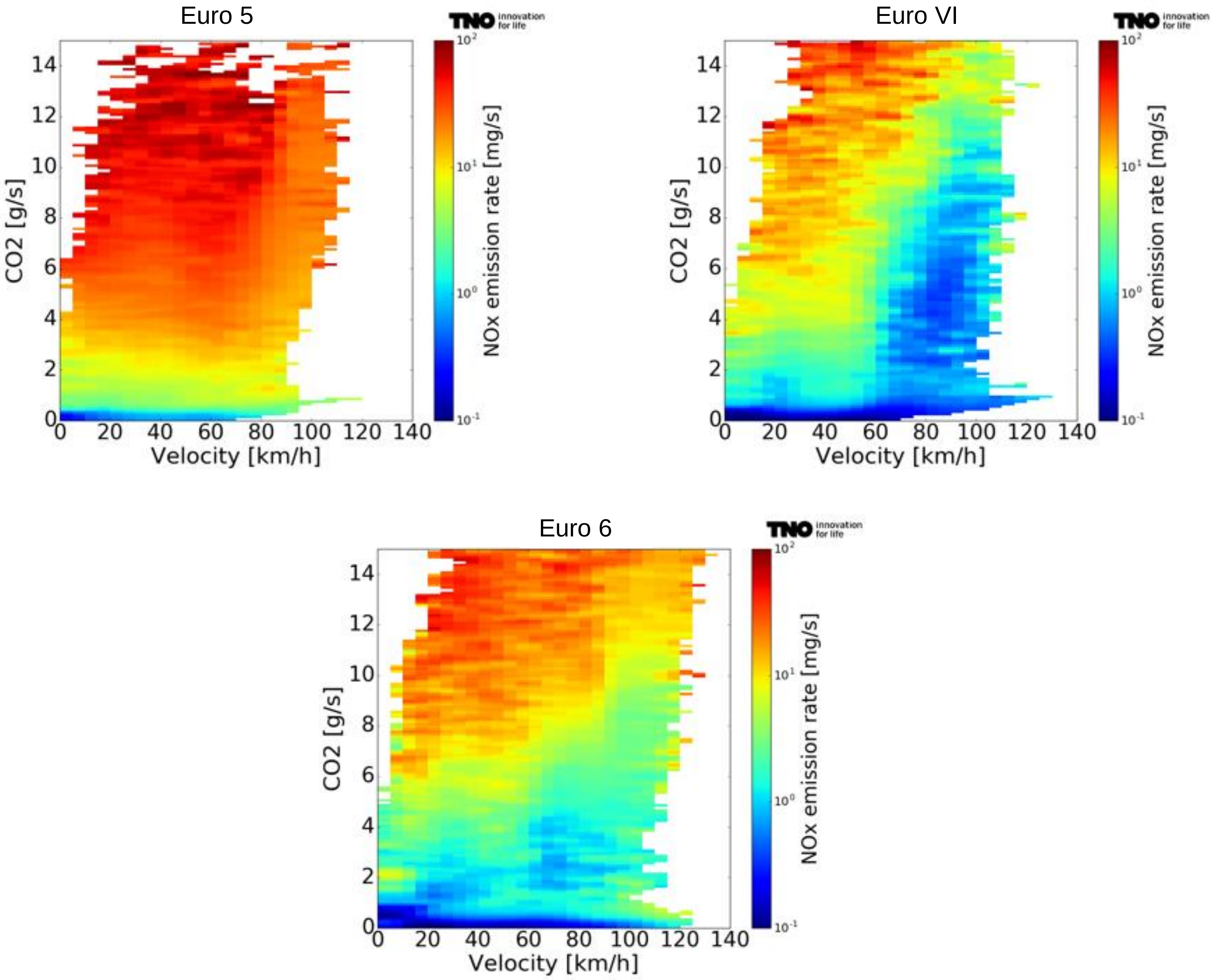
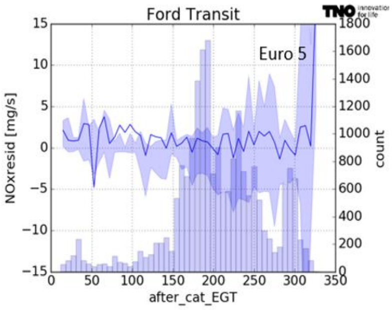
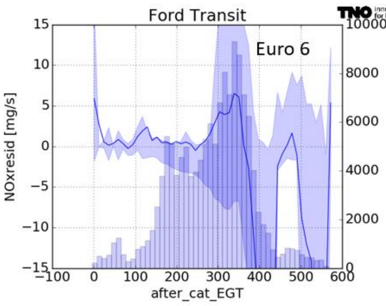


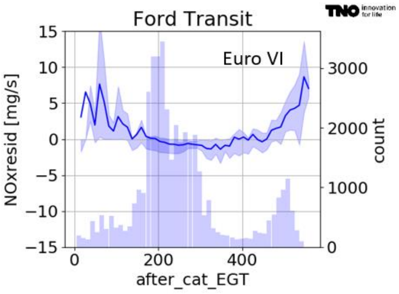
Figure 4-1: NO_x emissions as a function of velocity and CO_2, for the Mercedes Sprinter Euro 5 (top left), Euro VI (top right) and Euro 6 (bottom)

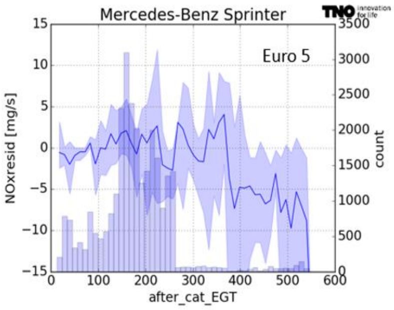
This parameterization provides a prediction for the most likely (primary) NO_x emission at a certain velocity and CO_2. Applying this average emission map to the second-by-second speed and acceleration values of all the recorded trips yields a prediction of the average second-by-second emissions. These predictions deviate from the actual recorded second-by-second emissions. If these deviations are either systematically below or above the average results, they may be attributed to specific causes other than the engine load defined by the combination of speed and acceleration. Such systematic deviations are observed for some time after a cold start: on top of the emissions associated with the driving dynamics additional emissions are observed.

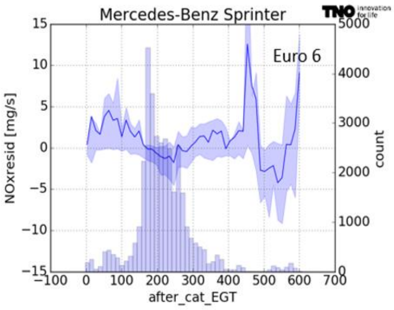
For 17 of the 18 tested vehicles the residual NO_x emission is plotted against the exhaust gas temperature in Figure 4-2.This shows that for most vehicles, lower exhaust gas temperatures result in higher residuals, hence higher NO_x emissions than expected just from the velocity and CO_2 emission at that time. At high exhaust gas temperatures, there are often large fluctuations that can be attributed to a limited amount of underlying data (shown as the histogram), and high absolute NO_x emissions.

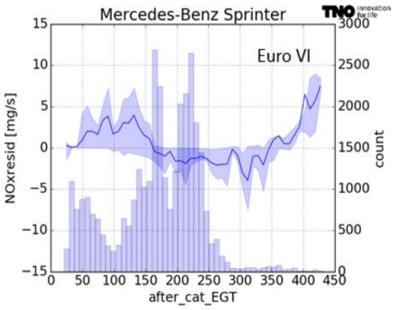


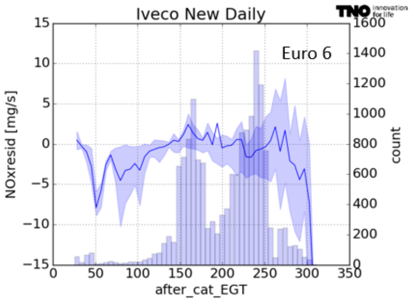


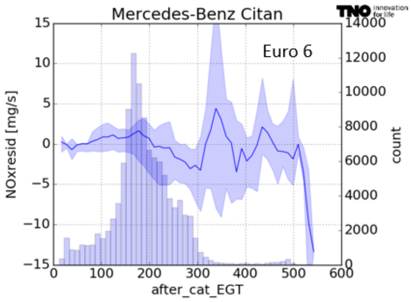


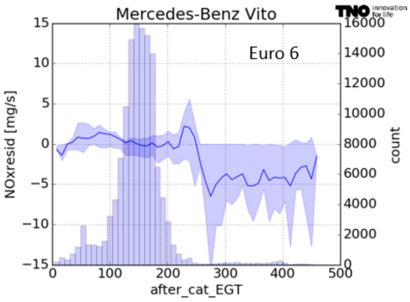


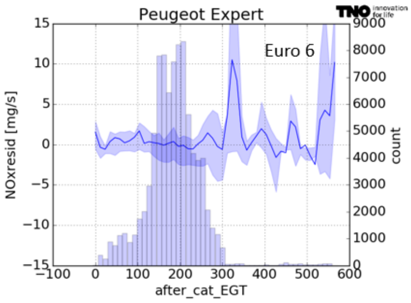


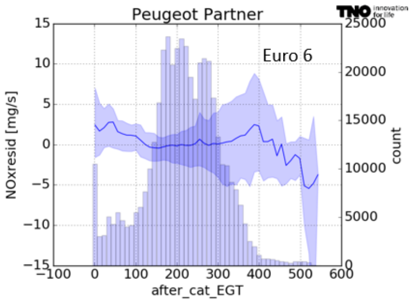


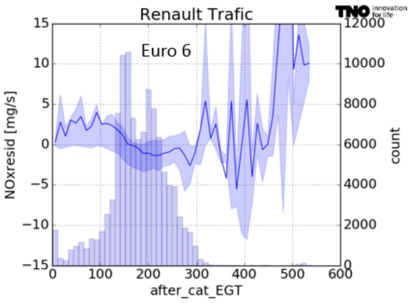












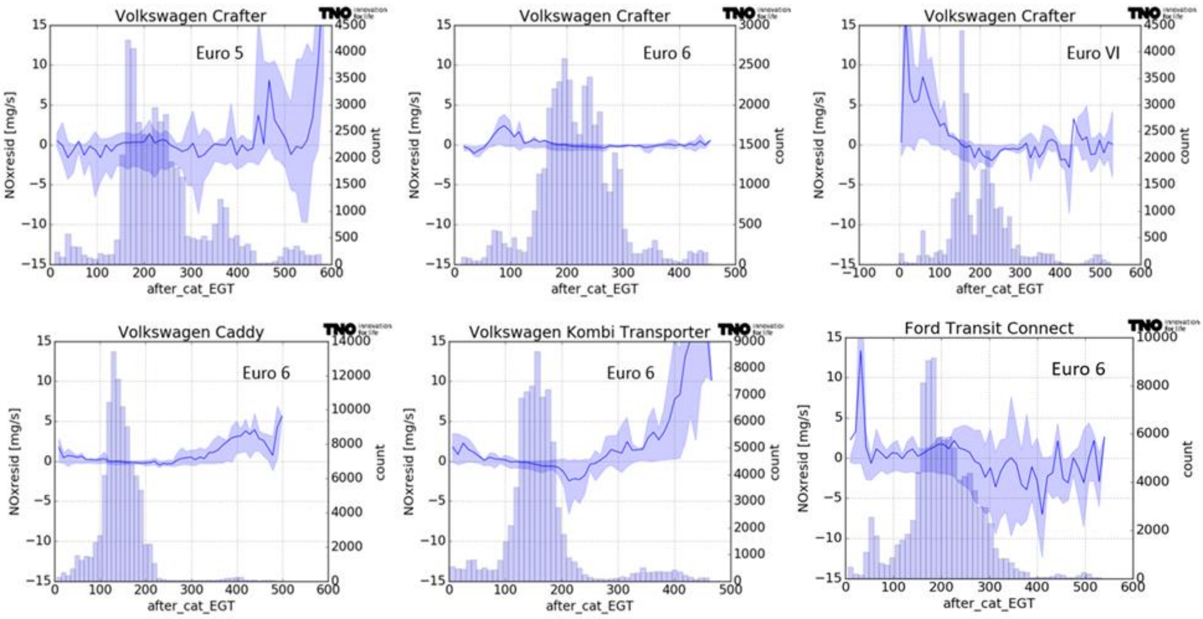


Figure 4-2 Residual NO_x emission per vehicle (in mg/s, left axis) with respect to the prediction from a parameterization using velocity and CO_2, plotted against the exhaust gas temperature. The shaded band reflects the standard deviation. The histogram displays the number of seconds of data available in each temperature bin (right axis).

A similar analysis can be performed for the residual varying over time. When this is done for the cold-start RDE trips, the time-dependent effects of the cold start will become visible, as explained in [TNO2016a]. The results of such analyses are shown for all vehicles in Figure 4-4. To explain these figures, Figure 4-3 shows a zoom-in, with the measured instantaneous velocity, engine coolant temperature and exhaust gas temperature over time. The result of the NO_x residual analysis is shown as the blue line, with an error band showing the standard deviation of the underlying residual values If there is a large spread in the values of the residuals, i.e. some measurements are close to the average and some are far away, the error band will increase. In this example, there are additional emissions (positive residual) at the start that decrease after some minutes, while the exhaust gas temperature is still rising. Cold starts, DPF regenerations and particular aspects of the LNT control strategy can be observed as large residuals, i.e. differences between the actual emissions and the predicted average instantaneous emissions with warm engine operation.

The duration of the cold start is determined from the exhaust gas temperature (EGT). The NO_x residuals are recorded until the EGT reaches 85% of the mean EGT during urban driving. The sum of the residuals over this time equals the extra NO_x emission during the cold start period of this trip. The duration and summed residuals of the cold start periods are reported for all vehicles in Table 4-1. One cannot, however, take these numbers as characteristic of each vehicle, since the cold start conditions were not similar for all trips and all vehicles. For example, the Ford Transit Connect was idling for several minutes during the cold start, which resulted in a higher than usual cold start NO_x-emission.

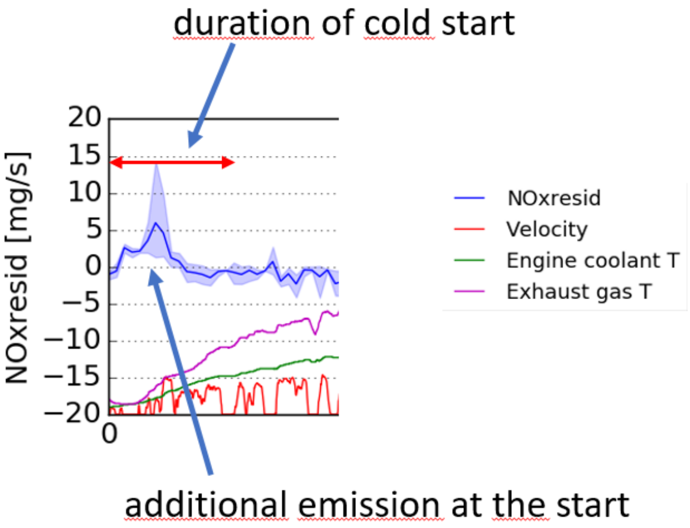


Figure 4-3: A detail plot of the time-dependent residual analysis: A clear initial peak of additional emissions is seen which decreases while the temperatures ECT and EGT increase. The area under the blue line yields the total estimated cold start contribution.

If a characteristic cold start effect per vehicle needs to be defined, it can best be described by the residual versus exhaust gas temperature (see **Fout! Verwijzingsbron niet gevonden.** to **Fout! Verwijzingsbron niet gevonden.**), combined with the typical warm-up time of the vehicle. One can integrate over the warm-up time, multiplying each exhaust gas temperature encountered with its corresponding NO_x residual, resulting in a total sum of residual NO_x in grams. The warm-up time can be different per trip, hence a different cold start effect occurs for every trip, as is evident in Table 4-1. Despite these small variations, from **Fout! Verwijzingsbron niet gevonden.** to **Fout! Verwijzingsbron niet gevonden.** it becomes clear that for most vehicles with SCR, all driving at lower exhaust gas temperatures results in higher emissions. The high residuals that sometimes appear at high exhaust gas temperatures have only a small amount of underlying data (counts). These points can often be associated with regenerations, where the output emissions are not only dependent on the input velocity and CO_2.

The warm-up times of the tested vehicles range from 340 to 878 seconds (6 to 15 minutes), see Table 4-1. The standard 5 minutes associated with the cold start in the RDE legislation is thus somewhat arbitrary. These 5 minutes are excluded in a warm RDE test, when starting with a cold engine. For SCR systems, the duration of the cold start is often longer than 5 minutes. The residual analysis shows a distinction between the LNT-equipped and the SCR-equipped vehicles.

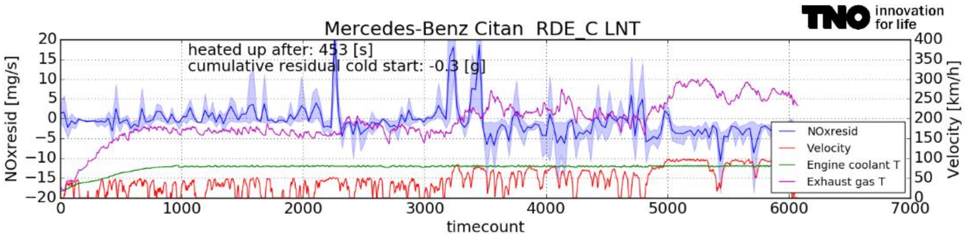
The tested SCR vehicles emit on average 0.4 g extra NO_x during the RDE cold starts which last on average about 600 seconds. In the first 300 seconds of the urban part of RDE trips with a cold start the three tested vehicles with an LNT have an average 0.05 g extra NO_x-emission. This may be explained by the fact that the NO_x absorption of an LNT typically starts at 80-100 °C while the light-off temperature of SCR catalysts is 150-200 °C.

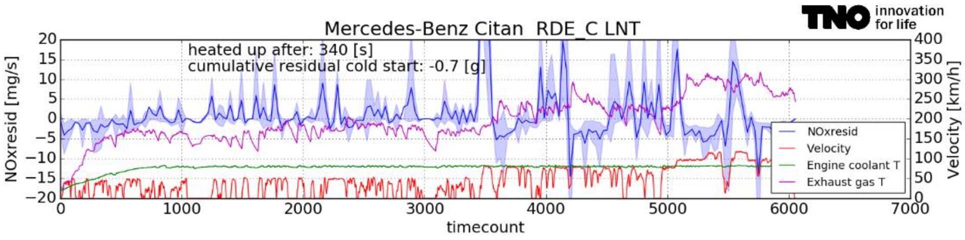
The cold start contribution to the emissions during urban driving in the RDE test is shown in Table 4-1. When the extra NO_x emissions are spread out over the (on average) 29 km urban driving, they result in about 5% extra emissions (in mg/km) on the urban part of a cold start trip compared to a hot start RDE trip. Note that the variation between vehicles and between trips is so large that these average numbers are not representative for individual vehicles. For example, some trips result in negative cold start contributions.

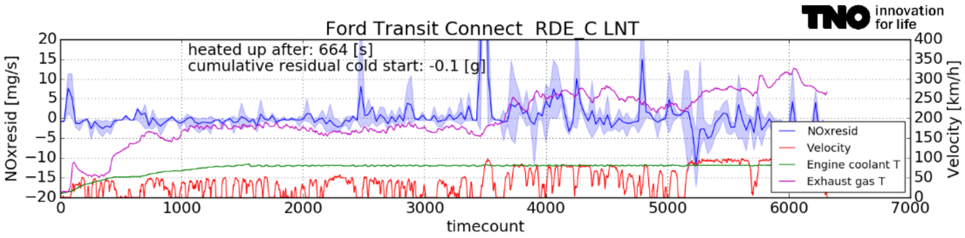
Table 4-1: The RDE trips with a cold start, with the additional emissions due to the cold start separated from the emissions associated with warm engine operation. The extra NO_x emission is compared to the total urban NO_x emissions of the trip. Only 7 vehicles were tested in cold start trips.

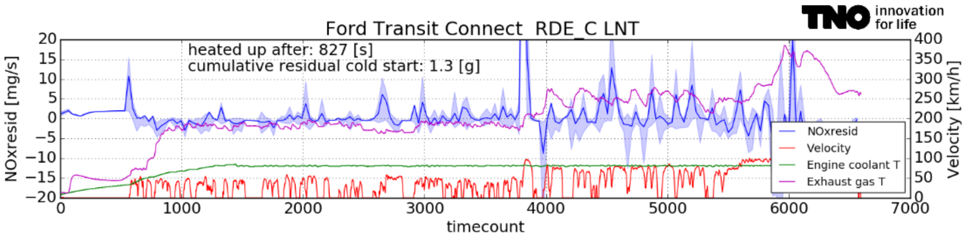
Vehicle	**Trip**	**AT**	**Time before warm Exhaust Gas [s]**	**Sum residual NO_x [g] during cold start**	**Urban NO_x [mg/km]**	**Extra NO_x during urban RDE [mg/km]**	**Extra NO_x during urban RDE (%)**
Mercedes Citan Euro 6	RDE_C 28%	LNT	453	-0.3	466	-10	-2%
Mercedes Citan Euro 6	RDE_C 55%	LNT	340	-0.7	676	-24	-4%
Ford Transit Connect Euro 6	RDE_C 28%	LNT	664	-0.1	382	-3	-1%
Ford Transit Connect Euro 6	RDE_C 55%	LNT	827*	1.3	561	45	8%
Mercedes Vito Euro 6	RDE_C 28%	SCR	761	0.2	902	7	1%
Mercedes Vito Euro 6	RDE_C 55%	SCR	529	-1.2	231	-41	-18%
Peugeot Expert Euro 6	RDE_C 28%	SCR	793	-0.3	299	-10	-3%
Peugeot Expert Euro 6	RDE_C 55%	SCR	559	-0.1	530	-3	-1%
Peugeot Partner Euro 6	RDE_C 28%	SCR	878	0.1	338	3	1%
Renault Trafic Euro 6	RDE_C 28%	SCR	648	1.5	495	52	11%
Renault Trafic Euro 6	RDE_C 55%	SCR	612	1.9	662	65	10%
VW Caddy Euro 6	RDE_C 28%	SCR	636	0.1	76	3	4%
VW Caddy Euro 6	RDE_C 55%	SCR	456	0.5	133	17	13%
VW Caddy Euro 6	RDE_C 28%	SCR	574	0.2	69	7	10%
VW Transporter Euro 6	RDE_C 28%	SCR	555	1.1	161	38	24%
VW Transporter Euro 6	RDE_C 55%	SCR	780	0.7	415	24	6%

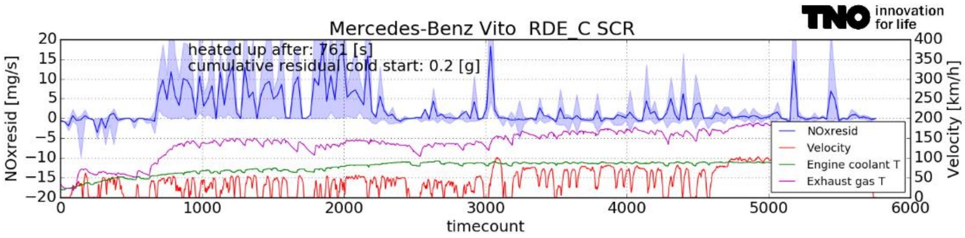
*) engine idling during warmup

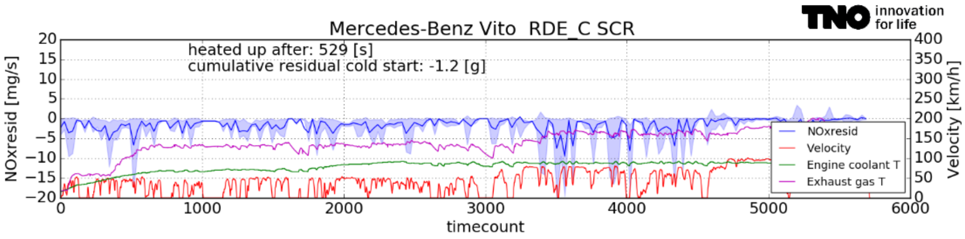

innovation for life
Mercedes-Benz Citan RDE_C LNT
heated up after: 453 [s]
cumulative residual cold start: -0.3 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
Velocity [km/h]
400
350
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
timecount
NOxresid
Velocity
Engine coolant T
Exhaust gas T

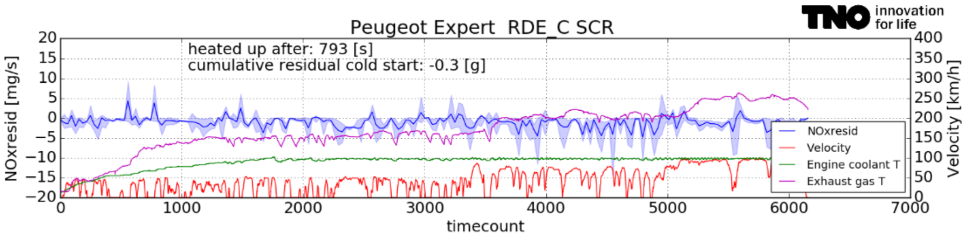

innovation for life
Mercedes-Benz Citan RDE_C LNT
heated up after: 340 [s]
cumulative residual cold start: -0.7 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
Velocity [km/h]
400
350
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
timecount
NOxresid
Velocity
Engine coolant T
Exhaust gas T

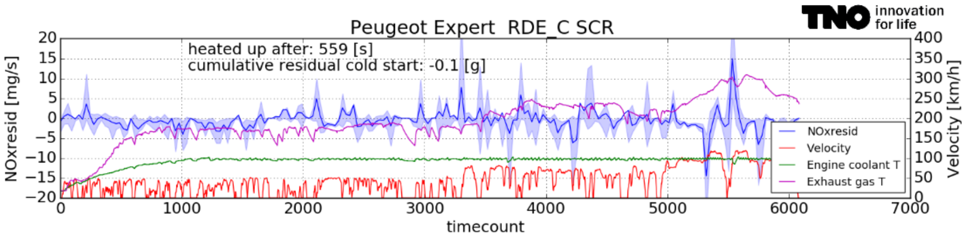

innovation for life
Ford Transit Connect RDE_C LNT
heated up after: 664 [s]
cumulative residual cold start: -0.1 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
Velocity [km/h]
400
350
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
timecount
NOxresid
Velocity
Engine coolant T
Exhaust gas T

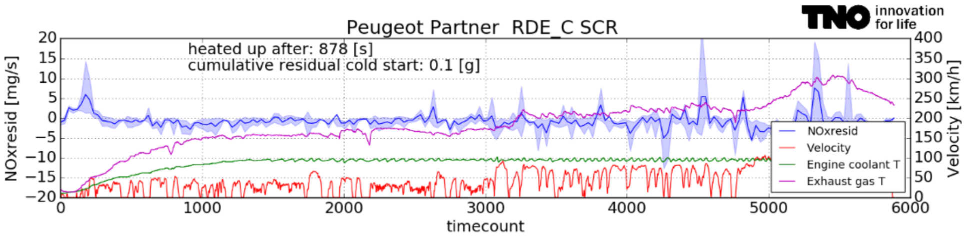

innovation for life
Ford Transit Connect RDE_C LNT
heated up after: 827 [s]
cumulative residual cold start: 1.3 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
Velocity [km/h]
400
350
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
timecount
NOxresid
Velocity
Engine coolant T
Exhaust gas T

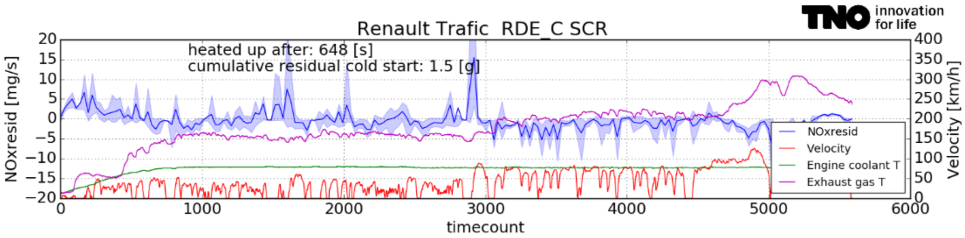

innovation for life
Mercedes-Benz Vito RDE_C SCR
heated up after: 761 [s]
cumulative residual cold start: 0.2 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
Velocity [km/h]
400
350
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
timecount
NOxresid
Velocity
Engine coolant T
Exhaust gas T

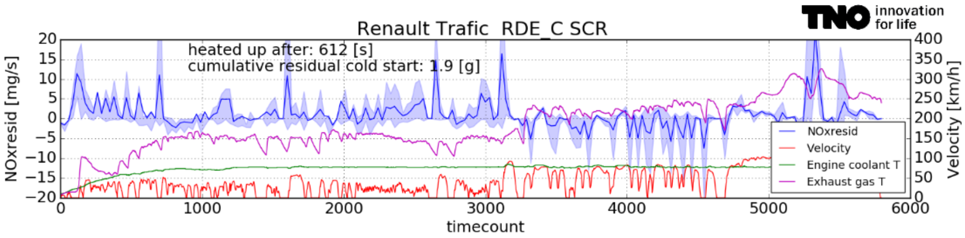

innovation for life
Mercedes-Benz Vito RDE_C SCR
heated up after: 529 [s]
cumulative residual cold start: -1.2 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
Velocity [km/h]
400
350
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
timecount
NOxresid
Velocity
Engine coolant T
Exhaust gas T

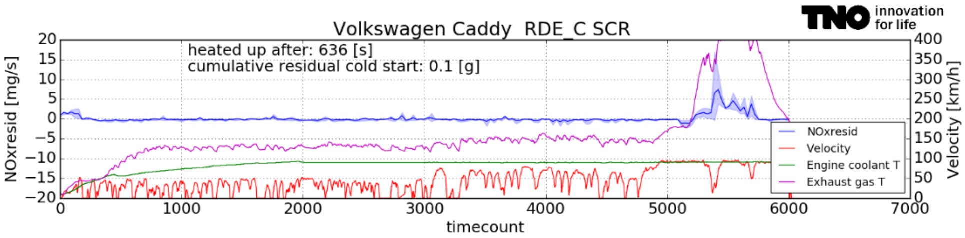

innovation for life
Peugeot Expert RDE_C SCR
heated up after: 793 [s]
cumulative residual cold start: -0.3 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
Velocity [km/h]
400
350
300
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
timecount
NOxresid
Velocity
Engine coolant T
Exhaust gas T

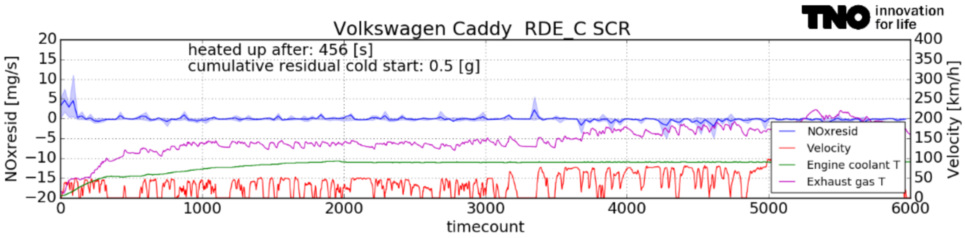

Peugeot Expert RDE_C SCR
heated up after: 559 [s]
cumulative residual cold start: -0.1 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
0
1000
2000
3000
4000
5000
6000
7000
timecount
Velocity [km/h]
400
350
300
250
200
150
100
50
0
NOxresid
Velocity
Engine coolant T
Exhaust gas T
TNO innovation for life

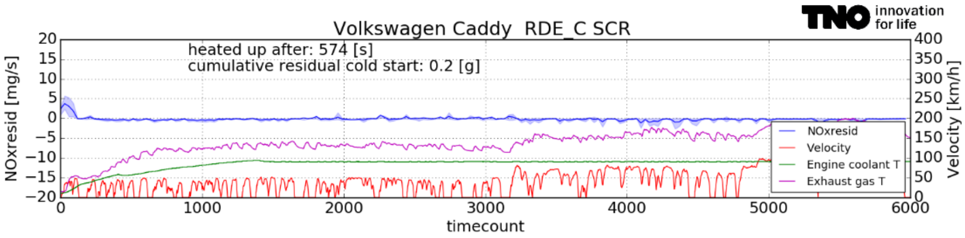

Peugeot Partner RDE_C SCR
heated up after: 878 [s]
cumulative residual cold start: 0.1 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
0
1000
2000
3000
4000
5000
6000
timecount
Velocity [km/h]
400
350
300
250
200
150
100
50
0
NOxresid
Velocity
Engine coolant T
Exhaust gas T
TNO innovation for life


Renault Trafic RDE_C SCR
heated up after: 648 [s]
cumulative residual cold start: 1.5 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
0
1000
2000
3000
4000
5000
6000
timecount
Velocity [km/h]
400
350
300
250
200
150
100
50
0
NOxresid
Velocity
Engine coolant T
Exhaust gas T
TNO innovation for life


Renault Trafic RDE_C SCR
heated up after: 612 [s]
cumulative residual cold start: 1.9 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
0
1000
2000
3000
4000
5000
6000
timecount
Velocity [km/h]
400
350
300
250
200
150
100
50
0
NOxresid
Velocity
Engine coolant T
Exhaust gas T
TNO innovation for life


Volkswagen Caddy RDE_C SCR
heated up after: 636 [s]
cumulative residual cold start: 0.1 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
0
1000
2000
3000
4000
5000
6000
7000
timecount
Velocity [km/h]
400
350
300
250
200
150
100
50
0
NOxresid
Velocity
Engine coolant T
Exhaust gas T
TNO innovation for life


Volkswagen Caddy RDE_C SCR
heated up after: 456 [s]
cumulative residual cold start: 0.5 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
0
1000
2000
3000
4000
5000
6000
timecount
Velocity [km/h]
400
350
300
250
200
150
100
50
0
NOxresid
Velocity
Engine coolant T
Exhaust gas T
TNO innovation for life


Volkswagen Caddy RDE_C SCR
heated up after: 574 [s]
cumulative residual cold start: 0.2 [g]
NOxresid [mg/s]
20
15
10
5
0
−5
−10
−15
−20
0
1000
2000
3000
4000
5000
6000
timecount
Velocity [km/h]
400
350
300
250
200
150
100
50
0
NOxresid
Velocity
Engine coolant T
Exhaust gas T
TNO innovation for life

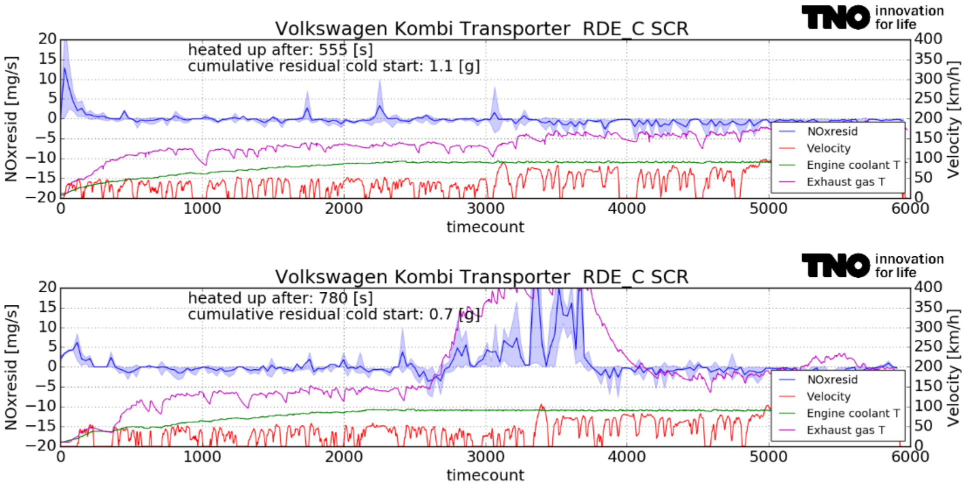


Figure 4-4: Residual NO_x versus time for all cold-start RDE trips of the seven Euro 6 light commercial vehicles of which the test programme included a cold start RDE trip.

5 Driving behaviour and RDE boundaries

The RDE boundaries specify the required characteristics of a valid RDE test. These specifications allow for some variation in the execution of the test. Variations in the driving behaviour during an RDE test, that are within these boundaries, are normalized by the RDE evaluation methods. Nevertheless, it is not trivial to drive a valid RDE test. In general, tests are executed on a standard trip, with moderate, i.e., "normal" driving behaviour. At the start of the 2017 test programme, it was investigated to what extent the range of all possible driving behaviours on a given route falls within the RDE boundaries.

Table 5-1 shows the results of 13 test trips on the same RDE-compatible route, executed with different driving styles and vehicle payloads. The route, the vehicle condition, and the ambient conditions were kept the same. Out of these 13 trips, 6 were valid according to the RDE requirements for driving dynamics and the EMROAD evaluation. Three "eco"-tests failed, as well as five tests with an aggressive driving style. However, the failures were for a multitude of reasons, as indicated in Table 5-1.

In response to the variation in driving styles and vehicle loads, the measured emissions show a very large variation, from 172 mg/km to 908 mg/km, which is more than a factor 5. In valid RDE tests the range is much smaller; from 280 mg/km to 513 mg/km, i.e. little under a factor 2. Interestingly, exclusion of invalid trips removes the tests with the lowest as well as well as with the highest NO_x emissions with this vehicle.

The driving behaviour investigations with this vehicle show a large variation of emissions with the details of the test execution. In the subsequent testing with the other vehicles, similar variations in emission with driving style and payload were observed.

Table 5-1: The RDE test trips, with variations in driving behaviour and payload, as carried out with the Peugeot Partner.

RDE compliant? (N1 Class II)	**ok**		Urban part too agressive			**ok**	skewed road type fractions	Urban part too agressive	1% to much stop time in urban part	**ok**			Not sufficient dynamics on highway
Trip	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Style	**normal**	**normal**	**sport**	**sport**	**sport**	**normal**	**eco**	**sport**	**sport**	**sport**	**normal**	**eco**	**eco**
Weight [kg]	**1482**	**1482**	1940	1940	1960	**1820**	1660	1940	1940	**1960**	**1820**	**1680**	1700
Average velocity [km/h]	**47.3**	**45.4**	38.5	38.5	39.6	**49.6**	46.5	44.2	44	**48.8**	**49.4**	**44.9**	46.3
Average velocity (v>0) [km/h]	**52.8**	**54.3**	52.1	55.9	56.5	**57.9**	53.1	57.5	56.1	**58.4**	**57.6**	**53.2**	52.3
CO2 [g/km]	**140**	**157**	175	179	194	**142**	122	180	175	**166**	**140**	**127**	116
EMROAD CO2	**159**	**178**				**159**				**199**	**152**	**145**	
NOx [mg/km]	**280**	**392**	579	623	**908**	**452**	281	734	557	**513**	**367**	**291**	**172**
EMROAD NOx	**174**	**240**				**291**				**329**	**235**	**187**	
NOx/CO2 [g/kg] per second	**1.8**	**2.3**	3.2	3	4.7	**3.1**	2.2	3.5	2.8	**2.7**	**2.3**	**2.3**	2.4
NOx/CO2 [g/kg] from EMROAD total	**2**	**2.5**				**3.1**				**3**	**2.6**	**2.3**	
Urb CO2 [g/km]	**159**	**173**				**160**				**183**	**151**	**137**	
Urb EMROAD CO2	**154**	**170**				**159**				**185**	**151**	**138**	
Urb NOx [mg/km]	**302**	**462**				**504**				**425**	**345**	**311**	
Urb EMROAD NOx	**162**	**269**				**346**				**304**	**235**	**203**	
Urb NOx/CO2 [g/kg] from EMROAD total	**2**	**2.7**				**3.3**				**2.5**	**2.6**	**2.3**	

The valid RDE results were also evaluated with EMROAD. Results are presented in Figure 5-1. It is found that in this case EMROAD always corrects the results downward, both for the whole trip and for the urban part. Given that the valid trips also contain one trip with an economic driving style, and that there is also variation between the trips with a “normal” driving style, it would be expected that some of the tests are corrected upward. The tests with this vehicle therefore seem to indicate a systematic effect in the corrections of the EMROAD evaluation method. With only two valid tests, according to CLEAR, no such analyses could be performed for the CLEAR evaluation tool.

These results have been shared with the stakeholders in the RDE-LDV group in Brussels. The systematic downward corrections are a matter of concern about the functionality of EMROAD. If the test were all too aggressive, then downward corrections are logical. Since the NO_x emissions in valid trips range from 280 mg/km to 513 mg/km, it is hard to maintain the assumption that all trips were executed aggressively.

The above-described findings with respect to RDE boundaries and different driving behaviours have led to driver instructions, as specified in Table 5-2, which were applied in the 2017 test programme.

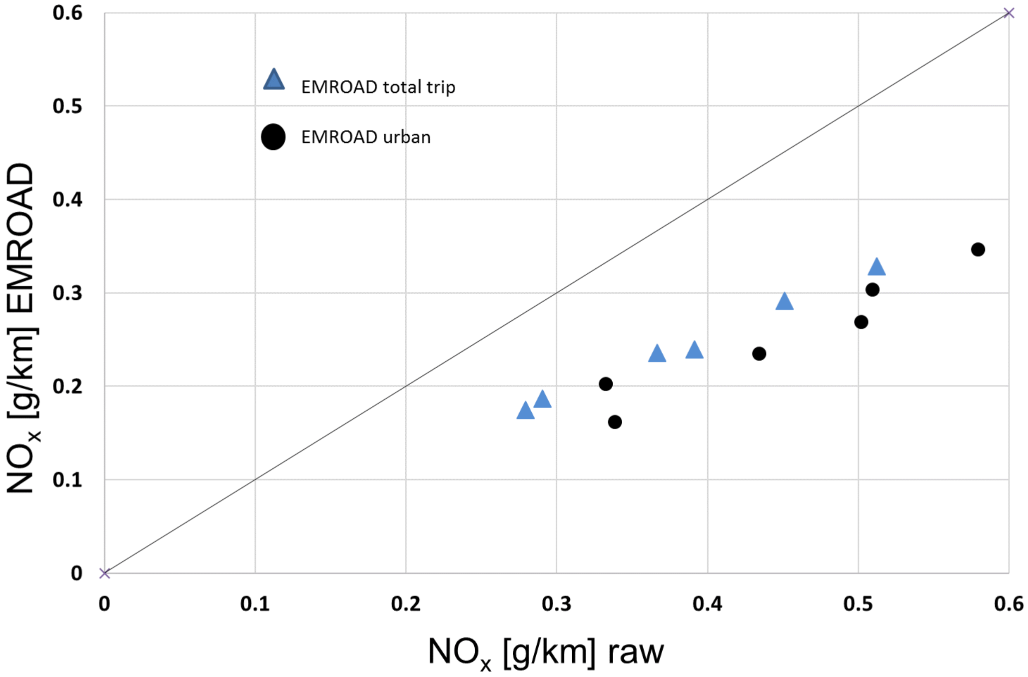


Figure 5-1: The measured total trip result set against the EMROAD evaluation results. The results are always corrected downward. The correction for the total trip is about 35%. For the urban part of the trips, the results are corrected downward by about 45%.

Table 5-2: Parameters of the three different driving styles

Driving style		**Economic**	**Normal**	**Sportive**
Driving behaviour		careful	regular	dynamic
Gearshift engine speed	[rpm]	2000	2500	3500
Distance to target at start of braking	[m]	90	60	30
Delay time speed to brake pedal	[s]	30	3	0
Start-stop system active		Yes	Yes	No
Vehicle stops of 120-180 s		0	0	2
Maximum position speed pedal	[%]	80	90	100
Speed pedal activation speed		slow	normal	fast
Maximum speed on the motorway	[km/h]	110	120	140

6 Discussion

6.1 Insights into the emission behaviour of Euro 6/VI light commercial vehicles

A large spread is observed in the on-road NO_x emission performance of the tested Euro 6/VI vehicles (with SCR and LNT technology). NO_x emissions in RDE tests were in the range of 40 to 500 mg/km. In ISC tests they varied from 30 to 450 mg/km and in delivery trips from 130 to 800 mg/km. These NO_x emissions of Euro 6/VI vehicles are substantially lower than the three tested Euro 5b samples, which have NO_x emissions in the range of 500 to 1800 mg/km.

The NO_x emissions seem to be independent from the vehicle size because the class II types have similar results as the class III types. Given the fact that the best performing vehicles have NO_x emissions lower than 130 mg/km while other models emit up to 650 mg/km in the same trips, it becomes evident that the real-world emission performance of a Euro 6/VI vehicle mainly depends on the applied hardware and emission control strategies.

It is expected that upcoming RDE legislation will decrease this range of NO_x emission as well as the maximum emissions because on-road (RDE) testing will become part of the type-approval procedure.

6.2 Impact of ambient temperatures on the comparability of test results

There are many factors affecting the results of on-road emission testing. These include driving patterns (determined by e.g. road type, traffic conditions and driving style) and weather conditions such as ambient temperature. Since variations in ambient conditions between different tests cannot be fully avoided, ambient temperature remains one of the main factors that limit the comparability between on-road emission test results obtained on different vehicles.

In this test programme, most vehicles were tested on the road at average ambient temperatures between 5 and 32 °C. It is expected that the emission behaviour of different vehicle models depends differently on ambient temperatures. Consequently, every test result must be judged with respect to the specific test conditions, and a comparison of the results for different vehicles cannot be directly used to rank vehicles in terms or their environmental performance. The current test temperatures lie well within the range of the most common ambient temperatures in the Netherlands. Hence it is expected the test results are representative for Dutch circumstances.

Similar to the cold start analysis in Section 4, emission residuals can be correlated with ambient temperature after calculating the expected emissions given the velocity and CO_2 emission. For most vehicles, no correlation is seen within the temperature range that was covered by the test programme. One of the vehicles, that did show an effect, is illustrated in Figure 6-1. The extra NO_x emission decreases with ambient temperature.

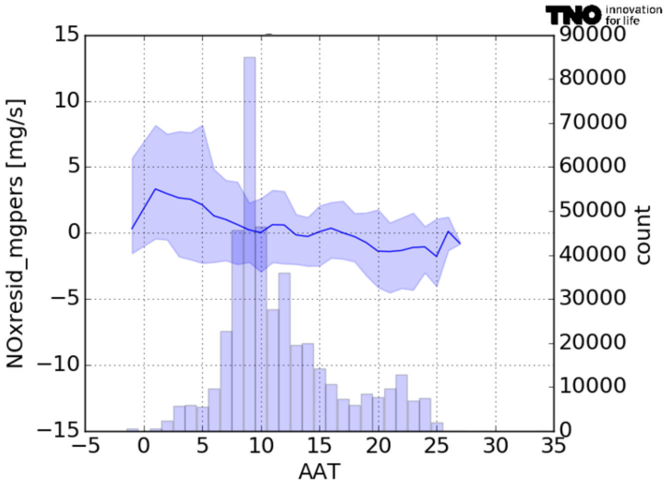


Figure 6-1: NO_x emission residual (blue line) versus ambient air temperature (AAT) of one Euro 6 light commercial vehicle. The amount of data per temperature bin is shown as the histogram.

6.3 Comparison of NO_x emissions levels of Euro 6 and Euro VI LCVs

For Euro 6 (LD) and Euro VI (HD) there is a clear difference in requirements with regard to type-approval and in-service conformity. For LD emission tests needs to be performed with a vehicle on a chassis dynamometer and for HD with an engine on an engine test bed. Emission limits are different and expressed in different units (LD class III N1 and N2: 125 g/km versus HD 0.46 g/kWh). Also, for the first generation of Euro 6 LD vehicles (2015 – September 2017), that were subject to the tests reported here, there is no real-driving test prescribed, whereas for Euro VI HD vehicles in-service conformity (ISC) needs to be checked with PEMS over a real-world test (as of December 2013). Such a difference might have led to a different approach of manufacturers in the design and layout of the concept of emission control for both type-approval regimes.

Given the mixed results of the tests, however, no conclusions could be drawn in this respect. With regard to the comparison of the NO_x emissions of vehicles with a Euro 6 and Euro VI type-approval there was no clear indication from the test performed that on average one regime is significantly more effective in achieving low real world NO_x emissions than another. For one type the Euro VI variant indeed showed lower NO_x emissions than the Euro 6 variant. Another type has comparably low NO_x emissions levels for both the Euro 6 and VI model and a third type showed a mixed result over the test trips. However, the Euro 6 vehicles show a lager spread than the Euro VI vehicles. The Euro VI vehicles show a more consistent low level of NO_x emissions. This may be caused by the real-world test that is mandatory for Euro VI engines and vehicles as of 2014.

The tests however demonstrate that at least for one type, vehicles of both regimes could achieve NO_x emissions levels in the range 30-90 mg/km over RDE and ISC trips.

6.4 Driving behaviour at 80 km/h on the motorway

In the Netherlands, emission factors of different vehicle categories are used to calculate the fleet emissions for e.g. air quality assessment. Emission factors exist for different road types, such as urban, urban congested, rural, motorway congested and motorway at different speed limits. Due to the increased dependency on dynamics of the emissions of Euro 6 vehicles, the necessity to distinguish between specific road types and speed limits increases. In the test programme, measurements were made at motorways with different speed limits, one of which was the A10 west of Amsterdam, where a limit of 80 km/h applies.

To illustrate the importance of distinguishing emission factors by road type, Table 6-1 shows the difference between emissions measured on rural roads and motorways where on both roads the maximum speed limit is mostly 80 km/h. The test programme showed that emissions on a motorway with 80 km/h speed limit are about three times lower than on an 80 km/h rural road. The reason is that on the motorway, the dynamics are minimal, whereas on rural roads much variation in velocity occurs due to e.g. roundabouts and road crossings.

The emission factors are calculated using average driving behaviour in terms of velocity and acceleration, and corresponding emissions. By matching the trip trajectories with map information, dependencies on road circumstances can be distilled. From the comparison of the emission factor model outcomes with the actual recorded emissions on certain trajectories, it became clear that the current emission factors for motorways with 80 km/h speed limit are not in line with the measurements. In fact, the emission factors were up to a factor 3 higher. To solve this, two measures were taken.

First, the driving behaviour parameters underlying the 80 km/h motorway emission factor were adjusted using the measurements for vans and passenger cars from the past three years on the trajectory A10 west of Amsterdam. This solved part of the problem because dynamics decreased and the average velocity was closer to 80 km/h than before. However, a gap remained, probably because driving at a constant velocity for a longer time has a positive influence on the emission reduction. This effect cannot be sufficiently represented by the current emission factor model which uses only instantaneous acceleration and velocity, without any history information.

To handle this issue, a second measure was taken, namely to use only the emission data recorded on the 80 km/h motorway trajectory for the calculation of emission factors for this specific road type. This brought the emission factors in line with the measured values.

Table 6-1: NO_x emissions of Euro 6 LCVs on the motorway with 80 km/h speed limit (= 80 MSH) with an average velocity of 80 km/h, and on rural roads with varying speed limits and average velocity around 50 km/h.

Vehicle	**NO_x emission motorway 80 MSH [mg/km]**	**NO_x emission rural [mg/km]**
Ford Transit Euro 6	137	587
Volkswagen Caddy Euro 6	14	45
Peugeot Partner Euro 6	103	377
Renault Trafic Euro 6	170	210
Volkswagen Transit Euro 6	34	86
Mercedes-Benz Vito Euro 6	150	130
Peugeot Expert Euro 6	59	441

7 Conclusions

7.1 General caveats regarding interpretation of the test results

- The tests performed by TNO are not intended nor suitable for enforcement purposes and are not suitable for identifying or claiming fraud or other vehicle-related irregularities in a technically and legally watertight way. The observed high NO_x emissions under real-world test conditions can and should therefore not be interpreted as an indication for the use of so-called “defeat devices”, “cycle beating” or other strategies that are prohibited by European vehicle emission legislation. Instead the test programme has been designed to generate insight in the overall real-world emission behaviour of vehicles, required for environmental policy making and evaluation, as well as inputs for the activities of the Dutch government in the context of decision making processes for improving vehicle emission legislation and the associated test procedures.
- For each make or model, only a single vehicle or a small number of vehicles are tested, which means that it cannot be ruled out that the results correlate to the specific condition of the tested vehicles.
- The results for individual vehicle models cannot be interpreted or used as emission factors. Emission factors are estimates of the overall average emissions of a specific vehicle category, or of the average emissions of a specific vehicle category under specific average driving conditions on a specified road type.
- Because of the myriad of factors that determine the outcome of a real-world emission test, the values reported cannot easily be used to rank vehicles with respect to their emission performance. The influence of differences in the tests executed on two vehicles may be larger than the difference in actual performance of engine, exhaust aftertreatment and control systems.

Numbers and bandwidths mentioned in the conclusions below are based on the data as presented in sections 3 and 4.

7.2 Impact of accuracy of the measurement method on the significance of results

In the on-road measurement method with SEMS, as used in this project, the NO_x and CO_2 mass emission rates are calculated based on measured concentrations, fuel parameters, and the mass-air-flow (MAF) signal from the vehicle’s CAN bus. For most vehicles, the air mass flow signals are calibrated and deviations are corrected. If the air mass flow signal is not calibrated it may deviate from actual values (i.e. +/- 10%), leading to inaccuracies in the overall test result. However, a comparison of the CO_2 and NO_x emission results from SEMS with results obtained with the chassis dynamometer measuring equipment yields typical deviations of less than 2% for the accumulated CO_2 and up to 0-8% for NO_x over a few trips.

It can therefore be concluded that the observed deviations between on-road and type-approval NO_x emissions of the tested Euro 5, 6 and VI diesel vehicles are up to two orders of magnitude higher than the inaccuracy of the SEMS-based measurement method.

7.3 Conclusions

In this research project the real-world NO_x and CO_2 emission performance of eighteen Euro 5, 6 or VI compliant diesel vehicles of legislative class N1 (light-commercial vehicles) and M1 (passenger vans) has been determined on the road in several test trips. The emissions were measured by means of TNO's Smart Emission Measurement System, which contains an automotive O_2/NO_x and NH_3 sensor. Combined with CAN bus data of the vehicle and a dedicated emission calculation method, the mass emission rates were determined.

Real-world NO_x emission levels of Euro 6/VI vehicles
On the road, the tested vehicles showed NO_x emission levels that are 1 to 8 times higher than the applicable type-approval emission limit of 105 or 125 mg/km. The average NO_x emissions in urban traffic ranged from 128 to 838 mg/km.

Despite the continuous tightening of the NO_x type-approval limit values from Euro 1 to Euro 6, real-world NO_x emission factors of LD light commercial vehicles have stabilized on average at around 600-1650 mg/km in the last decade. In other words: the difference between type-approval NO_x emissions and real-world NO_x has grown significantly over the years. Compared to the current type-approval limit value of 105 or 125 mg/km, the difference between type-approval emissions and real-world is substantial.

The results presented in this report are consistent with observations from previous TNO studies, namely that modern diesel cars that perform well during a type-approval test, generally have far higher NO_x emissions under real-world conditions. There is a large spread in the real-world emission results, as was observed before. Moreover, some vehicles perform consistently poorly or well across different tests, while other vehicles have very different emissions in different tests.

The effect of different payloads and driving styles on emission
Eight vehicles were tested in RDE tests with different payloads in combination with three different driving styles. The CO_2 emission generally increases with more demanding conditions of the RDE tests. Higher payloads and a dynamic driving style result for most vehicles in a CO_2 increase up to 25 to 35%. However, the NO_x emissions corresponding to different driving styles and payloads are more diverse. Some vehicles have very stable NO_x emissions but for other vehicles emissions vary widely (up to a factor 4 to 6). With high payloads and a sportive driving style the NO_x emissions can be 800 to 1000 mg/km. It must be noted that the emissions of these vehicles are optimized in for type-approval on fixed chassis dynamometer tests and not optimized for road tests.

Rural velocity profile and 80 km/h speed limit on the motorway
There is a clear distinction in the measured emissions on rural roads with an 80 km/h speed limit, and the 80 km/h speed limit on the motorway. The NO_x emissions on the motorway with speed limit enforcement are much lower than on rural roads. The difference in short time dynamics does not fully explain this difference. It seems that prolonged stable and moderate driving conditions on a motorway with 80 km/h

speed limit and strict enforcement have a beneficial effect on the performance of the emission control technology in Euro 6 diesel vehicles. There is almost a factor 2 difference between the 80 km/h speed limit motorway and all other traffic conditions.

SCR and LNT technologies and emission controls
Higher real-world NO_x emissions appear not to be correlated with the applied exhaust after treatment technologies: the ranges of NO_x emissions of the two groups of vehicles (SCR or LNT technology) both span a factor 4 between the best and the worst emission performance. This points to differences in the control strategies that are used to manage the emission control technologies (EGR, LNT and SCR) in real-world operation.

Cold start emissions
In order to get a view on cold start emissions all tested vehicles were subjected to (RDE) tests with a cold start. For current Euro 6 diesel vehicles (models from 2016) the amount of additional NO_x emission during a cold start is found to be related to the applied after-treatment technology. The tested SCR vehicles have a cold start period that lasts on average about 600 seconds in the performed RDE trips. The SCR vehicles emit on average 400 mg extra NO_x, compared to the expected emissions under the same conditions. In the first 300 seconds of the urban part of RDE trips with a cold start the three tested vehicles with a LNT have an average NO_x emission of 50 mg. This may be explained by the fact that the NO_x absorption of an LNT typically starts at 80-100 °C, while the light-off temperature of SCR catalysts is 150-200 °C.

Comparison Euro 6 and Euro VI NO_x emissions levels
No significant difference was found between the NO_x emissions of similar vehicles with a Euro 6 and Euro VI type-approval. The three vehicle types tested each showed a different trend. However, the Euro 6 vehicles clearly show a larger spread in the NO_x emissions, whereas the NO_x emissions of Euro VI vehicles are more consistently low. The larger consistency of low NO_x emissions of the Euro VI vehicles may be attributed to the real-world test that is mandatory as of 2014 for Euro VI engines and vehicles. Low NO_x emissions, in the range of 30-90 mg/km, were measured for both the Euro 6 and the VI variant of a particular vehicle model. Another Euro 6 vehicle showed similar low values. This indicates that low emission levels, below the type-approval limit value of 125 g/km, can be achieved in real-world tests.

8 References

The list below contains documents to which reference is made in this report, as well as additional literature that is considered relevant for the interpretation of the tests and test results described in this report.

[EU 2016a]	RDE-legislation package-1 (CELEX_32016R0427_EN_TXT).pdf alias "*COMMISSION REGULATION (EU) 2016/427 of 10 March 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)*", pp. 98. URL: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016R0427
[EU 2016b]	RDE-legislation package-2, (CELEX_32016R0646_EN_TXT).pdf alias *"COMMISSION REGULATION (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)"*, pp. 22. URL: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0646&rid=3
[EU 2016c]	RDE-legislation package-3, (CELEX_32017R1151_EN_TXT).pdf alias "*COMMISSION REGULATION (EU) 2017/1151 of 1 June 2017 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)"*, pp. 649. URL: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1507273829812&uri=CELEX:32017R1151
[Ligterink 2009]	Ligterink and De Lange, *Refined vehicle and driving-behaviour dependencies in the VERSIT+ emission model*, The joint 17th Transport and Air Pollution Symposium and 3rd Environment and Transport Symposium, 2009 Toulouse, France.
[Ligterink 2012]	Ligterink, *VERSIT+ theory and fitting routines*, TNO draft report, 18 November 2012.
[TNO2016a]	Heijne et al., *Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme*, TNO report 2016 R11178
[TNO 2016b]	Cuelenaere and Ligterink, *Assessment of the strengths and weaknesses of the new Real Driving Emissions (RDE) test procedure*, TNO report 2016 R11227

[TNO 2016c]	Heijne et al., NO_x emissions *of fifteen Euro 6 diesel cars: Results of the Dutch LD road vehicle emission testing programme 2016*, TNO report 2016 R11177
[TNO 2016d]	Kadijk et al., NO_x emissions *of Euro 5 diesel vans – test results in the lab and on the road*, TNO report 2016 R10356

9 Signature

The Hague, 6 December 2017	TNO
Sam van Goethem Project leader	Gerrit Kadijk Author