

TNO report**TNO 2016 R11177****NO_x emissions of fifteen Euro 6 diesel cars:
Results of the Dutch LD road vehicle emission
testing programme 2016**

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Author(s)	Veerle Heijne Gerrit Kadijk Norbert Ligterink Peter van der Mark Jordy Spreen Uilke Stelwagen
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Samenvatting

Om negatieve effecten van de uitstoot van luchtverontreinigende stoffen en het broeikasgas CO₂ 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 Milieu 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. Sinds 2015 worden testresultaten van individuele voertuigen door TNO aan de RDW opgestuurd. De RDW stuurt deze resultaten vervolgens ter informatie 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 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 veertien Euro 6 diesel personenwagens en één Euro 6 diesel bestelvoertuig. De voertuigen zijn hiervoor uitgerust met mobiele emissiemeetapparatuur, het door TNO ontwikkelde Smart Emission Measurement System (SEMS), en getest tijdens praktijkritten op de openbare weg. Drie voertuigen zijn bovendien onderworpen aan een meer gedetailleerd onderzoek op een rollenbank in het laboratorium.

Praktijkemissies op de weg

De gemiddelde NO_x-uitstoot van op de weg geteste Euro 6 diesel-voertuigen ligt in de praktijk twee tot zestien maal hoger dan de op de typekeuringstest geldende Euro 6 limietwaarde van 80 mg/km. De gemeten NO_x-emissie in stadsverkeer van deze voertuigen varieert in de praktijk van 162 tot 1306 mg/km. Deze meetresultaten zijn in lijn met eerder door TNO uitgevoerde metingen en vergelijkbaar met resultaten van andere Europese instituten die NO_x-praktijkemissies in RDE tests vonden van 100 tot 1100 mg/km.

Emissies op de rollenbank

De drie voertuigen die ook op de rollenbank in het laboratorium zijn getest, voldoen in een NEDC test volgens de typekeuringsprocedure aan de Euro 6 NO_x-norm van 80 mg/km. Als echter op de rollenbank dezelfde emissietest wordt uitgevoerd met een al opgewarmde motor dan stijgt de NO_x emissie van twee voertuigen tot zo'n

150 resp. 300 mg/km. Als de rollenbanktest wordt uitgevoerd bij een temperatuur van 15°C (in plaats van 23°C), of als er een andere testcyclus (bijv. een CADC-test) wordt gereden, dan neemt de NO_x-uitstoot toe tot wel zo'n 800 mg/km.

Koude start emissies

Van de huidige Euro 6 diesel voertuigen (modeljaar 2016) blijken de NO_x emissies bij de koude start gerelateerd aan de toegepaste voertuigtechnologie. In de eerste 300 seconden van het stadsgedeelte van een Real Driving Emission (RDE)-test met koude start hebben de negen voertuigen die zijn uitgerust met een LNT katalysator een gemiddelde NO_x emissie van 560 mg/km en de zes voertuigen uitgerust met SCR katalysator 1310 mg/km. Dit verschil kan worden verklaard uit het feit dat LNT katalysatoren NO_x gas absorberen boven een werkt temperatuur van 80-100°C terwijl SCR-katalysatoren pas boven een temperatuur van 150-200°C actief worden.

Het is de verwachting dat in de toekomst een groter aandeel Euro 6 dieselveertuigen ten gevolge van nieuwe RDE wetgeving wordt uitgerust met SCR-katalysator. SCR-katalysatoren worden pas boven een temperatuur van ongeveer 200 °C actief. Daarom, en vanwege de relevantie van koude-start emissies voor de luchtkwaliteit in stedelijke gebieden, is het van belang dat een koude start onderdeel is van RDE-wetgeving.

Trends in emissiegedrag moderne dieselveertuigen

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 valt buiten de scope van het hier gerapporteerde emissiemeetprogramma.

Al jaren laten onderzoeken van TNO zien dat de beoogde reducties van 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 onveranderd hoog blijft.

In het verleden waren verschillen tussen de typekeuringswaarde en de waarden in de praktijk deels te verklaren uit rijgedrag en rijomstandigheden. Deze testen en de uitgevoerde testen van de laatste jaren laten zien dat voor rijgedrag en gevraagde motorvermogens vergelijkbaar met de typekeurtest, de NO_x-emissies in de praktijk in veel gevallen veel hoger zijn. Dit geldt zowel op de weg als in het laboratorium. Een hogere NO_x-emissie treedt bijvoorbeeld op als een typekeuringstest met een al opgewarmde motor wordt begonnen. Deze hogere uitstoot kan niet worden verklaard door het gebruik van de marges in de testmethode (zogenaamde testflexibiliteiten) door fabrikanten. Deze testflexibiliteiten kunnen wel grotendeels het hogere brandstofverbruik en de hogere emissies van CO₂ in de praktijk en bij onafhankelijke rollenbanktests verklaren. Voor bepaling van de oorzaken van genoemde hogere NO_x emissies is een ander type onderzoek nodig.

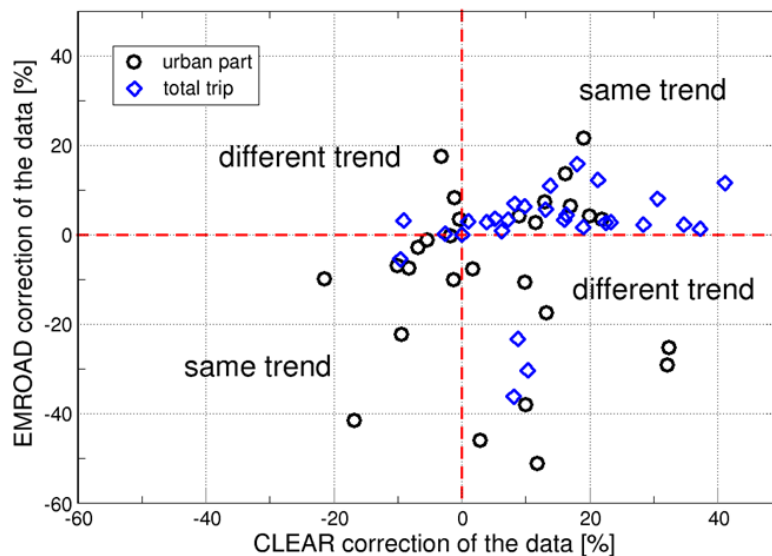
De verwachting is daarom dat een aanpassing van de testcyclus voor de rollenbank, zoals in de nieuwe WLTP (Worldwide harmonized Light vehicles Test Procedures), weinig soelaas biedt voor dit probleem. Het op de weg meten en monitoren van voertuigen met mobiele meetapparatuur en eisen stellen aan de

uitkomsten van dergelijke metingen, is een mogelijke oplossing 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 personenwagens en twee jaar later in 2019 voor alle nieuwe personenwagens verplicht wordt.

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 2017 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.

Evaluatie van RDE-normalisatiemethoden

Toepassing van de twee in de RDE-wetgeving beschreven normalisatiemethoden (met behulp van de rekentools EMROAD en CLEAR) op met een warme start uitgevoerde RDE-tests levert in veel gevallen sterk verschillende resultaten op (zie Figuur NS1). Aangezien de gebruikers een vrije keus hebben voor toepassing van één van deze normalisatiemethoden bij de toetsing van RDE-testresultaten aan de voor deze tests geldende normen, werkt dit mogelijk selectief gebruik in de hand.



Figuur NS1 Relatieve correctie van de op de praktijkritten gemeten NO_x -emissies als gevolg van normalisatie met EMROAD (y-as) en met CLEAR (x-as), gedefinieerd als $100 \cdot (\text{Genormaliseerde waarde} - \text{Actuele Waarde_TNO}) / \text{Actuele waarde_TNO} \%$, voor alle 28 warme RDE trips.

Summary

In order to reduce the negative impacts of the pollutant and greenhouse gas emissions of road transport, the European Commission has implemented emission regulations which set limits for various components 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 the Environment 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 Dutch type approval authority RDW (Rijksdienst voor het Wegverkeer). These test results are forwarded by the RDW to the type approval authority who is responsible for the Whole Vehicle Type Approval of that particular vehicle. Furthermore, the results are used to determine national vehicle emission factors, which are used for air quality modelling and the national emission registration.

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

This report describes real-world emission test results of fourteen Euro 6 compliant diesel passenger vehicles and one Euro 6 N1 class II light commercial vehicle. The vehicles were equipped with TNO's Smart Emission Measurement System (SEMS) and their emission performance was subsequently screened while driving representative routes on public roads. Three vehicles were also tested in greater detail on a chassis dynamometer in a laboratory.

Real-world emissions

The tested vehicles showed NO_x emission levels that are 2 to 16 times higher than the type approval emission limit value of 80 mg/km: their average NO_x emissions in urban traffic ranged from 162-1306 mg/km. These measurement results confirm findings in other European studies which reported comparable real-world NO_x emissions of around 100 to 1100 mg/km in RDE tests.

Emissions on the chassis dynamometer

Three vehicles were tested on the chassis dynamometer. When subjected to an NEDC type approval test, these vehicles complied with the Euro 6 type approval NO_x limit value of 80 mg/km. If, however, the same test on the roller bench was started with a warm engine, the NO_x emission of two vehicles were found to rise to around 150 resp. 300 mg/km. Chassis dynamometer tests at an ambient temperature of 15°C (instead of 23°C), with a real-world road load, or on a different test cycle (e.g. the CADC), caused NO_x emissions to go up to around 800 mg/km.

Cold start emissions

For current Euro 6 diesel vehicles the level of NO_x emissions during a cold start appears to correlate with the applied emission after treatment technology. In the first 300 seconds of the urban part of RDE trips with a cold start the nine tested vehicles with an LNT have an average NO_x emission of 560 mg/km while the six tested vehicles with an SCR have average NO_x emissions of 1310 mg/km. This may be explained by the fact that the NO_x absorption of an LNT starts typically at 80-100°C, while SCR catalysts have a light-off temperature of 150-200°C.

It is expected that an increasing share of the Euro 6c diesel vehicles will be equipped with SCR technology. For this reason, as well as because of the relevance of cold start emissions for urban air quality, it might be considered to add a cold start test to the current RDE legislation.

Trends in NO_x emissions of diesel cars

These test results confirm the results of earlier studies: Diesel cars comply with type approval requirements in the standardised laboratory test, but real-world NO_x emissions of these 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. However, the results seem to indicate that the difference between type-approval and real-world emissions is unchanged high.

In the past, this difference could be partly linked to a difference in driving pattern and ambient conditions between the real world and the type approval test. Modern diesel vehicles, however, show significantly elevated NO_x emissions, even when a vehicle is driven under conditions that are comparable to the type approval test conditions. For example, higher NO_x emissions are also observed when starting a type approval test with a hot engine. These increased NO_x emissions cannot be explained by the utilization of test margins, as is the case for fuel consumption and CO₂ emissions of which the real-world values are also known to be higher than type approval values.

The new emission data presented in this report will be used in 2017 by TNO to update the Dutch emission factors for Euro 6 diesel passenger cars.

Therefore, it is expected that a modification of the test cycle, like in the WLTP (Worldwide harmonized Light vehicles Test Procedures), will not solve 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, may be the means for closing the gap between the type-approval pollutant emission limits and the real-world values. The RDE legislation developed by the European Commission will become mandatory for new passenger vehicles by 1 September 2017 and two years later in 2019 for all new passenger vehicles.

RDE normalization tools

Application of the two normalization tools (EMROAD and CLEAR), described in the RDE regulation, to the results of RDE-compatible tests in many cases results in very different corrections (see Figure S1). As OEMs have the choice to use one instrument of the other for evaluating compliance of the on-road emissions with the RDE requirements, this may provoke a selective use of these tools.

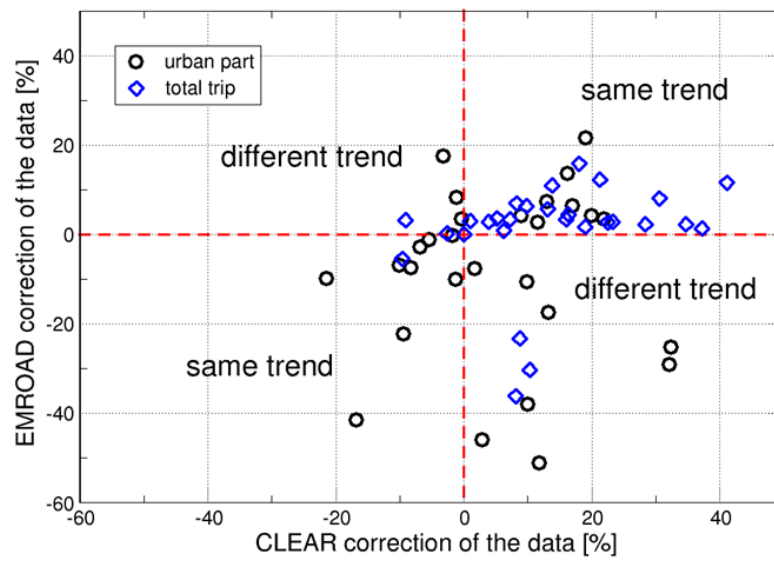


Figure S1 Relative correction of the NO_x emissions on RDE compatible tests resulting from normalisation with EMROAD (y-axis) and CLEAR (x-axis), defined as $100 \cdot (\text{Normalised_Value} - \text{Raw_Value_TNO}) / \text{Raw_Value_TNO} \%$, for all 28 RDE trips.

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1 Introduction

This document contains results from emission tests, carried out by TNO in the period 2015-2016. The specific focus is on NO_x emissions of Euro 6 diesel passenger cars. The emission tests were carried out as part of a project conducted by TNO for the Dutch Ministry of Infrastructure and the Environment.

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 they do and do not imply. TNO and the Dutch Ministry of Infrastructure and the Environment 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-duty passenger vehicles of category M1 must comply with the Euro 6b standard.

The Euro 6c standard, that further limits the emissions of light-duty vehicles, will become mandatory in 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 been reduced significantly over the past decade. However, under real driving conditions some emissions substantially deviate from their type approval values. The real driving emissions of nitrogen oxides, or NO_x, from diesel vehicles are currently the largest issue with regard to pollutant emissions. As NO_x represents the sum of NO and NO₂ emitted, and because in the outside air NO is converted to NO₂, reducing NO_x emissions of vehicles is important for bringing down the ambient air NO₂ concentration in cities. In the Netherlands, the ambient NO₂ concentration still exceeds European limits at numerous urban road-side locations¹.

Commissioned by the Dutch Ministry of Infrastructure and the Environment, TNO regularly performs emission measurements within the “in-use compliance

¹ <http://www.atlasleefomgeving.nl/en/meer-weten/lucht/stikstofdioxide>

programme for light-duty vehicles". In the early years, i.e., in 1987 to 2000, the focus was on performing a large number of standard type approval tests 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 driving cycles in the lab and by increasingly testing cars on the road with mobile emission measurement equipment.

TNO has performed real-world tests on multiple Euro 6 diesel vehicles over the years. In recent years Euro 6 production models have entered the market and emission factors for passenger vehicles have been established.

All real-world investigations considered, urban emission factors for NO_x emissions of Euro 3, 4, 5 and 6 diesel vehicles were a lot higher than expected, as Figure 1 shows.

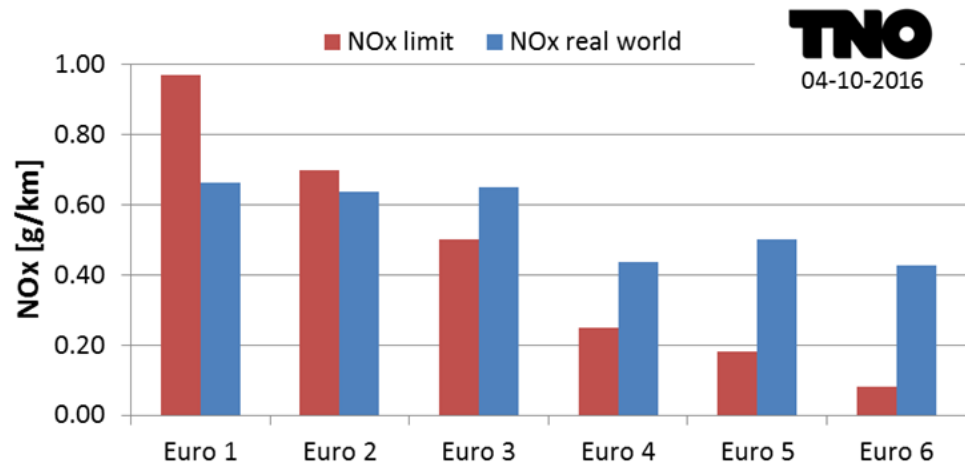


Figure 1 Emission limits and 2015 real-world emission factors for M1 class diesel passenger cars.

In this report the test results of fourteen Euro 6 diesel passenger vehicles (model year 2016) and one light commercial vehicle are presented and discussed. Estimates based on passenger car tests for Euro 6a NO_x emission factors, used for prognoses in 2016 are in between 0.40 g/km (highway), 0.40 g/km (rural) and 0.53 g/km (urban congestion). In 2015 the NO_x emission factors for diesel Euro 6 passenger cars were somewhat lower. However, until September 2015 for some vehicle models Euro 5 vehicles were still on sale and the picture for Euro 6 vehicles was not complete.

Based on the performed emission measurements, TNO develops, and annually updates, vehicle emission factors that represent the average real-world emissions data for specific various vehicle types categories under different driving / traffic conditions. Vehicle emission factors are used for emission inventories and air quality monitoring. TNO is one of the few institutes in Europe who perform independent emission tests. Dutch 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 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.

The insights obtained in the project furthermore serve as input for the activities of the Dutch government and the RDW in the context of decision making 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 this research is to assess the real-world emission performance of Euro 6 diesel passenger 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, or 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 is able to determine 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, some vehicles are tested for thousands of kilometres of normal operation.

A second aim of this test programme, of which results are reported here, has been to build up experience with RDE test practices and data evaluation and normalisation with the tools EMROAD and CLEAR.

This study involves SEMS measurements on fourteen Euro 6 passenger diesel vehicles and one light commercial vehicle. Most vehicles were tested in a two day test programme encompassing 9 different trips over 550 km. This relatively large number of vehicles provides a sufficient basis to observe trends in their emission behaviour and to generate representative average emission factors for the different traffic situations. Moreover, to validate the on-road measurements against laboratory measurements, three vehicles were tested on a chassis dynamometer as well.

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, and are given the opportunity to reflect on them.

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

- The tests performed by TNO are not intended for enforcement purposes and 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 it cannot be ruled out 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. Where results of individual vehicles were reported, these were always anonymised.

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 to issue this document in which test results are presented with reference to makes and models. This decision also meets a desire expressed by the Dutch Ministry of Infrastructure and the Environment. 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, we 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

Currently in Europe RDE legislation is under construction and will come into force in 2017. TNO has 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 for determination of emission factors and they are not fully RDE-compliant. Although the trips on which the measurements have been performed are 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. Normalised test results and resulting Conformity Factors are reported and discussed in Chapter 4. In Chapter 5 the topic of cold start effects is investigated. 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 that was performed. The measurement methods are described in greater detail in the TNO methodology report [TNO 2016].

2.1 Tested Vehicles

2.1.1 Vehicle selection

In January 2016 on the basis of Dutch new car sales data the Euro-6 diesel engines based on engine volume and engine power, for the different manufacturer group were identified. For these engines the Euro 6 diesel vehicles with the highest sales volumes were identified. With this limited sample of vehicles the largest representation of Euro-6 engines, and the largest representation of vehicles, in which these engines are used, are selected. Most selected test vehicles of Table 1 belong to the group of the highest sales vehicles. Some additional vehicles, of the same make and model, were included to test the reproducibility of earlier findings by two of the vehicles in the new test programme.

2.1.2 Vehicle specifications

In Table 1 some basic data, NO_x after treatment technologies (AT) and the test programme of the selected vehicles are specified. All vehicles were tested on the road and three vehicles were tested on the chassis dynamometer as well.

Table 1 Fifteen tested Euro 6 diesel vehicles

No.	Brand	Model	Category	Power [kW]	AT	Odometer [km]	Test Mass [kg]	Test programme
1	Citroen	Cactus	M	73	SCR	9.739	1141	On road
2	Ford	Fiesta	M	81	LNT	23.040	1155	On road
3	Ford	Focus	M	70	LNT	6.500	1400	On road + chassis dyno
4	Opel	Zafira	M	100	SCR	60.366	1776	On road
5	Peugeot	308	M	110	SCR	1.675	1478	On road
6	Peugeot	308	M	81	SCR	2.525	1313	On road
7	Peugeot	Partner	N1 CL II	73	SCR	5.740	1460	On road
8	Renault	Clio	M	66	LNT	3.623	1183	On road
9	Renault	Megane – a*	M	81	LNT	6.233	1371	On road
10	Renault	Megane – b	M	81	LNT	1.231	1380	On road + chassis dyno
11	Volvo	V40	M	88	LNT	6.862	1346	On road
12	VW	Golf	M	81	LNT	14.550	1280	On road + chassis dyno
13	VW	Passat	M	81	LNT	50.123	1446	On road
14	VW	Polo	M	55	LNT	30.187	1125	On road
15	Mercedes	C220	M	125	SCR	17.100	1625	On road

* In order to verify the emissions of the first Renault Megane (vehicle 10) a second sample was tested

2.2 On-road test trips

Twelve vehicles were tested according to a fixed trip schedule with a total length of 579 km. Some information of the test trips of this 2-day test programme is specified

in Table 2. The average velocity of the trips varies approximately from 18 – 83 km/h and the length of the trips is 22 – 87 km.

The trips 2 and 8 are equal and meant to obtain insight in the reproducibility of test results on this trip. In order to test vehicles in traffic with congestion the trips 4 and 5 were started during evening and morning traffic at motorways.

Four vehicles were tested over longer distances of 2900 - 12000 km and three of these vehicles were tested on the chassis dynamometer.

Some vehicles were tested in two different RDE-trips.

- RDE_A = Helmond, The Netherlands
- RDE_D = Delft, The Netherlands

Table 2 On-road test trips in the 2-days test programme in Delft

No.	Trip	Type	Start condition	Day	Distance [km]	Average velocity [km/h]
1	RDE_D_C	Urban / rural / motorway	Cold start	1	78	40
2	RDE_D_W	Urban / rural / motorway	Hot start	1	78	43
3	MOTORWAY	Motorway	Hot start	1	87	79
4	CONGEST_W	Motorway	Hot start	1	66	56
5	CONGEST_C	Motorway	Cold start	2	84	83
6	CITY	Urban	Hot start	2	22	18
7	RURAL	Rural	Hot start	2	85	55
8	RDE_D_W	Urban / rural / motorway	Hot start	2	78	43
	total				579	50

2.3 Measurement equipment

Emission measurements on the road were performed using a sensor-based Smart Emission Measurement System (SEMS). The chassis dynamometer measurements, performed on three vehicles as indicated in Table 1, were carried out at the facilities of Horiba, Oberursel (Germany).

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 and Figure 3. In four different tests the CO₂ 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 of the accuracy of the calibrated concentration measurements and the exhaust flow determination from the concentration measurements and the engine signals used.

For further information on the measurement methods used by TNO, the reader is referred to [TNO 2016].

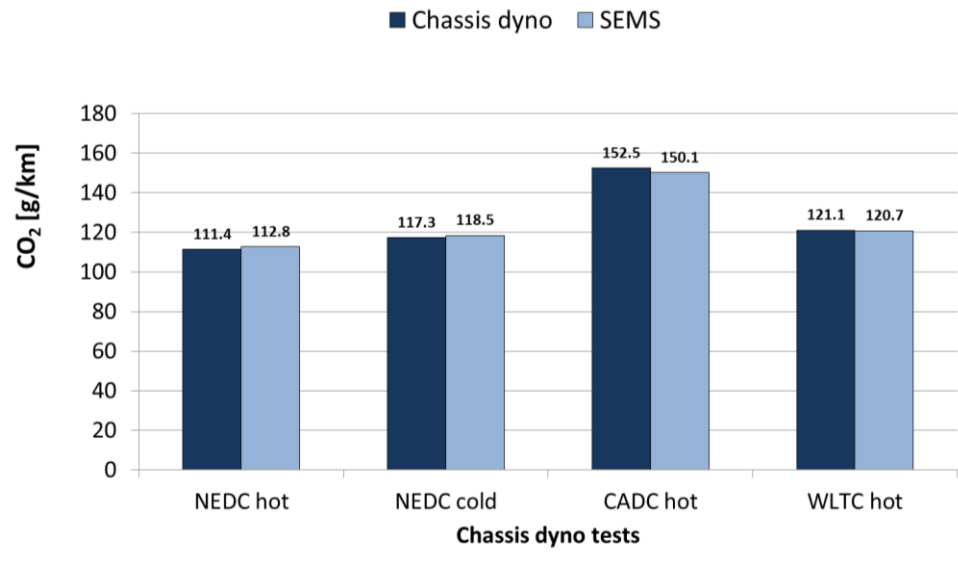


Figure 2 CO₂ emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS

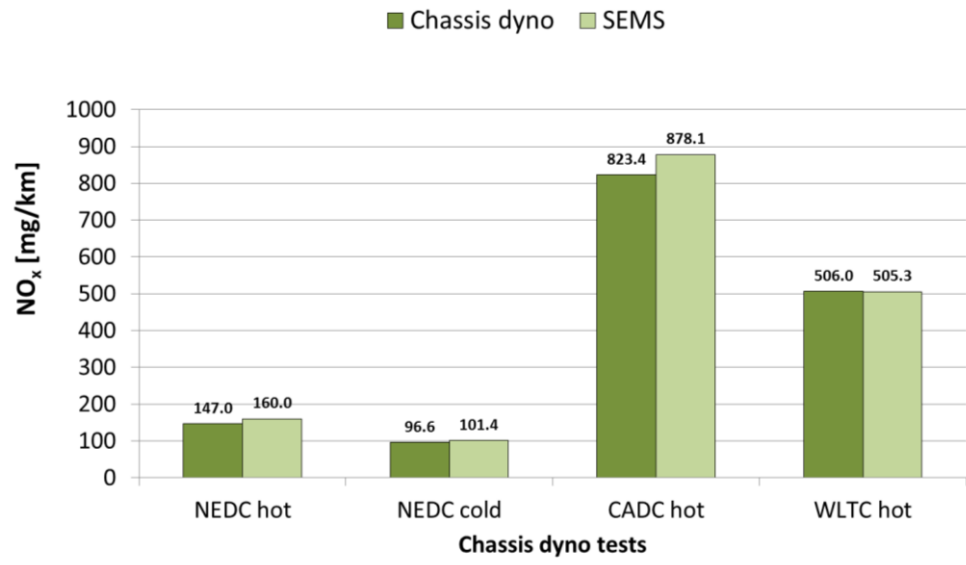


Figure 3 NO_x emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS

3 Emission test results

This chapter provides the measured 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 A NO_x emission map of the engine plus exhaust after treatment system
- 4 Normalised emissions per vehicle for different traffic conditions
- 5 Additional test results, e.g. from chassis dynamometer tests, where relevant

In paragraph 3.2 an overview of the normalised emissions of all vehicles is reported.

3.1 Emission test results per vehicle

The emission test results for each tested vehicle are summarised in the following paragraphs. First, the emission results per trip are summarised in a table. 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 vehicle speed is recorded. In order to compare better 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 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 spread is large indicated by the bars. If all the NO_x emissions in one velocity bin are all close together, the spread is small. For example, the bin at 110-120 km/h in Figure 4 has a large spread, so both very high and very 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 4, for example at velocities over 120 km/h, a limited amount of data is available. This is illustrated by the blue bars in Figure 5, which represent the number of seconds the vehicle is driving in that specific velocity regime. In this figure, most data is 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 6. This requires a large amount of data, as is collected in the two-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. In order to read the scale in these plots appropriately it should be noted 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 Citroen Cactus (73 kW)

In Table 3 the specifications of the tested Citroen Cactus are reported.

Table 3 Vehicle specifications of the Citroen Cactus

Trade Mark	[-]	Citroen
Type	[-]	Citroen C4 Cactus Bleu Hdi 100
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	1.6 Blue Hdi 100
Swept Volume	[cm ³]	1.560
Max. Power	[kW]	73
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	e2*2007/46*0440*02
Type Approval Number	[-]	France
Vehicle Empty Mass	[kg]	1045
Declared CO ₂ emission	[g/km]	82
Vehicle Identification Number	[-]	VF70BBHYBFE559341
Vehicle Test Mass*	[kg]	1231
Odometer	[km]	9739
Registration Date	[dd-mm-yy]	28-10-15

* Incl. driver and SEMS, 80+10 kg



In Table 4 the CO₂ and NO_x test results are reported. Due to difficulties during data acquisition, only five trips were recorded for the Citroen Cactus.

Table 4 Emission results per trip of a Citroen Cactus Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp			CO ₂ [g/km]	NO _x [mg/km]	NH ₃ [mg/km]
						min	max	avg [°C]			
RDE_D_C	2016-3-30	8:09	6342	77.9	44.2	1	11	8.4	141.4	436.4	1.6
RDE_D_W	2016-3-30	10:08	6570	77.8	42.6	5	14	10.9	128.6	513.6	0.4
MOTORWAY	2016-3-30	12:51	3118	79	91.2	2	15	12.5	111.4	541.4	0.0
CONGEST_W	2016-3-30	14:50	2845	53.2	67.3	10	13	11.6	104.8	402.3	0.0
CONGEST_C	2016-3-31	7:40	4607	83.9	65.5	2	11	8.1	104.8	401.6	0.1
TOTAL				371.8	57	1	15	10	118.8	462.2	0.4

Remarks:

- Regeneration of the DPF took place at the end of the cold RDE trip, RDE_D_C.
- Hardly any congestion in hot congestion trip (CONGEST_W), limited amount of congestion in cold congestion trip (CONGEST_C).
- Failure of connection with test equipment (SEMS) in final three tests. Results of these test are therefore not listed.

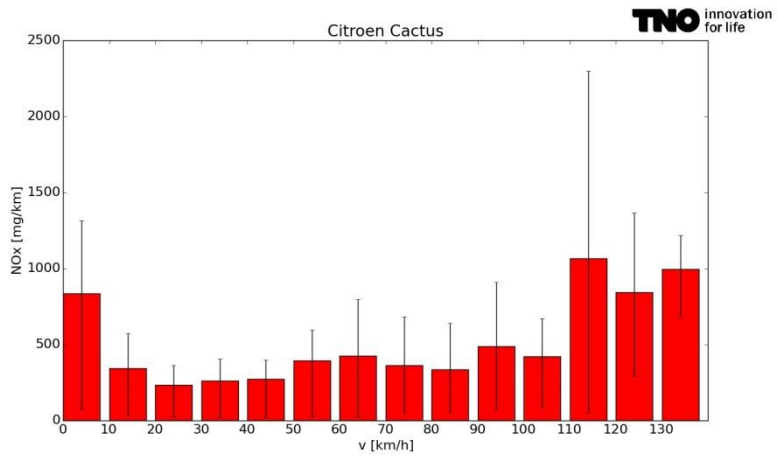


Figure 4 Average NO_x emissions of a Citroen Cactus Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

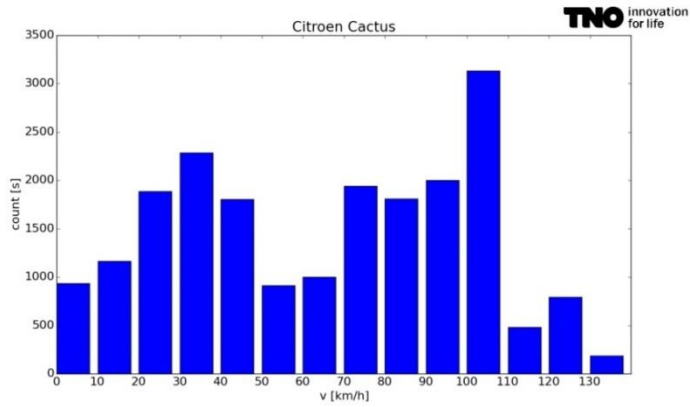


Figure 5 Number of seconds per velocity bin, over all trips. Idling is excluded.

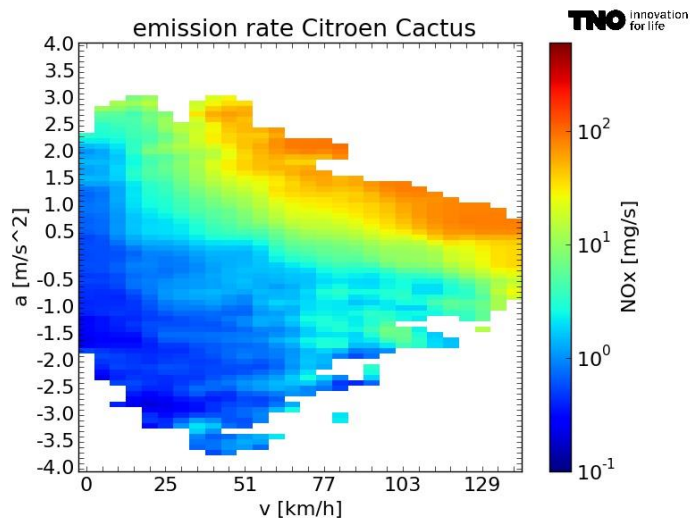


Figure 6 NO_x emission rate [mg/s] of a Citroen Cactus Euro 6 diesel in bins of velocity and acceleration

3.1.2 Ford Fiesta (70 kW)

In Table 5 the specifications of the tested Ford Fiesta are reported.

Table 5 Specifications of the Ford Fiesta

Trade Mark	[-]	Ford
Type	[-]	Fiesta 1.5 TDCI
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	1.5 TDCi DURATORQ diesel
Swept Volume	[cm ³]	1.499
Max. Power	[kW]	70
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	Spain
Type Approval Number	[-]	e9*2001/116*0069*20
Vehicle Empty Mass	[kg]	1036
Declared CO ₂ emission	[g/km]	82
Vehicle Identification Number	[-]	WF0DXXGAKDFY73802
Vehicle Test Mass*	[kg]	1245
Odometer	[km]	23040
Registration Date	[dd-mm-yy]	31-08-15

* Incl. driver and SEMS, 80+10 kg



In Table 6 the CO₂ and NO_x test results of the Ford Fiesta are reported.

Table 6 Emission results per trip of a Ford Fiesta Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp			CO ₂ [g/km]	NO _x [mg/km]
						min/max/avg [°C]				
RDE_D_C	2016-3-23	8:51	6971	78.3	40.4	6	10	8.3	123.7	371.5
RDE_D_W	2016-3-23	11:02	6604	78	42.5	9	13	9.1	119.1	372.8
MOTORWAY	2016-3-23	14:52	3958	87.1	79.2	9	13	10.7	108	128.6
CONGEST_W	2016-3-23	16:15	4282	66.3	55.7	8	12	9.7	106.6	220
CONGEST_C	2016-3-25	7:50	3655	83.9	82.6	3	8	6.1	104.1	128.4
CITY	2016-3-25	9:06	4346	21.9	18.2	5	9	6.9	144.5	205.6
RURAL	2016-3-25	10:26	5609	85.1	54.6	6	11	8.6	115.6	236.3
RDE_D_W	2016-3-25	12:19	6592	78	42.6	7	12	10.4	119.6	311.7
TOTAL				578.6	49.6	3	13	8.8	114.9	248.3

Remarks:

- Regeneration of the DPF took place at the beginning of the RURAL trip, with exhaust gas temperatures of 400 °C, for about 10 minutes.
- No significant congestion occurred in the cold congestion trip (CONGEST_C)
- The MOTORWAY trip had congestion for 10-15 minutes.

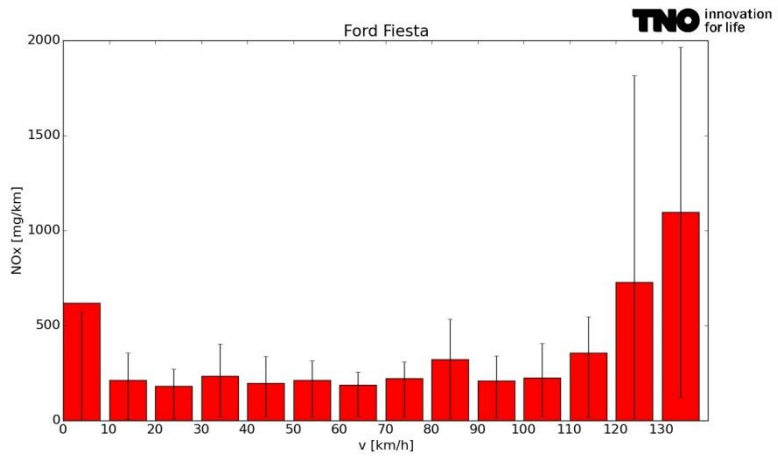


Figure 7 Average NO_x emissions of a Ford Fiesta Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

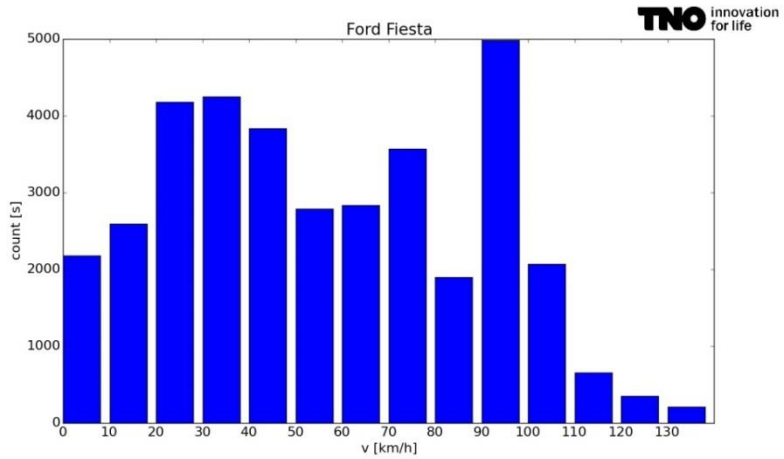


Figure 8 Number of seconds per velocity bin, over all trips. Idling is excluded.

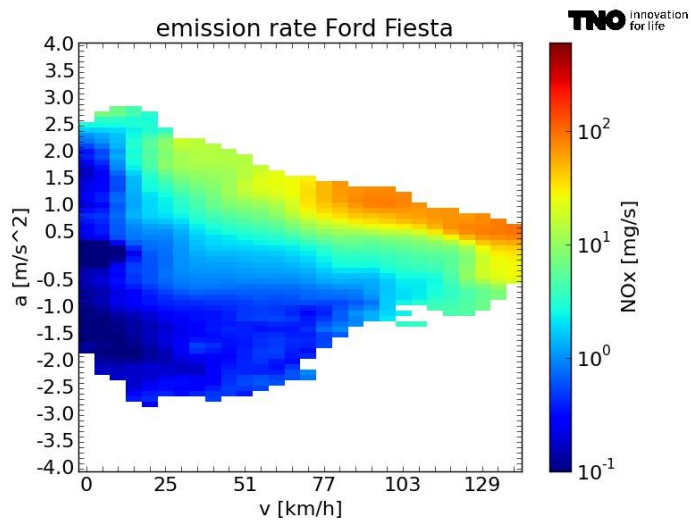


Figure 9 NO_x emission rate [mg/s] of a Ford Fiesta Euro 6 diesel in bins of velocity and acceleration

3.1.3 Ford Focus (70 kW)

In Table 7 the specifications of the tested Ford Focus are reported.

Table 7 Specifications of the Ford Focus

Trade Mark	[-]	Ford
Type	[-]	Focus
Body	[-]	Stationwagon
Vehicle Category	[-]	M
Fuel	[-]	Diesel
Engine Code	[-]	XXDC
Swept Volume	[cm ³]	1.499
Max. Power	[kW]	70
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	Luxembourg-SNCH
Type Approval Number	[-]	e11*715/2007* 2015/45W*8157*01
Vehicle Empty Mass	[kg]	1274
Declared CO ₂ emission	[g/km]	98
Vehicle Identification Number	[-]	WF06XXGCC6FJ71845
Vehicle Test Mass*	[kg]	1490
Odometer	[km]	6500
Registration Date	[dd-mm-yy]	30-09-15

* Incl. driver and SEMS, 80+10 kg



This vehicle was tested from 20-10-2015 to 24-11-2015 over a distance of 6462 km. During this period emission data of 6023 km was logged and stored and several emission tests on a chassis dynamometer were performed. This vehicle was not subjected to all on-road trips of the two-day emission test programme developed early 2016 for the subsequent vehicles.

The main objectives of this test programme for this vehicle were: Obtaining more insight in real world NO_x emissions and development of RDE trips at different locations.

In Table 8 the results of the chassis dynamometer tests are reported. In the cold NEDC test the applied inertia setting of the chassis dynamometer was 1470 kg and this was not according the specifications of the type approval test. The NO_x emission at this elevated inertia setting is 96.6 mg/km. In case of an official, declared inertia setting of 1360 kg this vehicle probably passes the emission test with a limit value of 80 mg/km. Elevated NO_x emissions are measured in the NEDC test with hot start (147 mg/km, CF=1.8), WLTC-test with hot start (506 mg/km, CF=6.3) and CADC-test with hot start (823.4 mg/km, CF=10.3).

Table 8 Chassis dynamometer test results of a Ford Focus Euro 6 diesel

	HC	CO	CO ₂	NO _x	NO	NMHC	CH ₄	HC + NO _x	PM	PN	Fuel cons.
	[mg/km]		[g/km]	[mg/km]						[1/km]	[l/100km]
Euro 6 limit value	-	500		80*	-	-	-	170	4.5	6.0E+11	-
NEDC-cold @ 23 °C	32.7	216.1	117.3	96.6**	62.2	22.9	9.8	129.3	0.1	4.7E+09	4.39
NEDC-hot @ 23 °C	22.6	74.3	111.0	147.0	89.3	15.8	7.8	169.6	0.1	3.5E+07	4.16
WLTC-hot @ 23 °C	2.8	11.1	121.1	506.0	233.8	0.8	2.3	508.9	0.1	7.7E+07	4.51
CADC150-hot @ 23 °C	5.6	13.1	152.5	823.4	424.3	3.1	2.8	829.0	0.5	1.1E+09	5.68

* inertia setting = 1360 kg ** inertia setting = 1470 kg.

In Table 9 the CO₂ and NO_x results of different RDE trips of the Ford Focus are reported. The RDE trips were executed at two different locations (Helmond and Delft) and they were executed by different drivers.

Table 9 RDE Emission results of a Ford Focus Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp*			CO ₂ [g/km]	NO _x [mg/km]
						min	max	avg [°C]		
RDE_D_C	2015-10-20	13:00	7599	92.4	43.8	-	-	12	122.6	494.9
RDE_D_C	2015-10-21	11:51	7086	100.1	50.9	-	-	12	116.6	425.8
RDE_D_C	2015-10-28	10:47	3679	66.4	65	-	-	13	116.3	534.2
RDE_D_W	2015-10-28	11:59	1184	31.2	94.9	-	-	13	126.3	473.9
RDE_D_W	2015-10-29	13:57	7218	97.6	48.7	-	-	15	116.2	541.7
RDE_A_W	2015-11-10	13:59	5986	75.6	45.4	-	-	15	117.5	370.7
RDE_D_W	2015-11-3	11:25	6231	76	43.9	-	-	16	115.8	567.8
RDE_A_C	2015-11-9	9:36	5899	76	46.4	-	-	15	125.1	411.4
RDE_A_W	2015-11-9	12:45	5666	75.5	48	-	-	16	120.8	480.6
RDE_A_W	2015-11-9	14:48	5816	75.5	46.7	-	-	17	127.5	393.1
TOTAL				766.4	48.9				120	469.6

*Source: KNMI (Dutch meteorology office) database

Remarks:

- Regeneration took place during the trips RDE_A_REG_W (9-11-2015 14:48) and RDE_REG_C (21-10-2015 11:51).

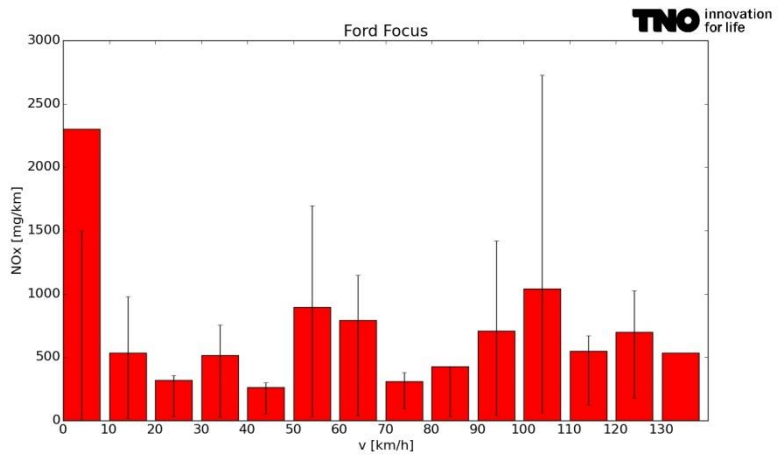


Figure 10 Average NO_x emissions of a Ford Focus Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

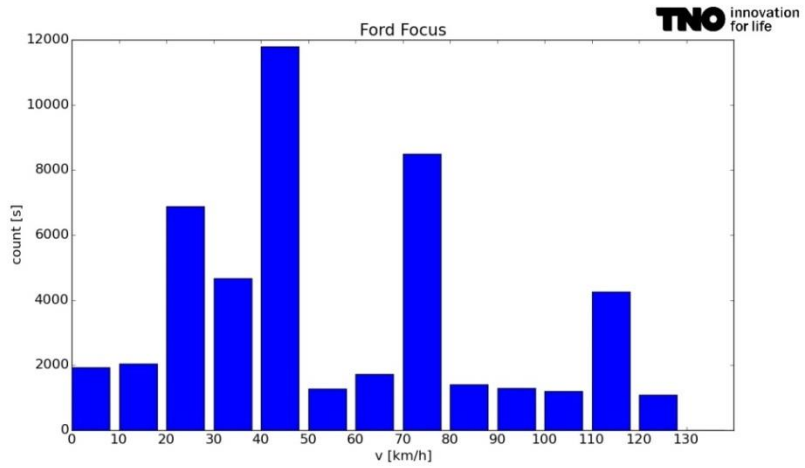


Figure 11 Number of seconds per velocity bin, over all trips. Idling is excluded.

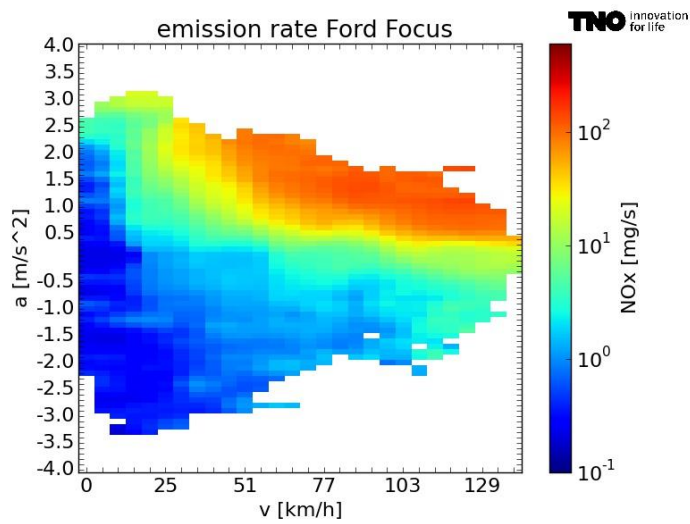


Figure 12 NO_x emission rate [mg/s] of a Ford Focus Euro 6 diesel in bins of velocity and acceleration

3.1.4 Opel Zafira (100 kW)

In Table 10 the specifications of the tested Opel Zafira are reported.

Table 10 Specifications of the Opel Zafira

Trade Mark	[-]	Opel
Type	[-]	Zafira
Body	[-]	Passenger vehicle
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	B16DTH
Swept Volume	[cm ³]	1.598
Max. Power	[kW]	100
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	the Netherlands
Type Approval Number	[-]	e4*2007/46*0204*15
Vehicle Empty Mass	[kg]	1701
Declared CO ₂ emission	[g/km]	109
Vehicle Identification Number	[-]	W0LPD9E36E2053094
Vehicle Test Mass*	[kg]	1866
Odometer	[km]	60366
Registration Date	[dd-mm-yy]	22-04-14

* Incl. driver and SEMS, 80+10 kg



In Table 11 the CO₂ and NO_x test results of the Opel Zafira are reported.

Table 11 Emission results per trip of an Opel Zafira Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp			CO ₂ [g/km]	NO _x [mg/km]	NH ₃ [mg/km]
						min/max/avg	[°C]				
RDE_D_C	2016-3-15	8:50	6460	77.9	43.4	0	9	6	166.3	919.1	1.0
RDE_D_W	2016-3-15	11:13	6000	77	46.2	0	9	7	150.2	876.6	0.1
MOTORWAY	2016-3-15	14:12	4054	94.4	83.8	0	11	8.2	126.5	678.6	0.0
CONGEST_W	2016-3-15	15:53	5203	53.3	36.9	0	10	8.6	137.2	746.2	0.1
CONGEST_C	2016-3-16	7:44	4455	83.7	67.6	0	5	2.7	131.6	819.1	0.1
CITY	2016-3-16	9:14	4159	21.8	18.9	1	10	6.2	181.2	1148.9	0.3
RURAL	2016-3-16	10:37	5966	83.3	50.2	5	14	9.7	132.5	763.4	0.0
RDE_D_W	2016-3-16	12:39	6291	77.7	44.5	3	15	10.4	144.6	833.4	0.0
TOTAL				569.1	48.1	0	15	7.5	142.4	816.9	0.2

Remarks:

- Regeneration of the DPF took place at the end of the cold RDE trip (RDE_D_C).

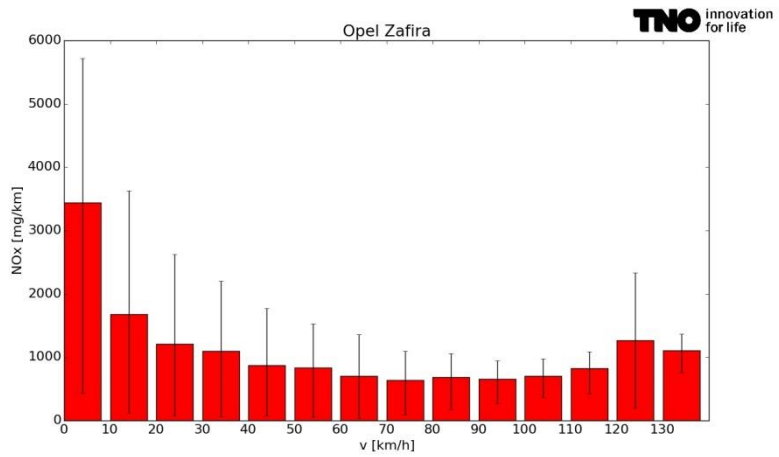


Figure 13 Average NO_x emissions of an Opel Zafira Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

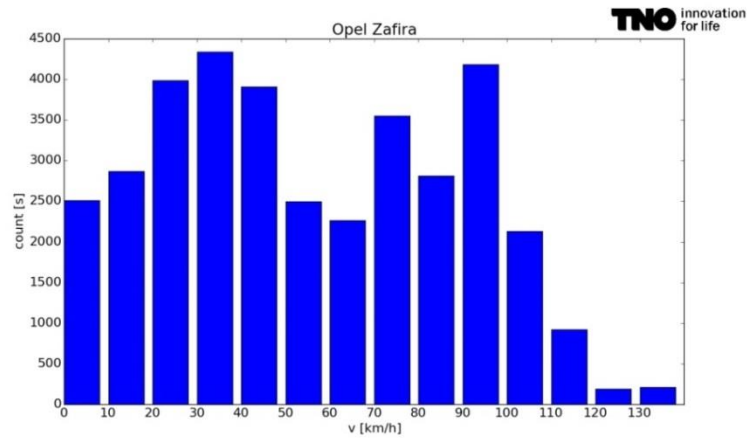


Figure 14 Number of seconds per velocity bin, over all trips. Idling is excluded.

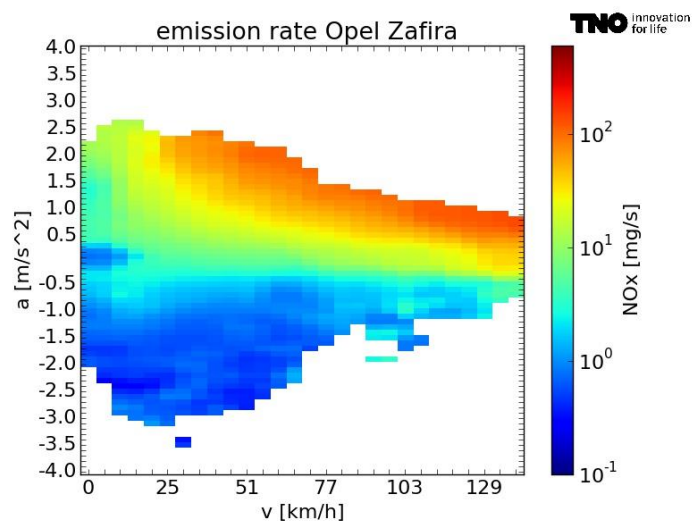


Figure 15 NO_x emission rate [mg/s] of an Opel Zafira Euro 6 diesel in bins of velocity and acceleration

3.1.5 Peugeot 308 (110 kW)

In Table 12 the specifications of the tested Peugeot 308 (110 kW) are reported.

Table 12 Specifications of the Peugeot 308 Break

Trade Mark	[-]	Peugeot
Type	[-]	308 SW 2.0 BlueHDi
Body	[-]	Station_wagon
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	2.0 BlueHDi
Swept Volume	[cm ³]	1997
Max. Power	[kW]	110
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	France
Type Approval Number	[-]	e2*2007/46*0405*11
Vehicle Empty Mass	[kg]	1390
Declared CO ₂ emission	[g/km]	97
Vehicle Identification Number	[-]	VF3L9AHRHGS030738
Vehicle Test Mass*	[kg]	1568
Odometer	[km]	1675
Registration Date	[dd-mm-yy]	18-02-16

* Incl. driver and SEMS, 80+10 kg



In Table 13 the CO₂ and NO_x test results of the Peugeot 308 (110 kW) are reported.

Table 13 Emission results per trip of the Peugeot 308 (110 kW)

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp			CO ₂ [g/km]	NO _x [mg/km]	NH ₃ [mg/km]
						min	max	avg			
RDE_D_C	2016-3-9	8:19	6935	78.6	40.8	1	8	5.4	156.6	494.6	0.4
RDE_D_W	2016-3-9	10:37	6471	79.1	44	6	10	7.9	151.5	461.6	0.4
MOTORWAY	2016-3-9	13:27	6494	143.1	79.3	7	13	10.4	128.4	288.7	0.1
CONGEST_W	2016-3-9	15:24	2926	49.6	61	8	12	10.4	142.5	412.0	6.1
CONGEST_C	2016-3-11	8:41	3852	84	78.5	0	8	3.8	124.3	204.6	0.1
CITY	2016-3-11	9:47	4876	23	16.9	3	9	4	167.1	353.2	0.0
RURAL	2016-3-11	11:16	6055	86.9	51.7	2	13	7.2	131.8	322.6	0.2
RDE_D_W	2016-3-13	16:32	6484	88.2	49	8	11	9.5	141.8	440.5	0.0
TOTAL				632.5	51.6	0	13	7.4	139.1	362.6	0.6

Remarks:

- Regeneration took place during the hot congestion trip (CONGEST_W).
- Due to quiet traffic there was no congestion in both congestion trips (CONGEST_W and CONGEST_C).

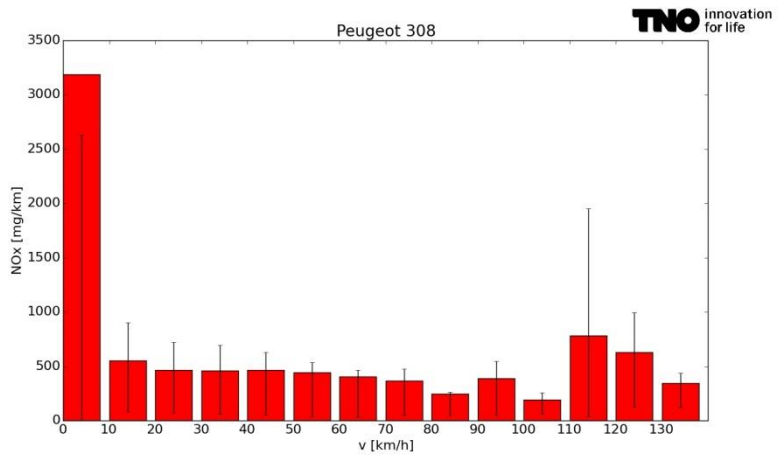


Figure 16 Average NO_x emissions of a Peugeot 308 (110 kW) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

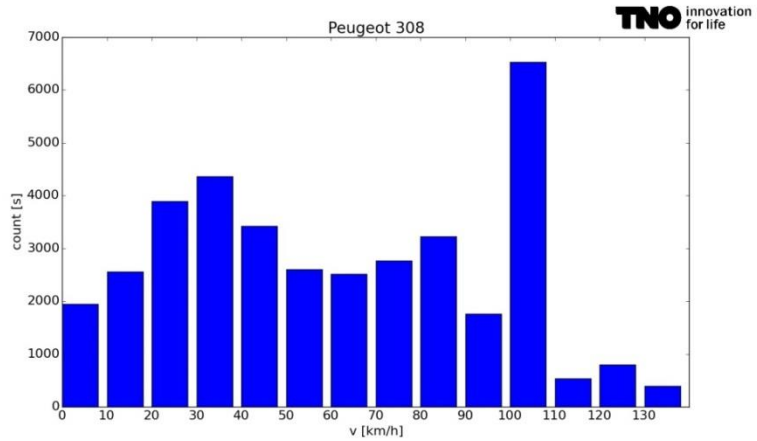


Figure 17 Number of seconds per velocity bin, over all trips. Idling is excluded.

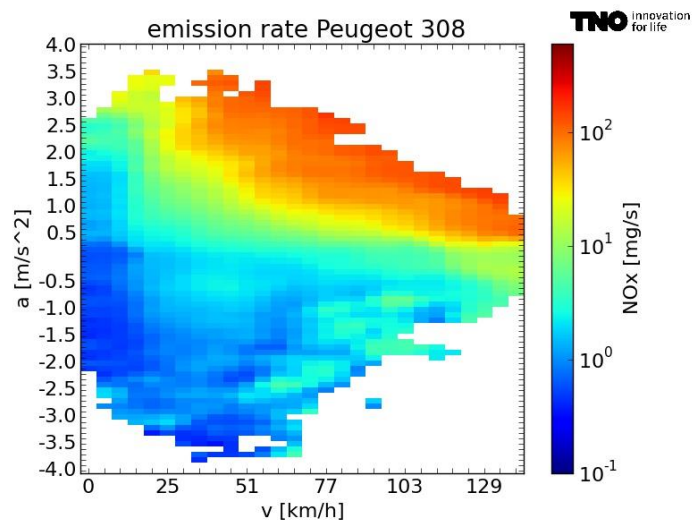


Figure 18 NO_x emission rate [mg/s] of a Peugeot 308 (110 kW) Euro 6 diesel in bins of velocity and acceleration

3.1.6 Peugeot 308 (88 kW)

In Table 14 the specifications of the tested Peugeot 308 (88 kW) are reported.

Table 14 Specifications of the Peugeot 308 Hatchback

Trade Mark	[-]	Peugeot
Type	[-]	308
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	1.6 blue HDI
Swept Volume	[cm ³]	1560
Max. Power	[kW]	88
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	e2*2007/46*0405*11
Type Approval Number	[-]	France
Vehicle Empty Mass	[kg]	1160
Declared CO ₂ emission	[g/km]	82
Vehicle Identification Number	[-]	VF3LBBHZHFS3347703
Vehicle Test Mass*	[kg]	1403
Odometer	[km]	2525
Registration Date	[dd-mm-yy]	28-12-15

* Incl. driver and SEMS, 80+10 kg



In Table 15 the CO₂ and NO_x test results of the Peugeot 308 (88 kW) are reported.

Table 15 Emission results per trip of a Peugeot 308 (88 kW) Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO ₂ [g/km]	NO _x [mg/km]	NH ₃ [mg/km]
RDE_D_C	2016-3-19	7:35	6116	77.9	45.9	0	11	5.5	125.7	475.0	0.4
RDE_D_W	2016-3-19	10:02	6066	81.3	48.2	7	10	8	123.1	473.7	0.2
CONGEST_C	2016-3-21	7:10	6160	84.5	49.4	5	10	7.4	117.7	411.3	0.2
CITY	2016-3-21	8:52	4124	23.6	20.6	3	10	8.9	152.5	196.7	0.3
RURAL	2016-3-21	10:01	5384	82.8	55.4	7	12	9.7	117.1	257.0	0.1
RDE_D_W	2016-3-21	11:54	6868	78.1	40.9	9	13	10.3	127.6	310.7	0.3
CONGEST_W	2016-3-21	15:28	2489	44.9	65	3	11	9.2	106.2	275.4	0.1
MOTORWAY	2016-3-21	16:14	3764	73.6	70.4	6	10	8.7	104	254.9	0.1
TOTAL				546.7	48	0	13	8.4	119.7	350.4	0.2

Remarks:

- Congestion during MOTORWAY trip for about 10-15 minutes.

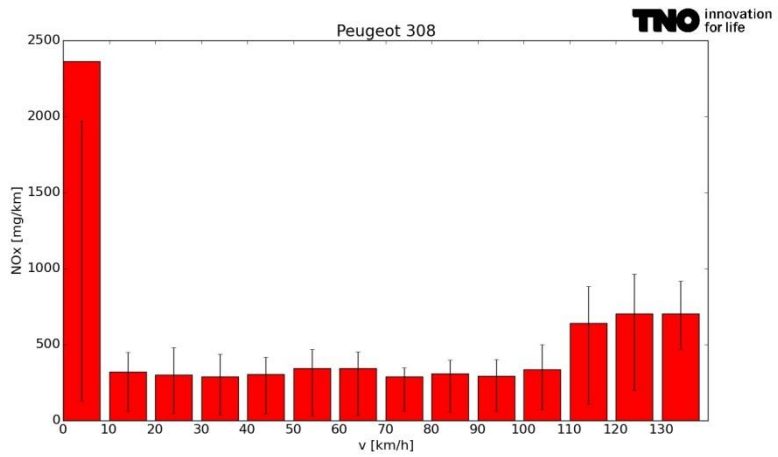


Figure 19 Average NO_x emissions of a Peugeot 308 (88 kW) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

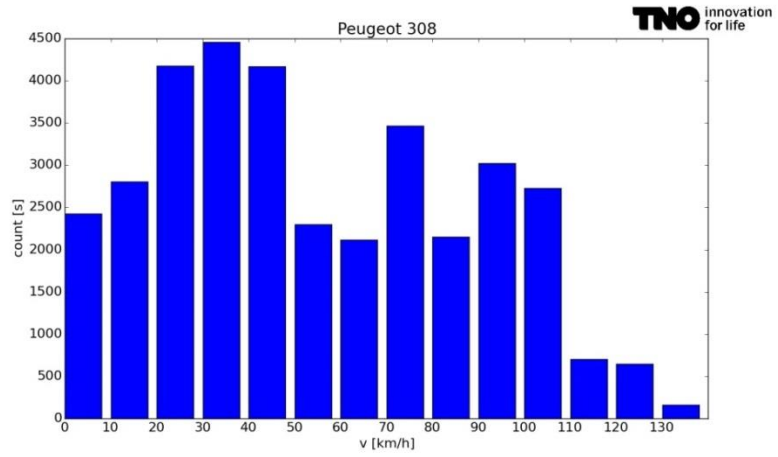


Figure 20 Number of seconds per velocity bin, over all trips. Idling is excluded.

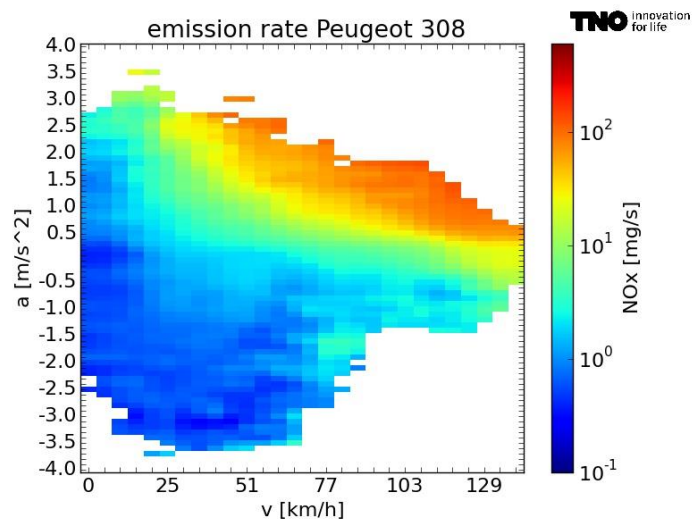


Figure 21 NO_x emission rate [mg/s] of a Peugeot 308 (88 kW) Euro 6 diesel in bins of velocity and acceleration

3.1.7 Peugeot Partner (73 kW)

In Table 16 the specifications of the tested Peugeot Partner are reported.

Table 16 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	[cm ³]	1560
Max. Power	[kW]	73
Euro Class	[-]	Euro 6
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]	1550
Odometer	[km]	5740
Registration Date	[dd-mm-yy]	31-08-15

* Incl. driver and SEMS, 80+10 kg



This vehicle was tested from 05-01-2016 to 03-03-2016 over a distance of 2900 km. During this period emission data of 2720 km was logged and stored. This vehicle was not subjected to all on-road trips of the 2-days emission test programme. The main objectives of this test programme were: Obtaining more insight in real world NO_x emissions and development of RDE trips at different locations.

In Table 17 the CO₂ and NO_x test results of different RDE trips (RDE_D in Delft and RDE_A in Helmond) of the Peugeot Partner are reported. The RDE trips are executed by one driver.

Table 17 RDE emission results of a Peugeot Partner Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO ₂ [g/km]	NO _x [mg/km]	NH ₃ [mg/km]
RDE_D_W	2016-1-15	14:51	7074	76.3	38.8			4	136.3	398.8	0.2
RDE_D_W	2016-1-20	15:11	6407	76.3	42.9			5	138.7	421.6	0.2
RDE_D_W	2016-1-8	16:03	6676	76.3	41.2			8	136.2	368.3	0.3
RDE_D_C	2016-2-15	8:15	6659	76.6	41.4			-1	148.5	549.2	0.2
RDE_D_C	2016-2-19	8:33	7101	81.1	41.1			0	139.5	534.1	1.0
RDE_A_C	2016-2-25	10:42	5586	76	49			0	136.7	419.9	0.3
RDE_A_W	2016-2-25	13:46	5401	75	50			4	135.3	449.5	0.1
TOTAL				537.6	43.1				138.8	449.6	0.3

Remarks:

- None

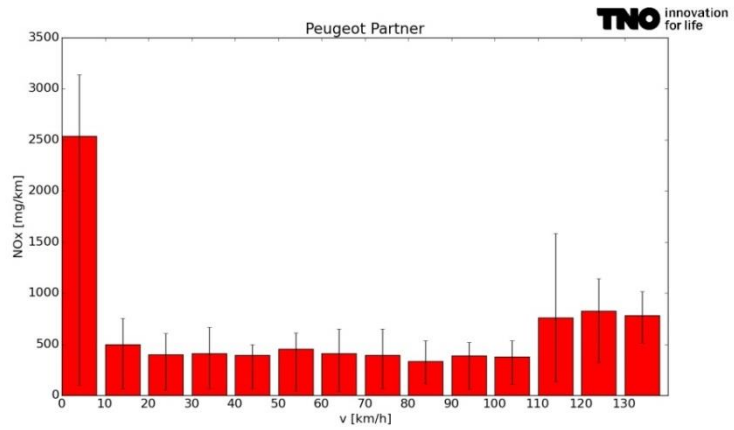


Figure 22 Average NO_x emissions of a Peugeot Partner Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

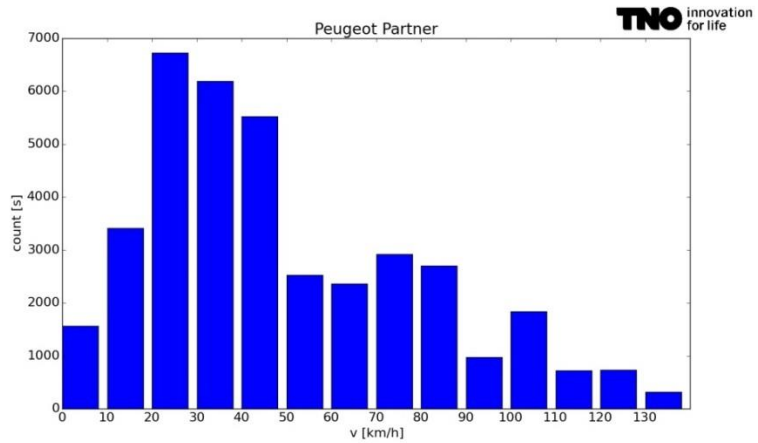


Figure 23 Number of seconds per velocity bin, over all trips. Idling is excluded.

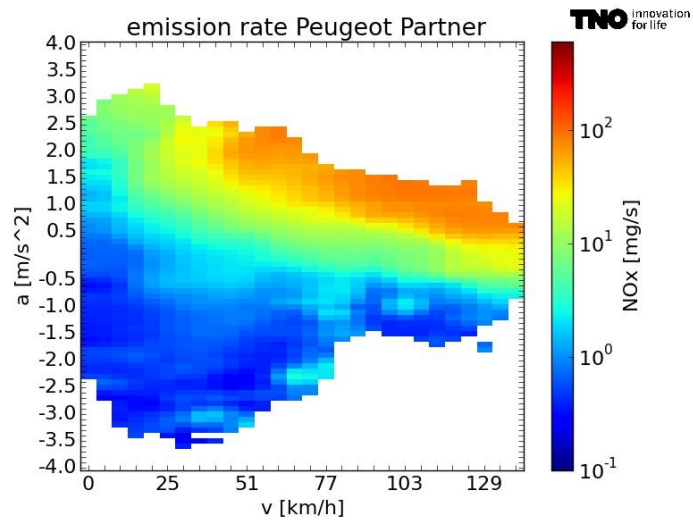


Figure 24 NO_x emission rate [mg/s] of a Peugeot Partner Euro 6 diesel in bins of velocity and acceleration

3.1.8 Renault Clio (66kW)

In Table 18 the specifications of the tested Renault Clio are reported.

Table 18 Specifications of the Renault Clio

Trade Mark	[-]	Renault
Type	[-]	Clio dCi
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	1.5 dCi - K9k
Swept Volume	[cm ³]	1461
Max. Power	[kW]	66 kW
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	e2*2001/116*0327*74
Type Approval Number	[-]	France
Vehicle Empty Mass	[kg]	1062
Declared CO ₂ emission	[g/km]	82
Vehicle Identification Number	[-]	VF15ROJOA54271709
Vehicle Test Mass*	[kg]	1273
Odometer	[km]	3623
Registration Date	[dd-mm-yy]	30-12-15

* Incl. driver and SEMS, 80+10 kg



In Table 19 the CO₂ and NO_x test results of the Renault Clio are reported.

Table 19 Emission results per trip of a Renault Clio Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO ₂ [g/km]	NO _x [mg/km]
RDE_D_C	2016-3-21	9:04	6278	77.8	44.6	8	11	9.3	107.9	881.8
RDE_D_W	2016-3-21	11:16	6439	77.7	43.4	10	13	11.1	107.9	929.7
CONGEST_W	2016-3-21	16:35	5871	87.9	53.9	8	11	9.4	100.4	620.8
CONGEST_C	2016-3-22	7:58	6571	83.6	45.8	9	13	10.3	101.4	760.7
CITY	2016-3-22	10:00	4184	23.5	20.2	11	13	11.8	120.9	1204.1
RURAL	2016-3-22	11:26	5714	83.2	52.4	10	14	11.8	101.2	845.1
RDE_D_W	2016-3-22	13:13	6143	77.5	45.4	11	17	13.1	108.6	992.2
MOTORWAY	2016-3-22	15:09	3571	86.9	87.6	10	13	11.9	98.4	564.4
TOTAL				598.1	48.1	8	17	11	104.2	808.5

Remarks:

- None

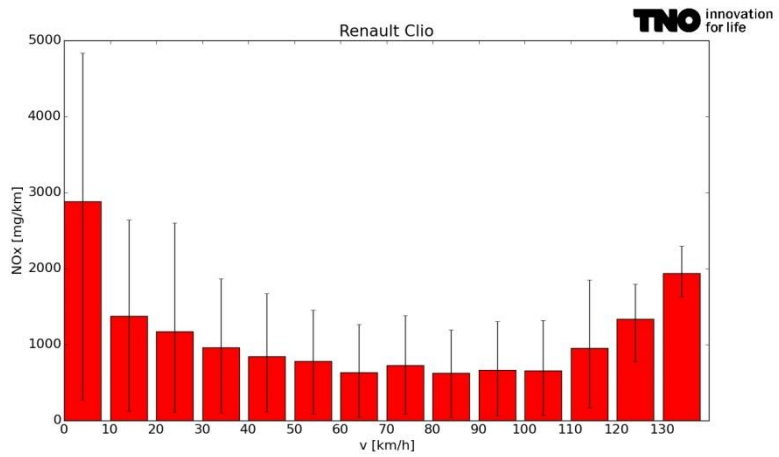


Figure 25 Average NO_x emissions of a Renault Clio Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

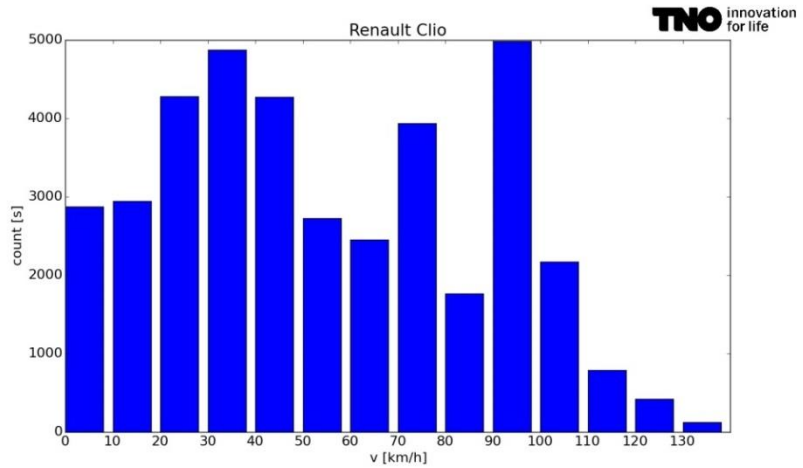


Figure 26 Number of seconds per velocity bin, over all trips. Idling is excluded.

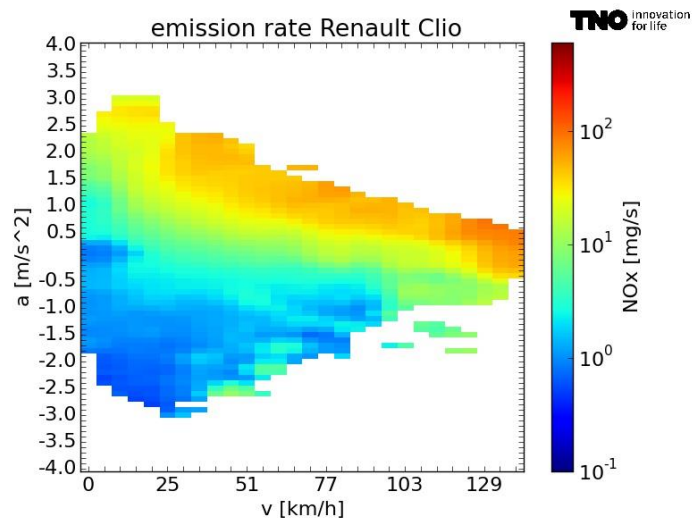


Figure 27 NO_x emission rate [mg/s] of a Renault Clio Euro 6 diesel in bins of velocity and acceleration

3.1.9 Renault Megane –a (81 kW)

In Table 20 the specifications of the tested Renault Megane (a) are reported.

Table 20 Specifications of the Renault Megane (a)

Trade Mark	[-]	Renault
Type	[-]	Megane
Body	[-]	Station_wagon
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	K9KG656 (Euro6)
Swept Volume	[cm ³]	1461
Max. Power	[kW]	81
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	France
Type Approval Number	[-]	e2*2001/116*0373*55
Vehicle Empty Mass	[kg]	1231
Declared CO ₂ emission	[g/km]	93
Vehicle Identification Number	[-]	VF1KZ890H53724934
Vehicle Test Mass*	[kg]	1461
Odometer	[km]	6233
Registration Date	[dd-mm-yy]	3 nov 2015

* Incl. driver and SEMS, 80+10 kg



In Table 21 the CO₂ and NO_x test results of the Renault Megane (a) are reported.

Table 21 Emission results per trip of a Renault Megane (a) Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO ₂ [g/km]	NO _x [mg/km]
RDE_D_C	2016-3-11	8:47	6845	77.7	40.9	1	12	6.8	132.7	897.3
RDE_D_W	2016-3-11	11:10	6462	77.7	43.3	8	17	11.6	120.5	917.5
MOTORWAY	2016-3-11	14:19	6305	127.9	73	9	15	11.2	114	685.7
CONGEST_W	2016-3-11	16:19	2908	56.1	69.4	8	12	10.5	105.7	717.3
CONGEST_C	2016-3-14	7:54	6152	83.7	49	0	7	3.3	119.2	939.9
CITY	2016-3-14	9:57	3824	23.6	22.2	4	10	6.5	136.3	911.8
RURAL	2016-3-14	11:12	6184	88	51.2	6	14	9.6	108.2	792.9
RDE_D_W	2016-3-14	13:18	6473	77.7	43.2	7	16	12.2	124.2	1017.9
TOTAL				612.3	48.8	0	17	9	118.5	845.9

Remarks:

- Regeneration took place at the end of the cold RDE trip (RDE_D_C) and during the MOTORWAY trip.
- Hardly any congestion during warm congestion trip (CONGEST_W).

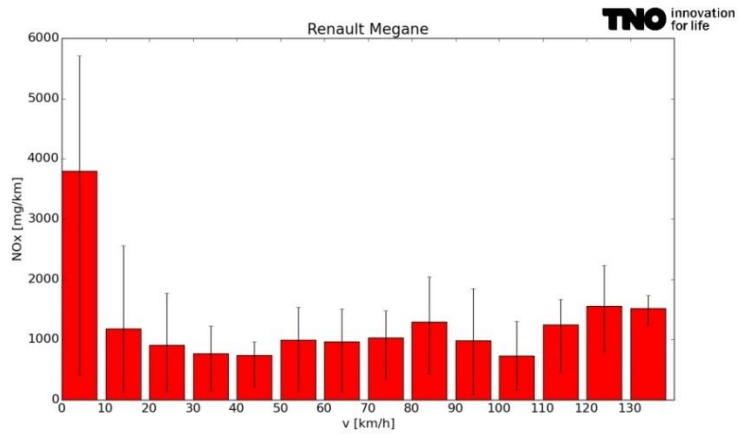


Figure 28 Average NO_x emissions of a Renault Megane (a) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

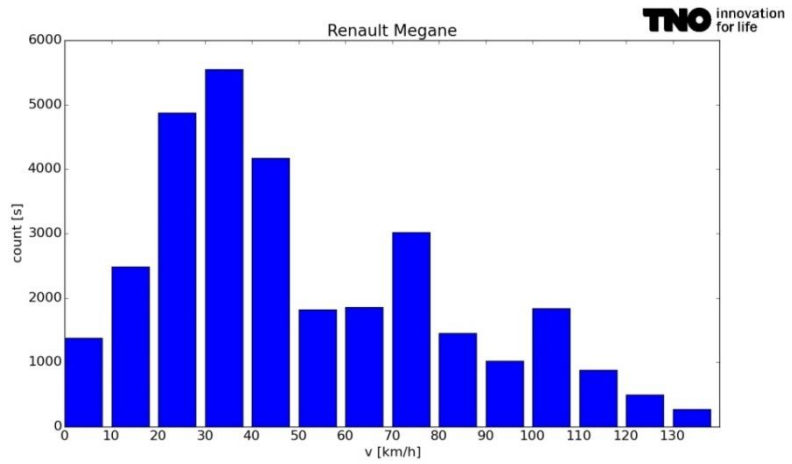


Figure 29 Number of seconds per velocity bin, over all trips. Idling is excluded.

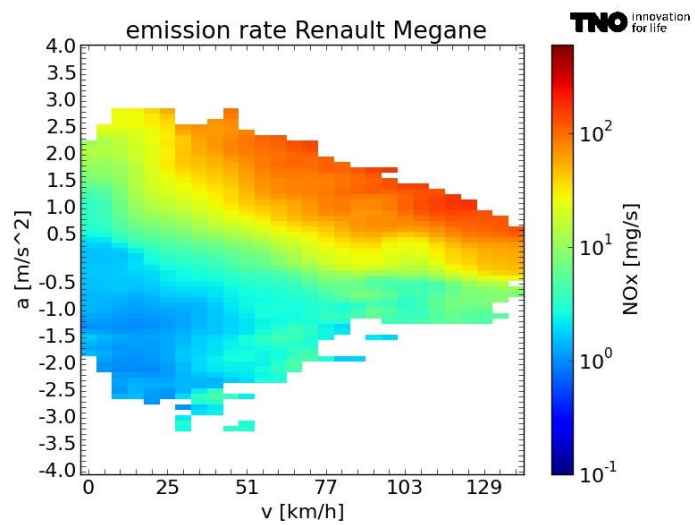


Figure 30 NO_x emission rate [mg/s] of a Renault Megane (a) Euro 6 diesel in bins of velocity and acceleration

3.1.10 Renault Megane - b (81 kW)

In Table 22 the specifications of the tested Renault Megane (b) are reported.

Table 22 Specifications of the Renault Megane (b)

Trade Mark	[-]	Renault
Type	[-]	Megane
Body	[-]	Station_wagon
Vehicle Category	[-]	M
Fuel	[-]	Diesel
Engine Code	[-]	K9KG656 (Euro6)
Swept Volume	[cm ³]	1461
Max. Power	[kW]	81
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	France
Type Approval Number	[-]	e2*2001/116*0373*54
Vehicle Empty Mass	[kg]	1231
Declared CO ₂ emission	[g/km]	93
Vehicle Identification Number	[-]	VF1KZ890H53724954
Vehicle Test Mass*	[kg]	1470
Odometer	[km]	1826 - 13978
Registration Date	[dd-mm-yy]	03-11-15

* Incl. driver and SEMS, 80+10 kg



This vehicle was tested from 01-12-2015 to 20-01-2016 over a distance of 12152 km. During this period emission data of 9004 km was logged and stored and several emission tests on a chassis dynamometer were performed.

The main objectives of this test programme were: Obtaining more insight in real world NO_x emissions and development of RDE trips at different locations. This vehicle was not subjected to all on-road trips of the 2-day emission test programme.

In Table 23 the results of the chassis dynamometer tests are reported. In the NEDC test with cold start the NO_x emission is 71.0 mg/km. This vehicle thus complies with the type approval limit value of 80 mg/km. However, the measured CO₂ emission is 117.3 g/km, which exceeds the specified type approval value of 93 g/km. This CO₂ gap of 24 g/km (+26%) may be caused by the condition of this vehicle. The internal frictions of the powertrain may be higher than in the type approved sample vehicle and different wheel/tyre configurations may be mounted.

Elevated NO_x emissions are measured in the NEDC test with hot start (220.9 mg/km, CF=2.8), WLTC-test with hot start (684.5 mg/km, CF=8.6) and CADC with hot start (807.3 mg/km, CF=10.1). NEDC tests with cold starts at two temperature levels (23 and 15 °C) result in a different NO_x emission (71.0 and 487.8 mg/km), while the NEDC-tests with hot start at these two ambient temperatures yield similar NO_x emission results (220.0 and 230.5 mg/km).

Table 23 Chassis dynamometer test results of a Renault Megane (b) Euro 6 diesel

	HC	CO	CO ₂	NO _x	NO	NMHC	CH ₄	HC + NO _x	PM	PN	Fuel cons.
	[mg/km]		[g/km]	[mg/km]						[1/km]	[l/100km]
Euro 6 limit value	-	500		80	-	-	-	170	4.5	6.0E+11	-
NEDC-cold @ 23 °C	17.0	93.0	117.26	71.0	47.0	11.0	5.0	88.0	0.0	4.7E+09	4.39
NEDC-cold @ 15 °C	43.3	302.0	109.31	487.8	291.5	33.7	7.6	531.1	0.2	1.0E+09	4.10
NEDC-hot @ 23 °C	12.3	7.4	102.08	220.9	116.6	4.3	9.2	233.2	0.2	3.4E+09	3.80
NEDC-hot @ 23 °C	10.7	6.8	99.84	293.9	152.6	3.2	8.6	304.6	0.2	3.1E+09	3.72
NEDC-hot @ 15 °C	3.6	7.1	103.23	230.5	140.8	1.2	2.8	234.2	0.1	8.9E+08	3.85
WLTC-hot @ 23 °C	1.5	7.9	120.25	684.5	289.5	1.1	0.6	686.0	0.1	1.0E+09	4.48
CADC150-hot @ 23 °C	8.8	11.6	151.30	807.3	280.1	4.2	5.3	816.1	0.4	1.1E+09	5.64

In Table 24 the CO₂ and NO_x results of different RDE trips of the Renault Megane are reported. The RDE trips were executed at two different locations (RDE_A = Helmond and RDE_D = Delft) and by different drivers. The results on similar RDE trips in different locations are very similar.

Table 24 Emission results per trip of a Renault Megane (b) Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO ₂ [g/km]	NO _x [mg/km]
RDE_A_C	2015-12-1	9:12	5699	76.2	48.2			9	132	1033
RDE_D_C	2015-12-24	8:32	6063	73.4	43.6			8	130.9	1031
RDE_D_C	2015-12-24	15:17	5717	69.4	43.7			13	125.8	921
RDE_D_W	2015-12-29	13:25	5996	75	45			10	130.5	1016
RDE_D_C	2015-12-31	11:36	6136	77.6	45.6			9	125.7	950
RDE_D_W	2016-1-21	9:25	6329	76.4	43.5			-3	135.6	1050
TOTAL				448.1	44.9				130.1	1001

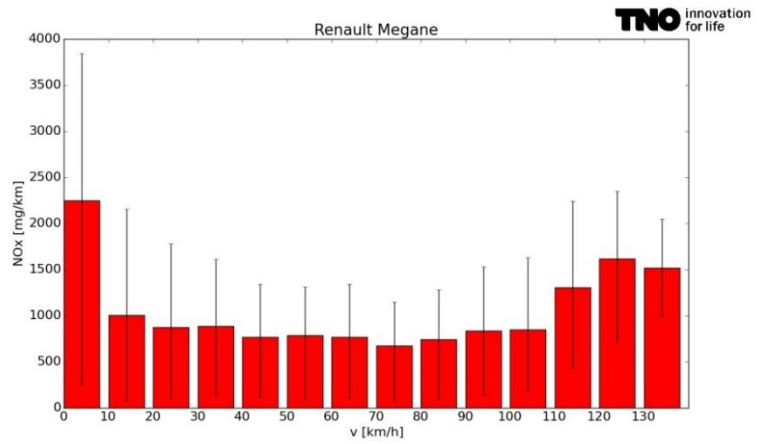


Figure 31 Average NO_x emissions of a Renault Megane (b) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

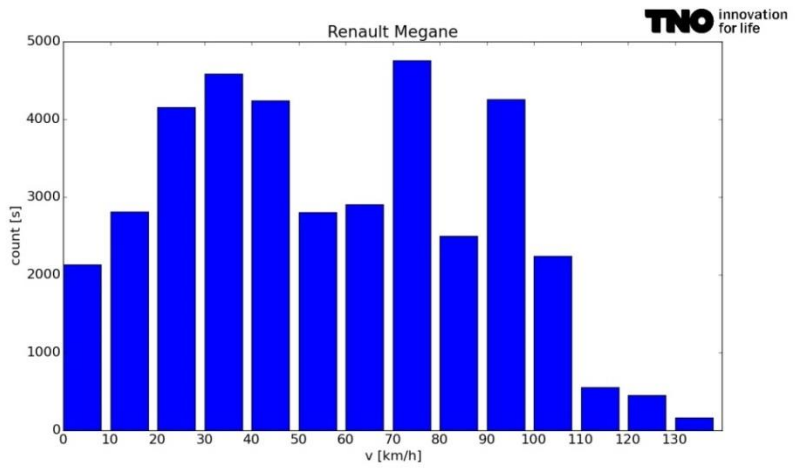


Figure 32 Number of seconds per velocity bin, over all trips. Idling is excluded.

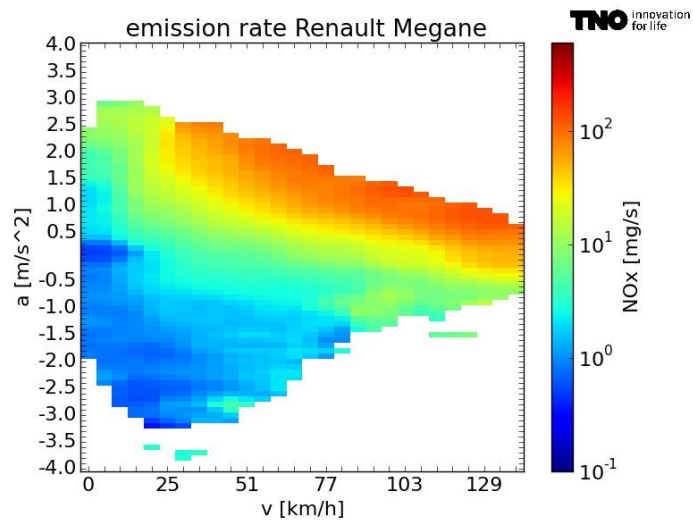


Figure 33 NO_x emission rate [mg/s] of a Renault Megane (b) Euro 6 diesel in bins of velocity and acceleration

3.1.11 Volvo V40 (88kW)

In Table 25 the specifications of the tested Volvo V40 are reported.

Table 25 Specifications of the Volvo V40

Trade Mark	[-]	Volvo
Type	[-]	V40
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	D2
Swept Volume	[cm ³]	1.969
Max. Power	[kW]	88
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	The Netherlands
Type Approval Number	[-]	e4*2007/116*0076*38
Vehicle Empty Mass	[kg]	1292
Declared CO ₂ emission	[g/km]	82
Vehicle Identification Number	[-]	YV1MV7431G2315816
Vehicle Test Mass*	[kg]	1436
Odometer	[km]	6862
Registration Date	[dd-mm-yy]	15-12-15

* Incl. driver and SEMS, 80+10 kg



In Table 26 the CO₂ and NO_x test results of the Volvo V40 are reported.

Table 26 Emission results per trip of a Volvo Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO ₂ [g/km]	NO _x [mg/km]
RDE_D_C	2016-3-16	9:29	6593	78	42.6	3	11	7.8	127.2	314.8
RDE_D_W	2016-3-16	11:34	6640	79.4	43	8	15	10.3	129.6	405.4
MOTORWAY	2016-3-16	14:35	4776	107.8	81.3	10	14	12	123.4	327.4
CONGEST_W	2016-3-16	16:00	5274	88.9	60.7	9	13	11.1	122.2	328
CONGEST_C	2016-3-17	8:48	4346	84.1	69.7	2	12	7.5	116.2	255.7
CITY	2016-3-17	10:05	3779	23.6	22.5	7	17	11.1	134.3	407.1
RURAL	2016-3-17	11:12	6171	86.9	50.7	10	16	12.8	111.4	325.1
RDE_D_W	2016-3-17	13:31	6997	77.8	40	10	17	13.9	125.2	409.5
TOTAL				626.5	50.6	2	17	10.9	122.5	339.1

Remarks:

- Slight congestion in MOTORWAY trip.

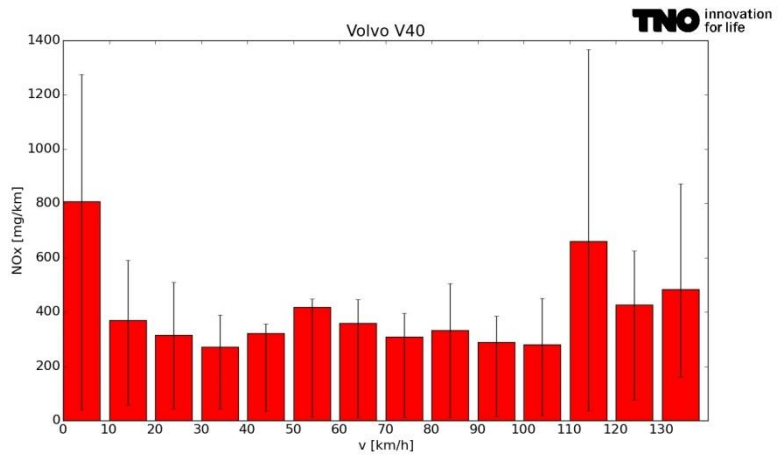


Figure 34 Average NO_x emissions of a Volvo V40 Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

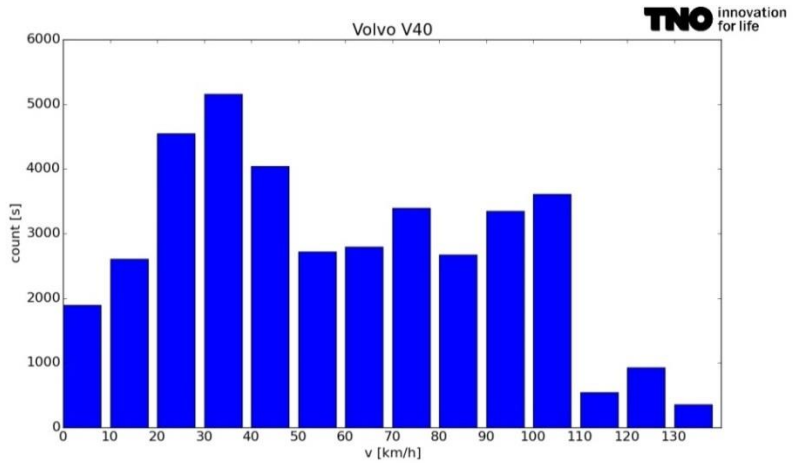


Figure 35 Number of seconds per velocity bin, over all trips. Idling is excluded.

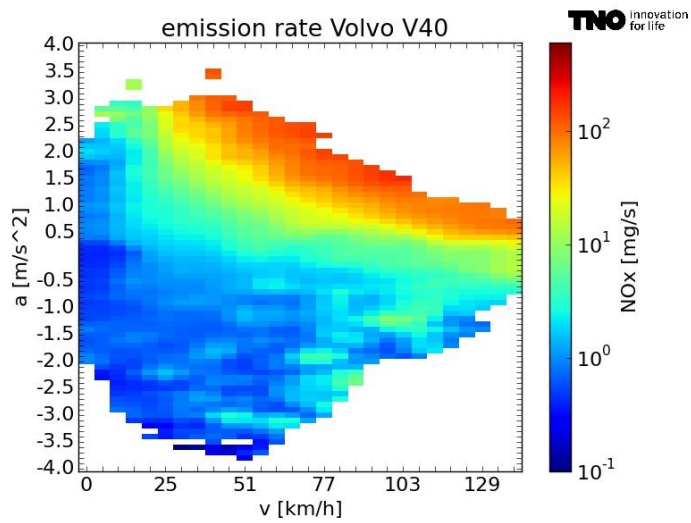


Figure 36 NO_x emission rate [mg/s] of a Volvo V40 Euro 6 diesel in bins of velocity and acceleration

3.1.12 Volkswagen Golf 81 kW

In Table 27 the specifications of the tested VW Golf are reported.

Table 27 Specifications of the VW Golf

Trade Mark	[-]	Volkswagen
Type	[-]	Golf
Body	[-]	Hatchback
Vehicle Category	[-]	M
Fuel	[-]	Diesel
Engine Code	[-]	CXXB
Swept Volume	[cm ³]	1.598
Max. Power	[kW]	81
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	Germany-KBA
Type Approval Number	[-]	e1-715-2007-136- 2014W-1145-02
Vehicle Empty Mass	[kg]	1221
Declared CO ₂ emission	[g/km]	89
Vehicle Identification Number	[-]	WVWZZZAUZGW061142
Vehicle Test Mass*	[kg]	1370
Odometer	[km]	14550
Registration Date	[dd-mm-yy]	23-09-15

* Incl. driver and SEMS, 80+10 kg



This vehicle was tested from 22-01-2016 to 07-03-2016 over a distance of 5828 km. During this period emission data of 2858 km was logged and stored and several emission tests on a chassis dynamometer were performed. This vehicle was not subjected to all on-road trips of the 2-days emission test programme.

The main objectives of this test programme were: Obtaining more insight in real world NO_x emissions and development of RDE trips at different locations.

In Table 28 the results of the chassis dynamometer tests are reported. In the NEDC test with cold start the NO_x emission is 62.8 mg/km. This vehicle complies with the type approval limit value of 80 mg/km. However the measured CO₂ emission is 118.3 g/km, which exceeds the specified type approval value of 96 g/km. This CO₂ gap of 22 g/km (+23%) may be caused by the condition of this vehicle. The internal frictions of the powertrain may be higher than in the type approved sample vehicle and different wheel/tyre configurations may be mounted..

The NO_x emissions in the NEDC test with hot start are 76.5 and 87.0 mg/km. Elevated emissions are observed in the WLTC-test with hot start (172.6 mg/km, CF=2.2) and CADC with hot start (273.0 mg/km, CF=3.4). In NEDC tests with cold starts at two temperature levels (soak and test cell at 23 and 15 °C) a relatively slight increase of NO_x emission from 62.8 to 94.1 mg/km with a reduction of the ambient soak and test temperature.

Table 28 Chassis dynamometer test results of a VW Golf Euro 6 diesel

	HC	CO	CO ₂	NO _x	NO	NMHC	CH ₄	HC + NO _x	PM	PN	Fuel cons.
	[mg/km]	[mg/km]	[g/km]	[mg/km]						[1/km]	[l/100km]
Euro 6 limit value	-	500		80	-	-	-	170	4.5	6.0E+11	-
NEDC-cold @ 23 °C	21.6	115.9	118.3	62.8	42.1	13.8	8.8	84.5	0.1	1.4E+10	4.42
NEDC-cold @ 15 °C	26.6	196.1	124.7	94.1	70.4	18.9	8.9	120.7	0.0	1.7E+09	4.66
NEDC-hot @ 23 °C	6.0	19.7	119.1	76.5	46.4	0.9	5.3	82.6	0.1	5.4E+11	4.44
NEDC-hot @ 23 °C	8.9	20.2	118.8	87.0	51.5	3.3	6.4	96.0	0.2	1.8E+09	4.43
WLTC-hot @ 23 °C	15.1	48.9	124.0	172.6	85.6	7.0	9.3	187.7	0.1	1.4E+09	4.63
CADC150-hot @ 23 °C	10.5	21.1	152.0	273.0	129.3	4.1	7.4	283.5	0.1	1.3E+09	5.67

In Table 29 the CO₂ and NO_x results of different RDE trips of the VW Golf are reported. The RDE trips are executed by the same driver at two different locations (Helmond RDE_A and Delft RDE_D).

Table 29 Emission results per trip of a VW Golf Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]		CO ₂ [g/km]	NO _x [mg/km]
RDE_A_C	2016-2-12	15:53	5767	75.3	47		7.2	156.4	445.6
RDE_D_C	2016-2-22	8:30	6705	80.6	43.3		5.0	126.2	185.9
RDE_D_W	2016-2-3	13:56	6174	76.4	44.6		6.9	147.7	353.4
RDE_D_C	2016-2-4	9:44	6142	76.1	44.6		3.5	131.8	198.2
TOTAL				308.5	44.8			140.3	293.8

Remarks:

- Regeneration of the DPF took place during the trip RDE_REG_W (3-2-2016 13:56) and RDE_A_REG_C (12-2-2016 15:53).

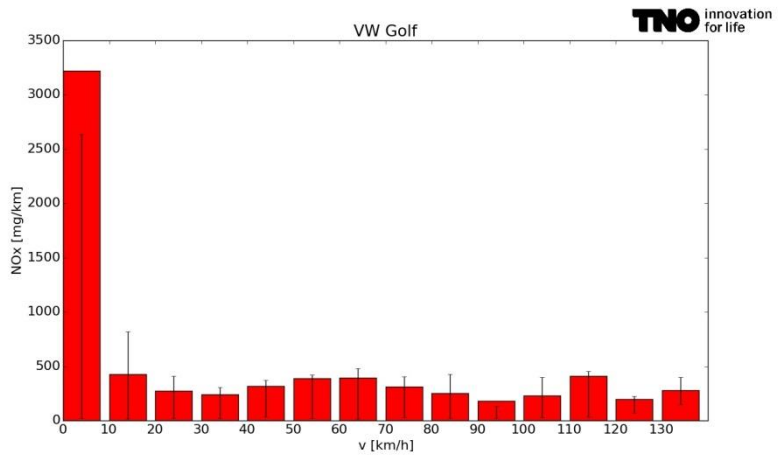


Figure 37 Average NO_x emissions of a VW Golf Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

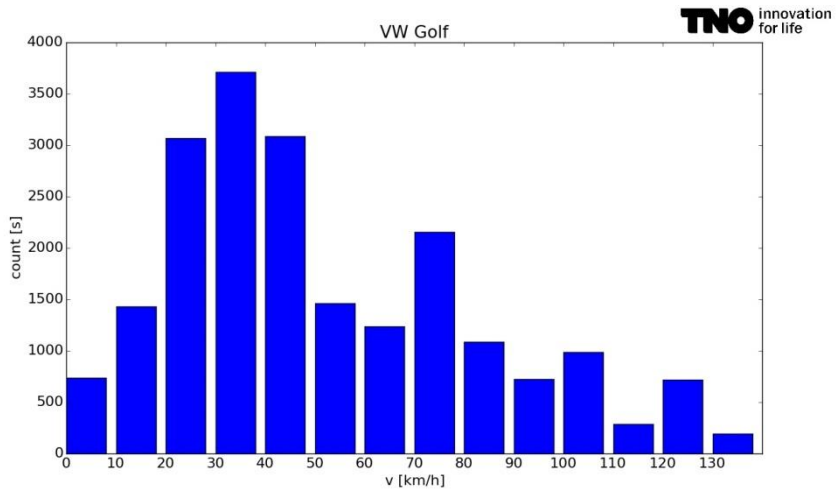


Figure 38 Number of seconds per velocity bin, over all trips. Idling is excluded.

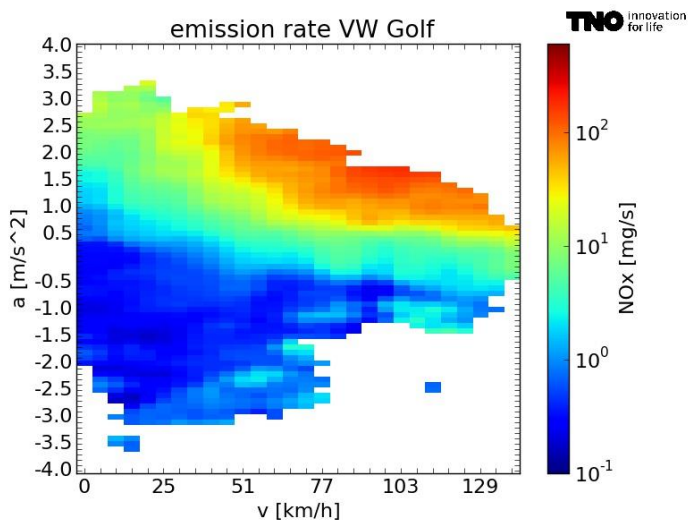


Figure 39 NO_x emission rate [mg/s] of a VW Golf Euro 6 diesel in bins of velocity and acceleration

3.1.13 Volkswagen Passat (81kW)

In Table 30 the specifications of the tested VW Passat are reported.

Table 30 Specifications of the VW Passat

Trade Mark	[-]	Volkswagen
Type	[-]	Volkswagen Passat B8 – Bluemotion TDI
Body	[-]	Sedan
Vehicle Category	[-]	M
Fuel	[-]	diesel
Engine Code	[-]	DCX 009316
Swept Volume	[cm ³]	1.598
Max. Power	[kW]	88
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	Germany
Type Approval Number	[-]	e1*2001/116*0307*38
Vehicle Empty Mass	[kg]	1344
Declared CO ₂ emission	[g/km]	103
Vehicle Identification Number	[-]	WVWZZZ3CZFE439405
Vehicle Test Mass*	[kg]	1536
Odometer	[km]	50123
Registration Date	[dd-mm-yy]	29-01-15

* Incl. driver and SEMS, 80+10 kg



In Table 31 the CO₂ and NO_x test results of the VW Passat are reported.

Table 31 Emission results per trip of a Volkswagen Passat Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp			CO ₂ [g/km]	NO _x [mg/km]
						min	max	avg [°C]		
RDE_D_C	2016-3-29	8:22	6240	77.8	44.9	2	12	8.5	154.1	272.7
RDE_D_W	2016-3-29	10:35	6424	77.7	43.6	2	14	11.1	136.9	173.9
MOTORWAY	2016-3-29	13:30	3659	86.8	85.4	9	16	12.8	106.4	64.4
CONGEST_W	2016-3-29	15:12	4050	77.6	69	10	15	13.1	109.7	82.5
CONGEST_C	2016-3-30	6:56	5223	83.6	57.6	7	12	9.6	107.1	63.5
CITY	2016-3-30	8:38	4001	23.5	21.2	8	13	10.9	157.3	150.7
RURAL	2016-3-30	9:58	5742	83.3	52.2	1	15	12.2	135.8	153.4
RDE_D_W	2016-3-30	11:50	6400	77.7	43.7	8	16	13.1	129.9	183.5
	2016-3-29	8:22	41739	588	50.7	1	16	11.3	126.6	140.5

Remarks:

- Regeneration took place during the cold RDE trip (RDE_D_C) and the RURAL trip

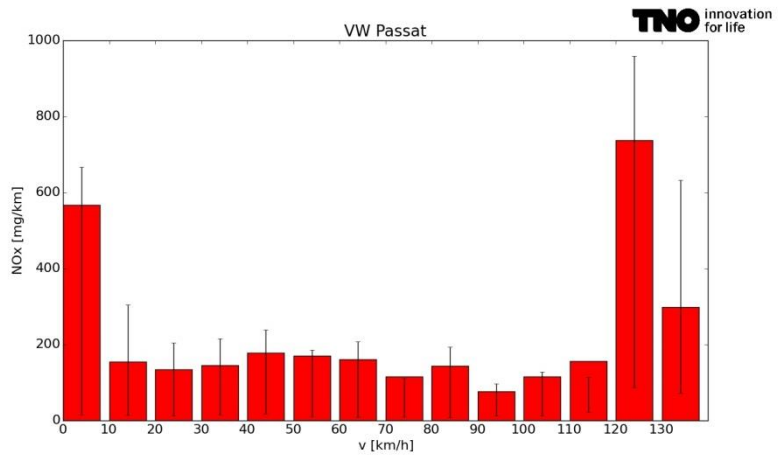


Figure 40 Average NO_x emissions of a VW Passat Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

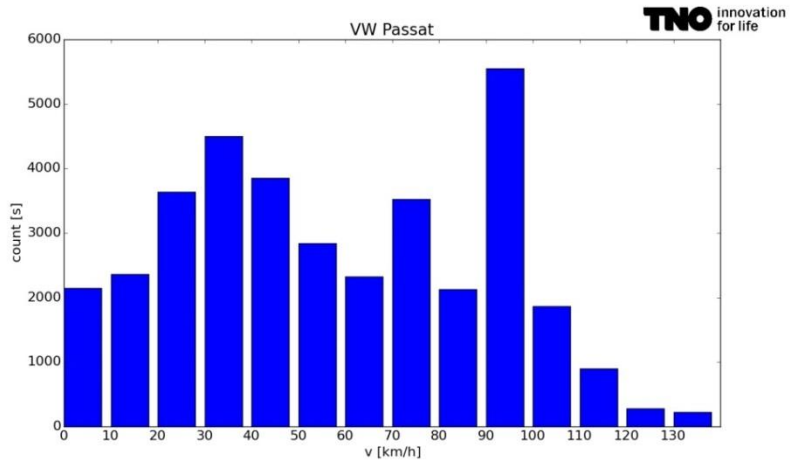


Figure 41 Number of seconds per velocity bin, over all trips. Idling is excluded.

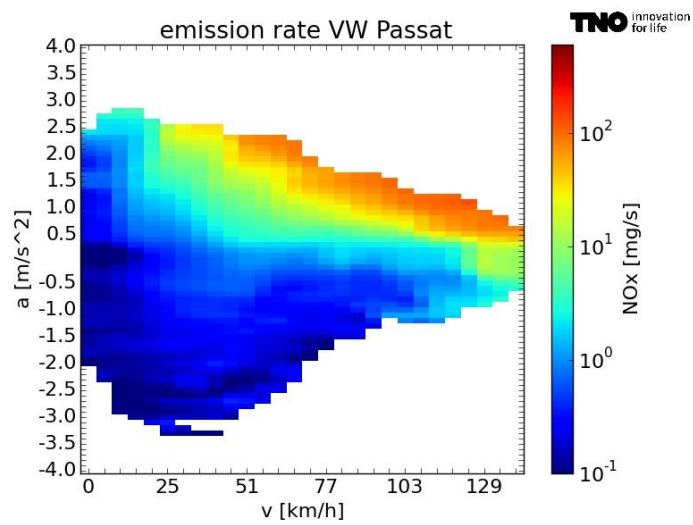


Figure 42 NO_x emission rate [mg/s] of a VW Passat Euro 6 diesel in bins of velocity and acceleration

3.1.14 Volkswagen Polo (55kW)

In Table 32 the specifications of the tested VW Polo are reported.

Table 32 Specifications of the VW Polo

Trade Mark	[-]	Volkswagen
Type	[-]	Polo 1.4 Blue Motion TDI diesel
Body	[-]	Hatchback
Vehicle Category	[-]	M1
Fuel	[-]	diesel
Engine Code	[-]	
Swept Volume	[cm ³]	1.422
Max. Power	[kW]	55
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	Germany
Type Approval Number	[-]	e1*2001/116*0510*23
Vehicle Empty Mass	[kg]	1065
Declared CO ₂ emission	[g/km]	82
Vehicle Identification Number	[-]	VWZZZ6RZFY195100
Vehicle Test Mass*	[kg]	1215
Odometer	[km]	30187
Registration Date	[dd-mm-yy]	08-01-15

* Incl. driver and SEMS, 80+10 kg



In Table 33 the CO₂ and NO_x test results of the VW Polo are reported.

Table 33 Emission results per trip of a VW Polo Euro 6 diesel

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO ₂ [g/km]	NO _x [mg/km]
RDE_D_C	2016-3-23	9:09	6796	78.4	41.5	0	11	9.4	135.8	292.5
RDE_D_W	2016-3-23	11:14	5834	78.4	48.4	8	13	10.6	137.8	303.7
MOTORWAY	2016-3-23	13:30	4778	114.3	86.1	7	15	12.3	114.7	157
CONGEST_W	2016-3-23	14:54	3344	78	84	10	13	11.9	108	64.3
CONGEST_C	2016-3-24	9:03	4118	84.6	73.9	0	12	8.8	112.5	114.1
CITY	2016-3-24	10:13	4654	23.9	18.5	7	12	10.8	147.7	382.2
RURAL	2016-3-24	11:32	5288	85.4	58.2	4	14	11.9	139	428.2
RDE_D_W	2016-3-24	13:12	6061	78.3	46.5	0	14	12.4	135	316.3
TOTAL				621.3	54.7	0	15	11	126.3	241.2

Remarks:

- Regeneration was ongoing during the first 5 minutes of the MOTORWAY trip, and regeneration took place for about 15 minutes in the RURAL trip
- No congestion in CONGEST_W trip

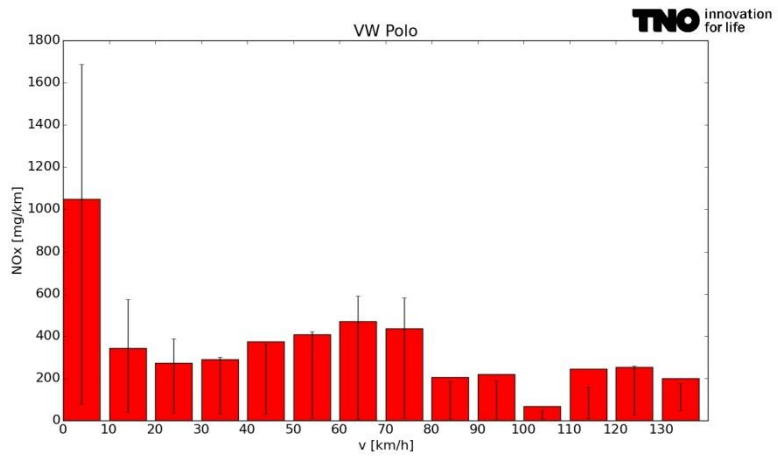


Figure 43 Average NO_x emissions of a VW Polo Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

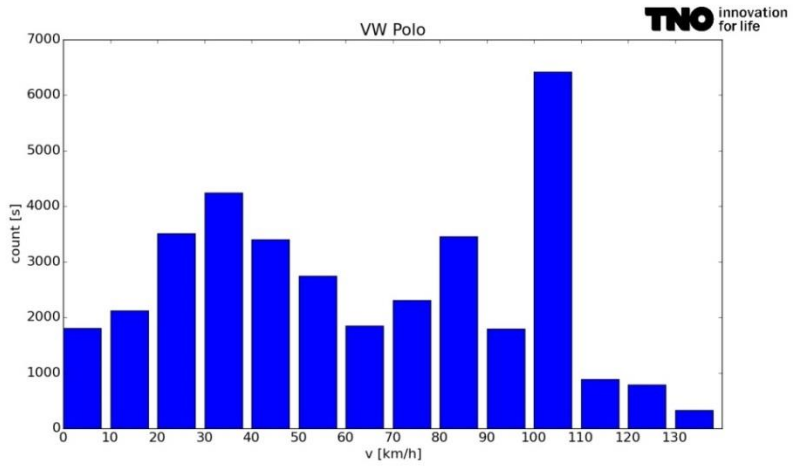


Figure 44 Number of seconds per velocity bin, over all trips. Idling is excluded.

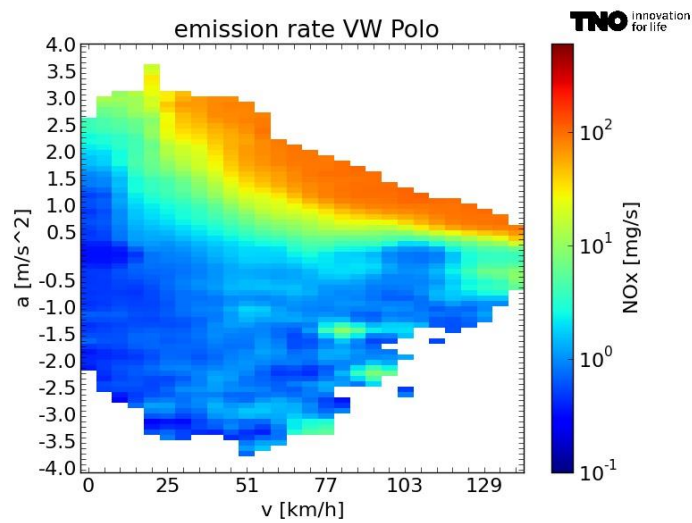


Figure 45 NO_x emission rate [mg/s] of a VW Polo Euro 6 diesel in bins of velocity and acceleration

3.1.15 Mercedes C220 (125 kW)

In Table 34 the specifications of the tested Mercedes C220 are reported.

Table 34 Specifications of the Mercedes C220

Trade Mark	[-]	Mercedes-Benz
Type	[-]	C220
Body	[-]	Passenger vehicle
Vehicle Category	[-]	M1
Fuel	[-]	Diesel
Engine Code	[-]	Diesel
Swept Volume	[cm ³]	2,143
Max. Power	[kW]	125
Euro Class	[-]	Euro 6
Type Approval Authority	[-]	Germany KBA
Type Approval Number	[-]	e1*2001/116*0431*30
Vehicle Empty Mass	[kg]	1470
Declared CO ₂ emission	[g/km]	110
Vehicle Identification Number	[-]	WDD 205004 1F 001337
Vehicle Test Mass*	[kg]	1715
Odometer	[km]	17100
Registration Date	[dd-mm-yy]	20-01-16

* Incl. driver and SEMS, 80+10 kg



In Table 35 the CO₂ and NO_x test results of the Mercedes C220 are reported.

Table 35 Emission results per trip of a Mercedes C220 Euro 6 diesel

	Time	Distance	Av speed	Tave	Tmin	Tmax	CO ₂	NO _x	NH ₃
	[s]	[km]	[km/h]	[°C]			[mg/km]		
RDE_D_C	6701	72.8	39.1	17.9	15	24	149.5	59.0	2.5
RDE_D_W	6393	71.8	40.3	18.8	16	26	145.9	85.7	1.2
MOTORWAY	3570	89.9	90.7	20.0	18	23	115.7	16.1	5.2
CONGEST_W	5360	63.2	42.3	22.1	20	26	120.0	91.1	0.6
CONGEST_C	5345	86.3	58.0	15.2	13	17	121.0	51.7	0.7
CITY	5149	22.0	15.3	16.5	15	22	192.2	344.1	0.8
RURAL	6711	93.7	50.3	18.0	16	22	125.2	76.8	0.5
RDE_D_W	5437	72.8	48.2	7.9	6	15	136.5	264.7	0.2
TOTAL	44666	572.5	46.1				132.2	98.1	1.3

Remarks:

- This vehicle was tested over a longer period and the tests were carried out later in the years at different ambient temperatures. A more detailed investigation of the relationship between ambient temperature and the NO_x emission of this vehicle type is reported in Reference [TNO 2016b].
- Due to road works some deviations had to be taken in the rural trip.

More detailed emission results of this vehicle at different ambient temperatures are reported in a separate report [TNO 2016b].

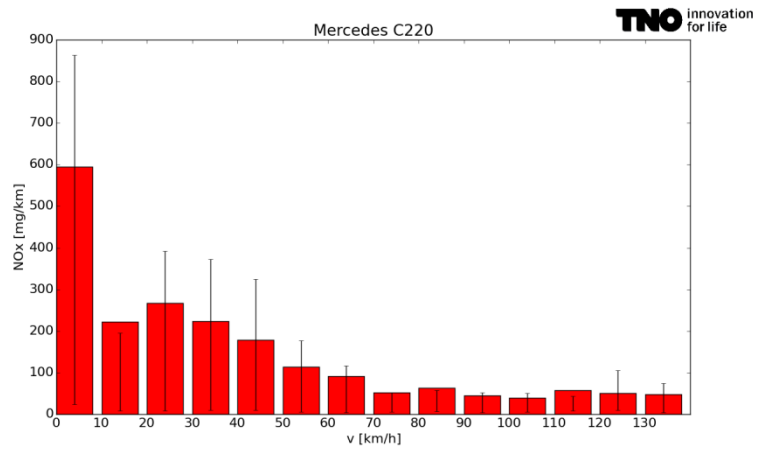


Figure 46 Average NO_x emissions of a Mercedes C220 Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

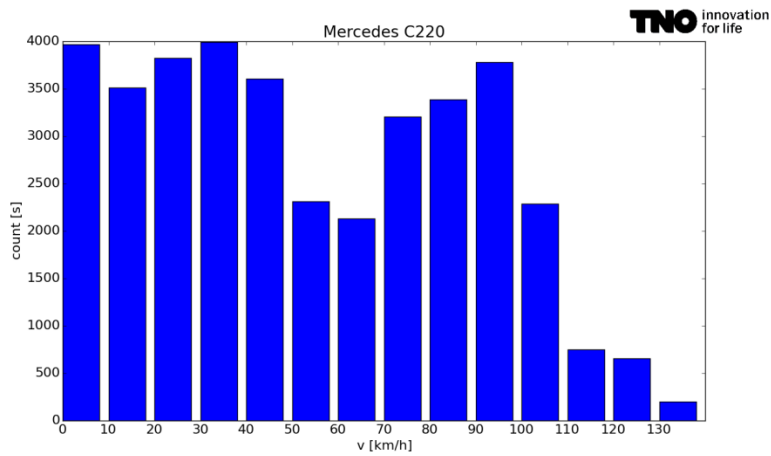


Figure 47 Number of seconds per velocity bin, over all trips. Idling is excluded.

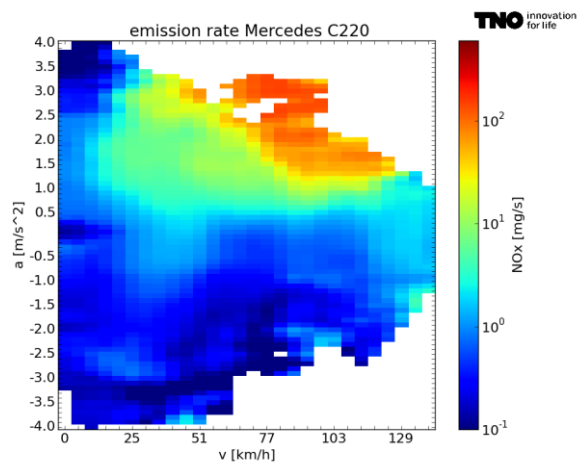


Figure 48 NO_x emission rate [mg/s] of a Mercedes C220 Euro 6 diesel in bins of velocity and acceleration

3.2 Normalised emissions per vehicle for different traffic conditions

Due to slight differences in test conditions, trip characteristics and driving behaviour, it would be unfair to make a one-to-one comparison between vehicles based on the results per trip, as reported in paragraph 3.1. The characterization of driving behaviour includes for example average velocity, average acceleration and idling time per trip. The dependency on these conditions can, however, be eliminated to a large extent by parameterizing each data point in a trip in terms of velocity and acceleration, and reweighing them all to the same driving behaviour, derived from the average driving patterns for a specific road type and traffic condition category. This parameterisation is used by TNO to derive so-called normalised emissions per vehicle, and it is applied in this section to the test results for the different vehicles.

Normalised emissions per vehicle serve as input for the determination of emission factors per vehicle category. These emission factors represent the real-world emissions of specific vehicles categories for various road types and driving behaviour, and they are used in Dutch air-quality models and emission inventories.

VERSIT+ is a statistical emission model that calculates real-world emissions of road vehicles for given driving behaviour by fitting the representative measurement data for velocity and acceleration. The calculated emissions are, de facto a reweighing of the results according to the difference in driving behaviour between the test data and the average driving behaviour. The VERSIT+ model is described in more detail in [Ligterink 2009], and the implementation is described in *VERSIT+: theory and fitting routines* [Ligterink 2012]. Hence, the test data is normalized for variations in on-road driving behavior in the different tests. For example, congestion on the motorway varied greatly across the test programme. This is corrected for in the average motorway emissions of the different vehicles.

In order to compare the tested vehicles the total emission results of the trips in the test programme were processed using the TNO VERSIT + method. Table 36 shows the results for four main road types: urban congestion, urban, rural and motorway.

Whether the highest emissions occur in urban congestion or on the motorway is strongly dependent on the vehicle, which underlines the large differences in emission behaviour between vehicles. On all four road types the highest emitting vehicles (884-1306 mg/km) emit 6-7 times more NO_x than the lowest emitting vehicle (140-191 mg/km).

Table 36 Normalised NO_x emissions of the tested Euro 6 diesel vehicles

	Test temperature Range	Normalised NO _x emissions [mg/km]			
		Urban congestion	Urban	Rural	Motorway
Vehicle	[°C]	WS1	WT1	WT2	WT3
Regular 2-days test programme					
Citroen Cactus	1 - 15	395	322	339	543
Ford Fiesta	3 - 13	243	220	218	426
Opel Zafira	0 - 15	1306	973	747	862
Peugeot 308 110kW	0 - 13	604	441	322	404
Peugeot 308 81kW	0 - 13	424	326	282	456
Renault Clio	8 - 17	1227	941	758	858
Renault Megane - a	0 - 17	1024	840	772	1018
Volvo V40	2 - 17	433	342	292	410
VW Passat	1 - 16	191	162	140	263
VW Polo	0 - 15	393	315	247	251
Mercedes C220	6 - 26	413	310	202	148
RDE test programme					
Ford Focus	5 - 25	498	466	442	377
Peugeot Partner	-1 - 15	567	448	394	523
VW Golf	1 - 10	351	303	261	249
Renault Megane- b	-3 - 20	1159	949	884	1050
Average		615	491	420	523

In Table 37 the normalised NO_x emissions of the tested vehicles of Table 36 are divided in two groups (six vehicles with SCR-technology and nine vehicles with LNT-technology). For the SCR equipped vehicles the normalised NO_x emissions are in the range of 148 to 1306 mg/km and for the LNT equipped vehicles the normalised NO_x emissions are in the range of 140 to 1227 mg/km. For both groups of Euro 6 diesel vehicles the NO_x emission performance is in the same range.

Two Renault Meganas of the same vehicle model were tested in the two different test programmes in similar ambient temperature ranges. The variations in the normalized result range between 5% - 15% across the different traffic situations.

Table 37 Normalised NO_x emissions of the tested Euro 6 diesel vehicles grouped per after treatment technology

		Normalised NO _x emissions [mg/km]			
		Test temperature Range	Urban congestion	Urban	Rural
Vehicle	[°C]	WS1	WT1	WT2	WT3
SCR equipped vehicles					
Mercedes C220	6 - 26	413	310	202	148
Citroen Cactus	1 - 15	395	322	339	543
Peugeot 308 81kW	0 - 13	424	326	282	456
Peugeot 308 110kW	0 - 13	604	441	322	404
Peugeot Partner	-1 - 15	567	448	394	523
Opel Zafira	0 - 15	1306	973	747	862
LNT equipped vehicles					
VW Passat	1 - 16	191	162	140	263
Ford Fiesta	3 - 13	243	220	218	426
VW Golf	1 - 10	351	303	261	249
VW Polo	0 - 15	393	315	247	251
Volvo V40	2 - 17	433	342	292	410
Ford Focus	5 - 25	498	466	442	377
Renault Clio	8 - 17	1227	941	758	858
Renault Megane - a	0 - 17	1024	840	772	1018
Renault Megane- b	-3 - 20	1159	949	884	1050

4 Normalisation of test results for comparison with RDE legislation

For determination of final results from Real Driving Emission tests several steps need to be taken:

- Check of the validity of the RDE test trip with respect to:
 - Boundary conditions to overall trip characteristics, e.g., minimum trip length, duration and temperature and the share of urban, rural, and highway driving;
 - Requirements for trip dynamic or driving behaviour;
- Normalisation of the measured results;
- Validation of the test results.

If an RDE test complies with the boundary conditions and the trip dynamics conditions, then the test is considered to be valid. For an exhaustive review of the strengths and weaknesses of RDE tests see [TNO 2016c].

In the RDE legislation two evaluation tools, EMROAD and CLEAR, have been introduced. The tools will check the validity of the RDE trip driven and will normalize the severity of the RDE trip to the severity of a WLTP type approval test.

This chapter presents and discusses the results of normalisation of the RDE tests at TNO with CLEAR and EMROAD.

4.1 Assessment of trip dynamic conditions

To be valid an RDE trip must be carried out within specified boundary conditions with respect to overall trip characteristics as well as trip dynamics. In the development stage of RDE testing at TNO the first priority was the development of robust RDE trips with the right driving behaviour and trip dynamics. The focus was on collecting data of valid RDE tests. The current RDE tests are therefore not intended to collect data from driving close to the boundaries of the test windows allowed in the RDE legislation. Therefore, only minor corrections from normalisation are to be expected.

To assess trip dynamics two requirements have been introduced in the RDE legislation: the 95th percentile (P95) of $v \cdot a_{\text{pos}}$ and the average RPA. The parameter $v \cdot a_{\text{pos}}$, the product of vehicle speed and positive acceleration, is commonly used as an indicator for high(er) dynamics of a trip and RPA, the relative positive acceleration, as an indicator for the lack of dynamics in a trip.

These two RDE trip dynamics parameters are determined² in three speed bins, i.e., the 'urban' (below 60 km/h), the 'rural' (60 to 90 km/h) and the 'motorway' speed bin (above 90 km/h). With the average speed per speed bin, the result is three pairs of an average speed and a dynamics parameter as graphically illustrated for one of the trips in Figure 49.

² See reference [EU 2016b] for how this should be done according to EU RDE legislation.

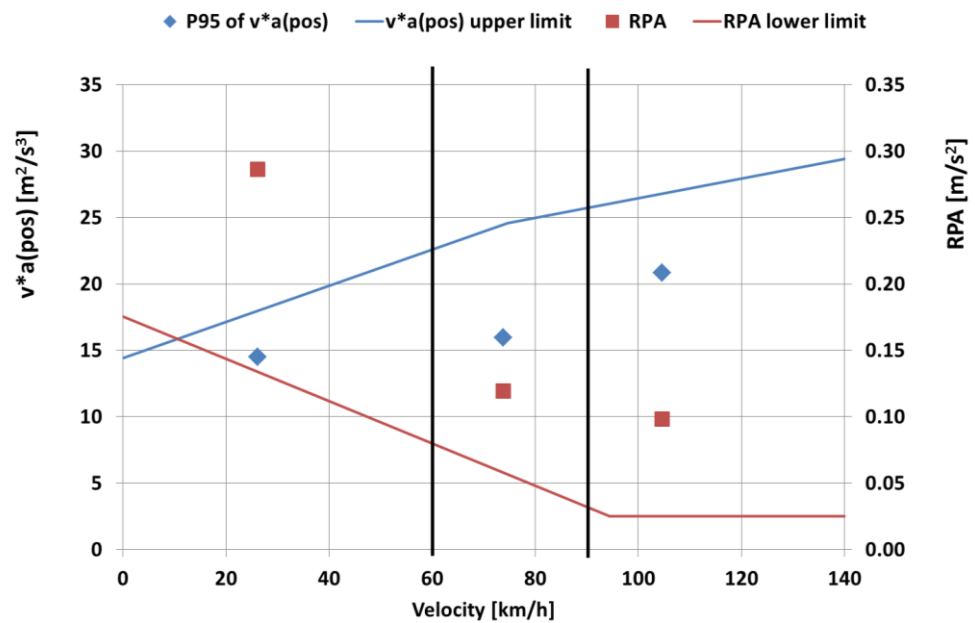


Figure 49 Values of driving dynamics parameters P95 of v^*a_{pos} and average RPA from one of the RDE trip performed at TNO compared to the RDE limits for P95 of v^*a_{pos} and average RPA.

The three blue diamonds in Figure 49 represent the 95th percentile values (P95) of v^*a_{pos} . The average RPA values are represented by the three red squares. The blue line is the upper limit for P95 of v^*a_{pos} . As all blue diamonds are below the limit, the trip is valid or, in other words, not too 'rough'. Similarly, the red line is the lower limit for average RPA and as all red squares are above this lower limit, the trip is valid or not too 'tame' as well. Being valid for all three data pairs, this example RDE trip is valid with respect to the requirements for trip dynamics.

EMROAD has been used to calculate the trip dynamics parameters P95 of v^*a_{pos} and average RPA. The generated values are tabulated in Appendix A, in which for all 28 RDE test trips the following results are reported:

- The average speed for the speed bins urban ($v < 60$ km/h), rural ($60 \leq v < 90$ km/h) and motorway ($v \geq 90$ km/h);
- P95 of v^*a_{pos} for each speed bin in m^2/s^3 ;
- Validity of the trip part (logical value 1=valid, 0=invalid) w.r.t. P95 of v^*a_{pos} ;
- Average RPA for each speed bin in m/s^2 ;
- Validity of the trip part w.r.t. RPA.

The total trip is valid if and only if all logical values are 1.

4.2 Assessment of RDE emissions with EMROAD and CLEAR

EU RDE legislation [EU2016a, EU2016b] requires RDE test data to be normalized with the evaluation tools EMROAD or CLEAR. For more details on how EMROAD and CLEAR are applied to RDE tests by TNO, see [TNO 2016a]. For a more comprehensive discussion on the EMROAD and CLEAR algorithms as well as their implications see [TNO 2016c].

After a concise description of the EMROAD and CLEAR normalisations, the normalisation results for the 28 RDE tests will be presented and discussed.

Descriptions of EMROAD and CLEAR data normalisation

The normalisation process applied in EMROAD is known as the ‘*Moving Average Window*’ or MAW normalisation method and is described in detail in [EU 2016a], see “*Appendix 5 Verification of trip dynamic conditions with method 1 (Moving Averaging Window)*”. There it is summarised as:

“The Moving Averaging Window method provides an insight on the real-driving emissions (RDE) occurring during the test at a given scale. The test is divided in sub-sections (windows) and the subsequent statistical treatment aims at identifying which windows are suitable to assess the vehicle RDE performance.

The “normality” of the windows is conducted by comparing their CO₂ distance-specific emissions [...] with a reference curve. The test is complete when the test includes a sufficient number of normal windows, covering different speed areas (urban, rural, motorway).”

An illustration to the EMROAD MAW normalisation process is given in Figure 50. In this figure each dark brown diamond is a CO₂ emission (in g/km) calculated from one of the many windows which are moved along the instantaneous CO₂ emission signal (in g/s). The black line represents the so called vehicle CO₂ characteristic curve and is derived from the results of driving the type-approval WLTP test. The green lines and red lines represent a 25% respectively 50% deviation from the black line. A trip is valid if, for every section (urban/rural/motorway), at least 50% of the windows is in between the green lines. The final emission result of a valid RDE trip is obtained by a weighted average of the individual windows. The weight given to a window depends on the distance to the vehicle characteristic CO₂ curve. If the windows falls within the green lines in Figure 50 the window gets full weight. The weight diminishes in the areas between the green and red lines in Figure 50, from 100% for windows on the green lines to 0% for windows on the red lines.

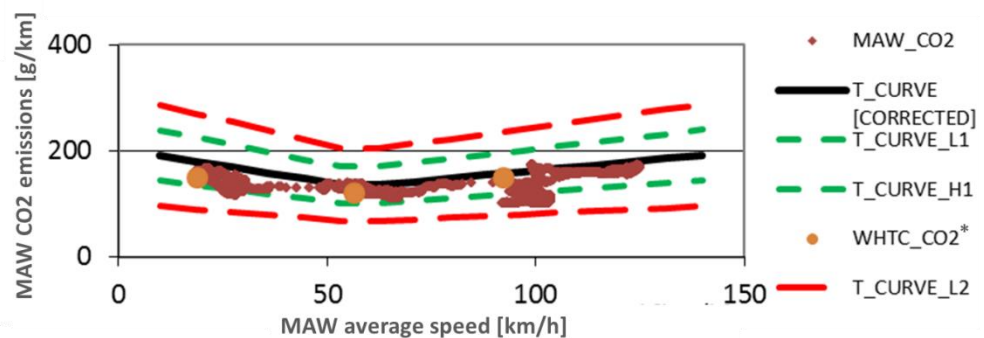


Figure 50 MAW CO₂ emission results (in g/km) for an RDE trip evaluated with EMROAD.
*) In output of EMROAD these points are incorrectly labelled. The correct label is WLTC_CO₂.

The normalisation process applied in CLEAR is known as the ‘*Power Binning*’ normalisation method and is also described in detail in [EU 2016a], see “*Appendix 6 Verification of trip dynamic conditions with method 2 (Power Binning)*”.

There it is summarised as:

“The data evaluation according to the power binning method, [is a] normalisation to a standardised power frequency (SPF) distribution.”

EMROAD and CLEAR generate final normalised emission results not only for the total trip, but also separately for the urban part.

EMROAD and CLEAR data normalisation results

The normalised urban and total trip NO_x emissions in g/km generated for all 28 RDE test trips using EMROAD and CLEAR ('CLEAR Weighted' resp. 'EMROAD MAW') have been tabulated in Appendix B. For comparison, the raw NO_x emissions, i.e. calculated without any normalisation, are included. Raw NO_x emissions are calculated using CLEAR, EMROAD and TNO RDE evaluation software³.

As some of the required input data for the CLEAR and EMROAD normalisations, including the measured WLTC result and type approval vehicle characteristics, were not (yet) available to TNO for the considered vehicles, the results were generated using default settings in CLEAR and EMROAD. See the Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme [TNO 2016a] for full details. Note that this means that the CLEAR and EMROAD normalisation results are indicative values.

In Figure 53 the raw and normalised **urban** NO_x emissions (in g/km) are graphically presented for all 28 RDE trips. Similarly, the **total trip** NO_x emissions (in g/km) are presented in Figure 54.

From Figure 53 and Figure 54 and the table in Appendix B the following observations are made:

- Differences between raw urban NO_x emissions and total trip raw values of the same vehicle on the same trip are substantial: in the range of 0-50% either upward or downward.
- Comparing the emissions between all 15 vehicles the raw urban NO_x emissions range from about 0.12 to 1.20 g/km and the raw total trip values from 0.09 to 1.05 g/km.
- Comparing the normalised NO_x emissions, for both urban and total trip (same trip), the normalisation correction roughly ranges from zero to 50%.

³ The differences in a raw emission result calculated with EMROAD, CLEAR of the TNO RDE evaluation software is not more than a few tenths of a percent.

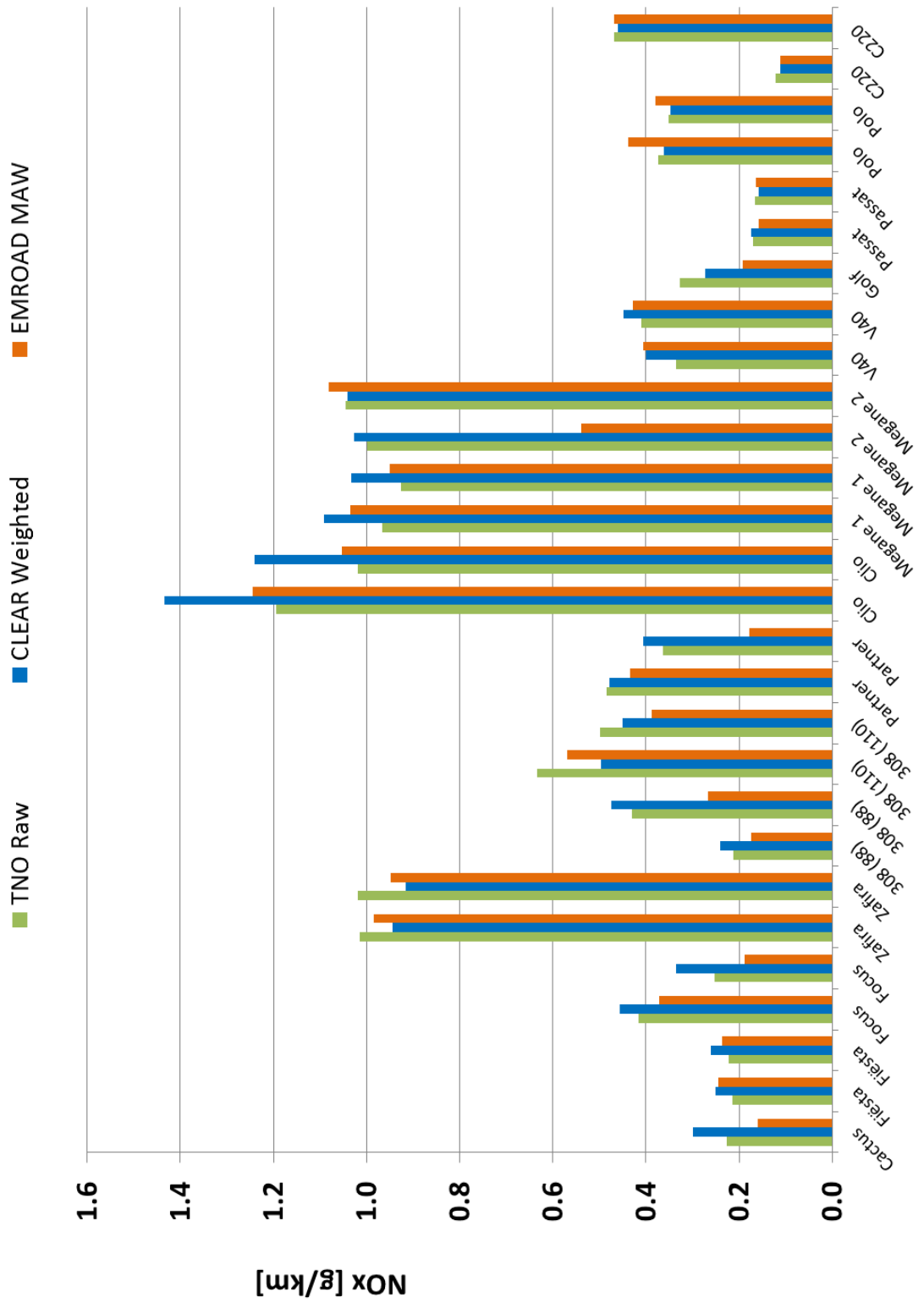


Figure 51 Raw and normalised (CLEAR Weighted and EMROAD MAW) urban NO_x emissions (in g/km) for all 28 RDE trips.

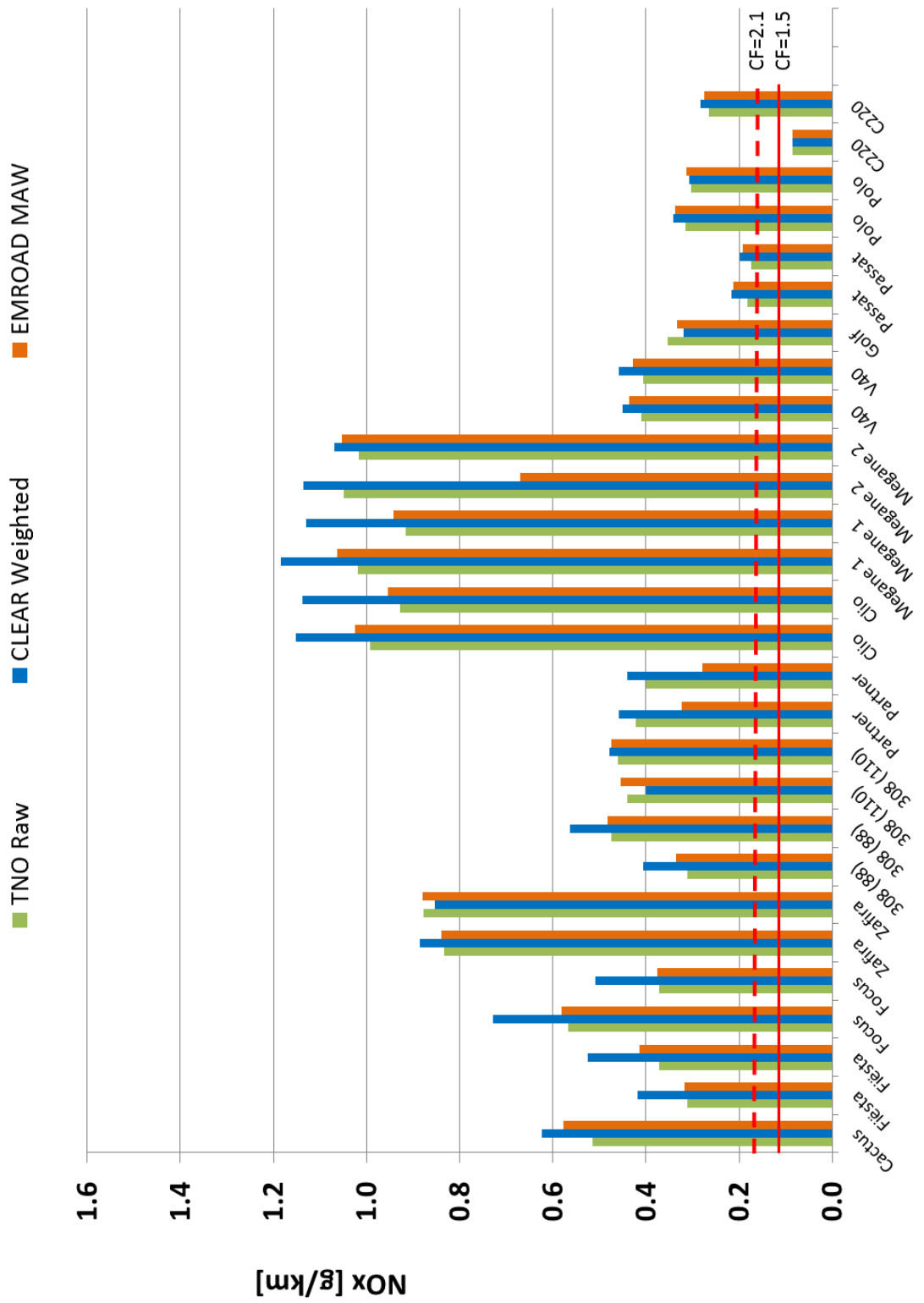


Figure 52 Raw and normalised (CLEAR Weighted and EMROAD MAW) total trip NO_x emissions (in g/km) for all 28 RDE trips.

To further analyse the effects of normalisation on the NO_x emission result, the normalised NO_x emissions (in g/km) were plotted as function of the raw NO_x emissions. In Figure 53 this is done for the urban emissions and in Figure 54 for the total trip emissions. In most cases the corrections are within a bandwidth of 20%.

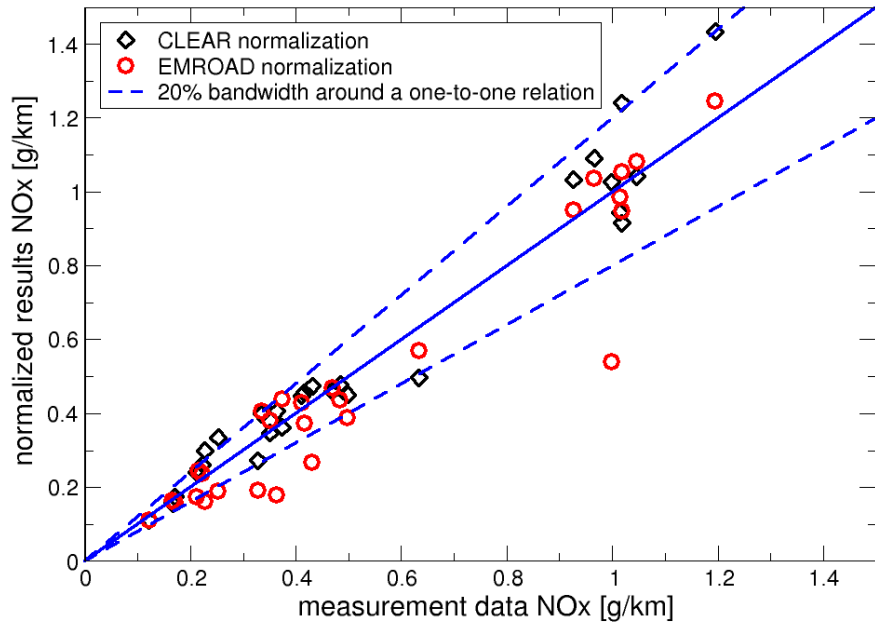


Figure 53 **Urban NO_x emissions** (in g/km) after normalisation with CLEAR and EMROAD, as function of the raw NO_x emission result (TNO values in g/km), for all 28 RDE trips.

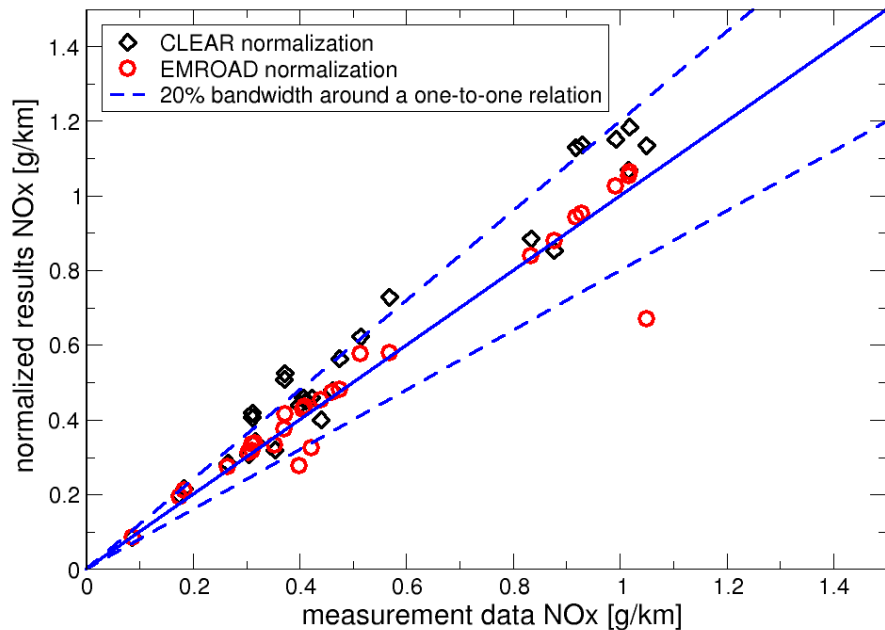


Figure 54 **Total trip NO_x emissions** (in g/km) after normalisation with CLEAR and EMROAD, as function of the raw NO_x emissions (TNO values in g/km), for all 28 RDE trips.

To investigate a possible explicit relationship between the CLEAR and EMROAD normalisations, for both tools the relative corrections of the normalised NO_x emissions with respect to the corresponding raw values have been calculated and plotted against each other. The results are shown in Figure 57 and do not show a clear relationship between the CLEAR and EMROAD normalisation for the data of the 28 RDE trips. The 56 data points are quite widely scattered over a large area in all four quadrants. This means that the CLEAR and EMROAD normalisation results are uncorrelated and may differ largely, in spite of being calculated from the same data for the same purpose (i.e. normalisation). A more detailed assessment of the strengths and weaknesses of the new Real Driving Emissions (RDE) test procedure is reported in [TNO 2016c].

It should be noted that this has serious implications for the use of CLEAR and EMROAD. As the EU RDE legislation prescribes the use of either CLEAR or EMROAD but leaves the actual choice to the tester, this opens the door to selective data processing, i.e. data processing where only the most favourable results are presented.

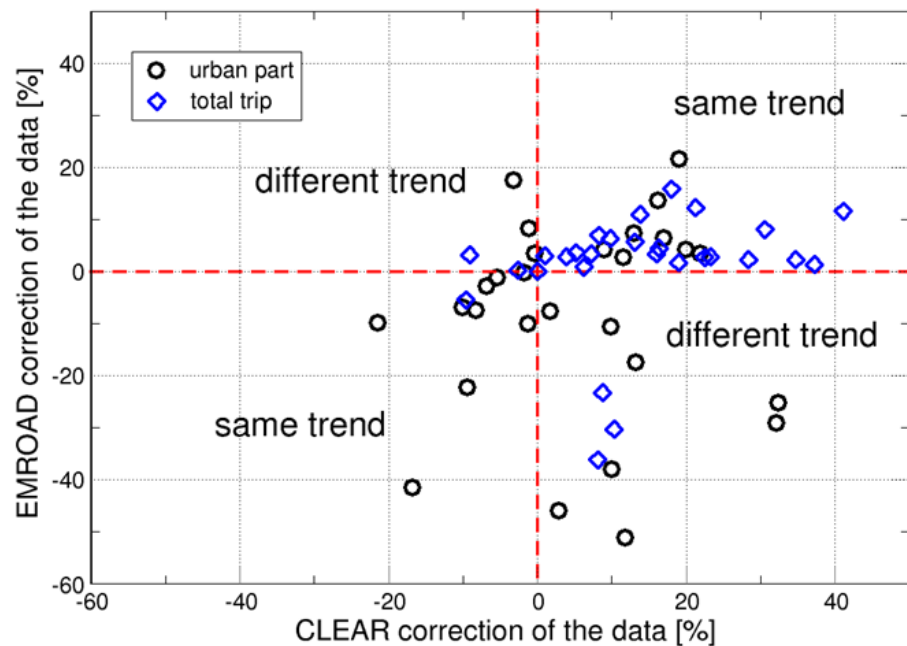


Figure 55 Relative correction of the NO_x emissions as a result of normalisation with EMROAD (y-axis) and with CLEAR (x-axis), defined as $100 \cdot (\text{Normalised_Value} - \text{Raw_Value_TNO}) / \text{Raw_Value_TNO} \%$, for all 28 RDE trips.

5 Cold start effects

The impacts of variations in driving behaviour, vehicle preconditioning, and ambient conditions are all intertwined in the tailpipe emissions during a RDE test trip. For example, it is difficult to separate the effects of cold start from other effects. This requires more complex analysis. Since cold start test is to be part of the RDE legislation, cold start assessment is warranted. The cold start RDE test procedure is not fixed, nor is the separation of cold start from the other effects properly possible. In this chapter the cold starts effects, both in magnitude as in duration, are substantial for SCR vehicles and limited for LNT-equipped vehicles.

For the larger part, emissions are 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. Different emission control strategies and buffering of emissions may have started to play a larger role in the results, yielding variations. Consequently, the emissions are less directly related to the velocity of the vehicle. The cold start emissions are a well-known effect, unrelated to driving behaviour, of catalytic after-treatment technologies, which are, however, novel technologies for diesel passenger cars. Hence, a complex situation arises where emission control strategies can vary not only with the catalyst temperature but with many other aspects. In this chapter an attempt is made to quantify the variation of emissions for the same driving behaviour, of which the cold start is a major aspect. 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 expected to become 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 isolated in the results. This separation of the cold start is done by performing a residual analysis on the results. All the emission data of a vehicle is collected to determine the average emission with certain driving behaviour. For all tested vehicles emission maps with the emission rates in mg/s for each velocity and acceleration bin are given in the previous chapter (see e.g. Figure 6).

Applying this average emission map to the second-by-second speed and acceleration values of 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. This is illustrated in Figure 56. In the case of SCR-equipped vehicles the effects are often larger and longer than with the LNT-equipped vehicles.

The difference of the measured emission and the expected emissions based on the average is called the residual. The large and systematic residual signals a deviating emission unrelated to the instantaneous driving behaviour. Cold starts, DPF

regenerations and particular aspects of the LNT control strategy can be observed as a large residuals, or differences between the average and the actual emissions.

LNT vehicles store NO_x emissions from the engine to convert it to harmless components in the regeneration phase. Therefore, it is also likely that NO_x emissions of LNT bear a limited relation with the actual driving behaviour. In the results, shown in Figure 59, the LNT vehicles show spikes in emissions, above the emission expected for that velocity and acceleration, mainly in rural driving around 80 km/h with stops. The LNT vehicles have problems with the dynamic driving with higher engine loads, and they are probably responsible for higher average NO_x emissions on rural roads.

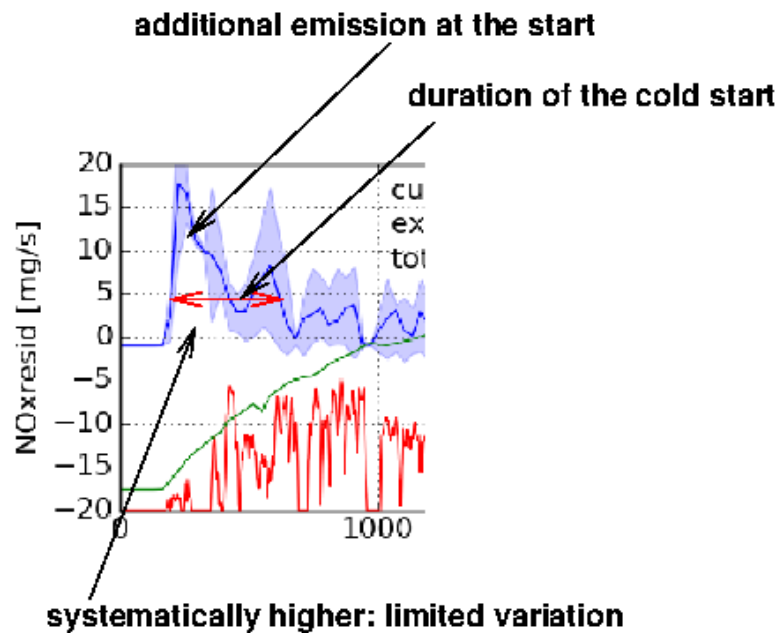


Figure 56 A detail of a plot of the residual analysis: A clear initial peak of additional emissions is seen which decreases in about 800 seconds. The second-by-second variation in the average over a time window, indicated by the shaded area is small, which indicates a significant effect. Determining the area under the blue line yields the total estimated cold start contribution.

For the cold-start analyses only the RDE trips with a cold start are selected, as they fall in the legislative framework. Moreover, it ensures the driving behaviour, unlike the cold-start test with motorway congestion, in the RDE cold-start test is also replicated in other tests and the remaining, or residual, effect can be separated from driving behaviour. The results are summarized in Table 38.

In the residual analysis the SCR technology stands out more clearly than using the first 5 minutes as a rule given in the RDE legislation to select the cold start. The initial driving is generally different from the rest of the urban trip. For example, the average velocity is lower. From current analysis a switch in control strategy associated with light-off temperature of the SCR cannot be deduced. The NO_x emissions gradually decrease with time.

The standard 5 minutes associated with the cold start in the RDE legislation is 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 the 5 minutes.

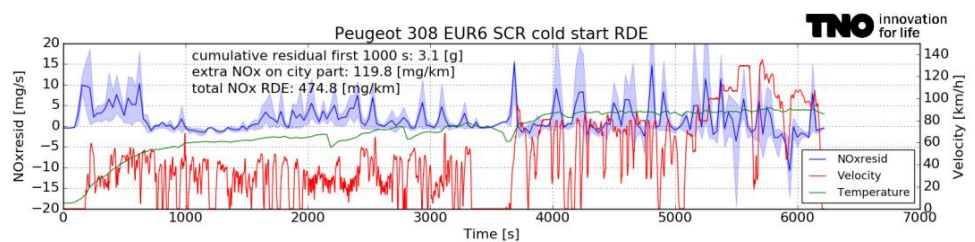
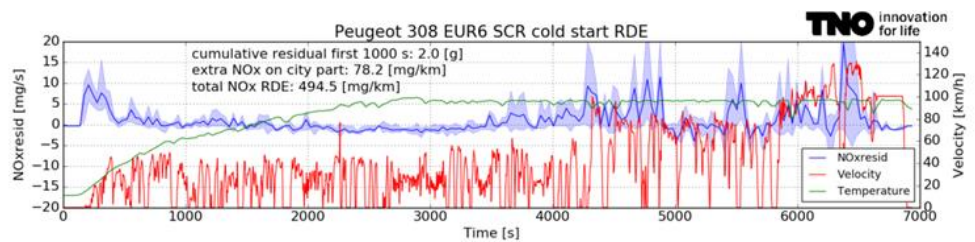
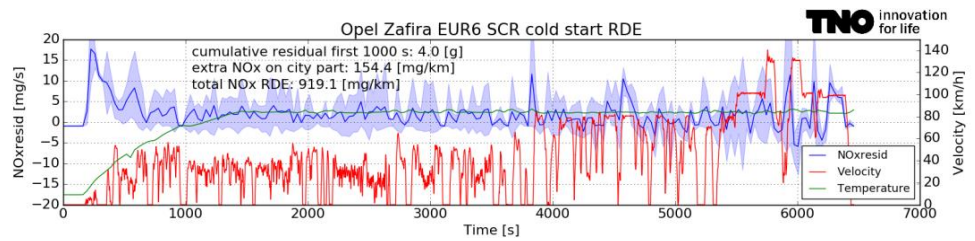
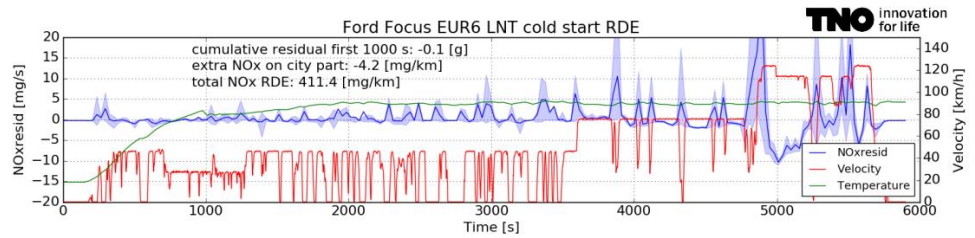
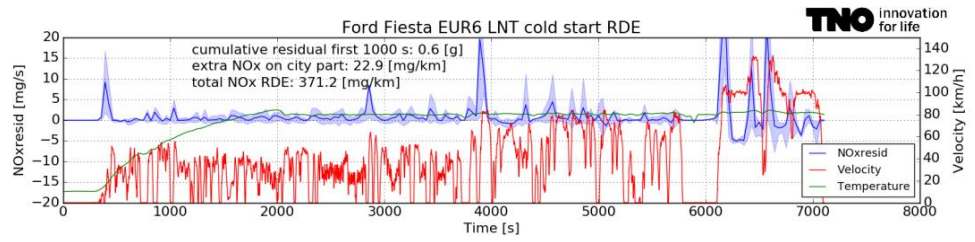
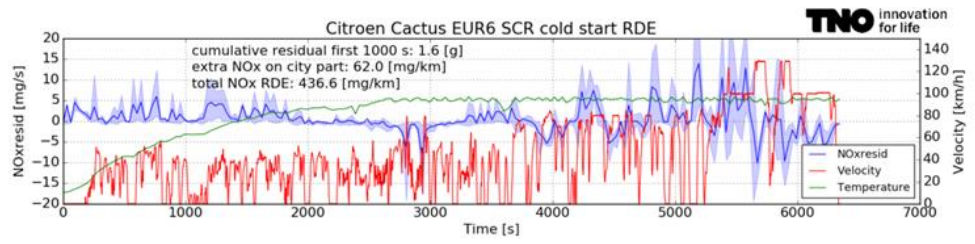
Table 38 The RDE trips with a cold start, with the additional emissions over 1000 s due to the cold start separated from the emissions associated with warm engine operation. In standard assumption the cold start last for 5 minutes. This yields a larger effect and different trends than the residual analysis.

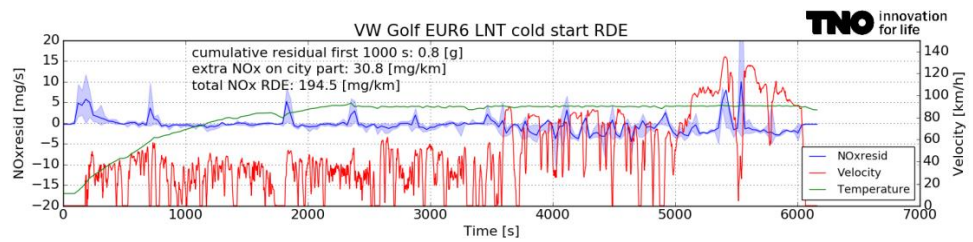
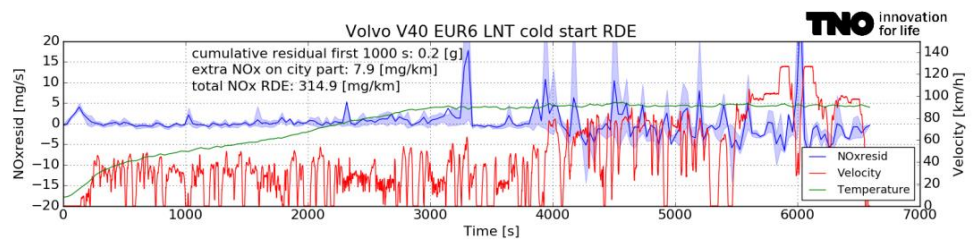
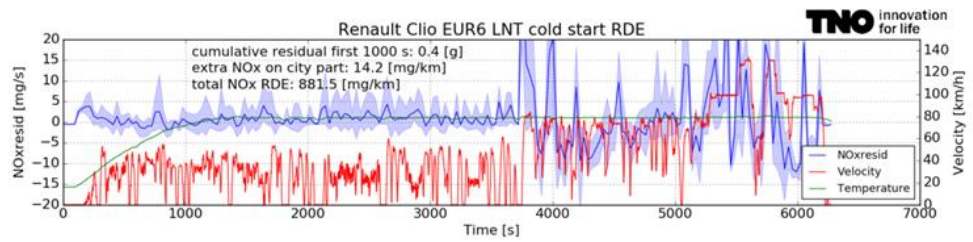
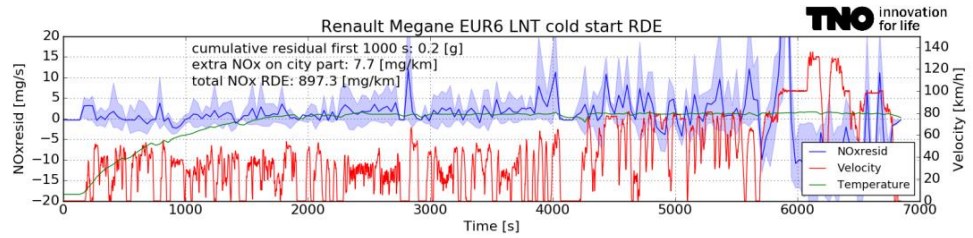
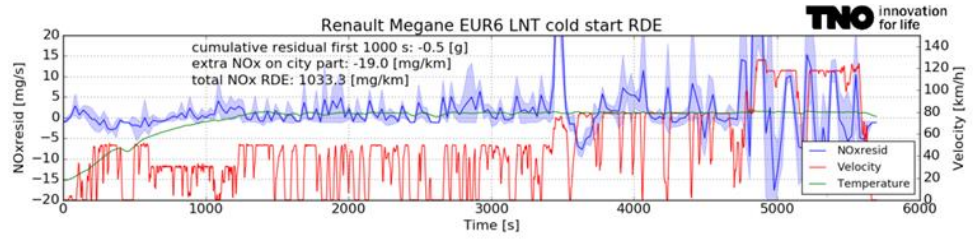
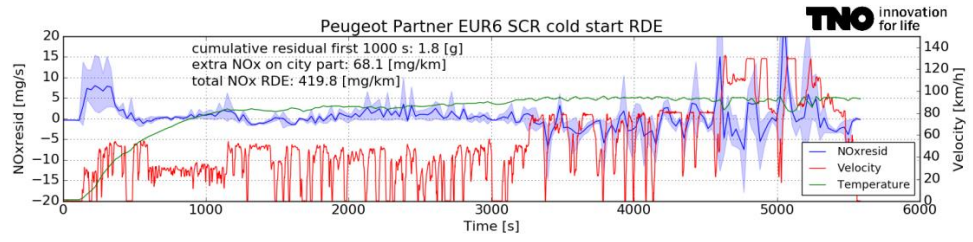
Brand	Model	AT	NOx	NOx	NOx	Distance	NOx (300 s)	Distance (300 s)	NOx (300 s)	NOx residual (1000 s)
			[g/km]	[g/km]	[g]	[km]	[g]	[km]	[g/km]	[g]
			Total	City		Cold start				
Citroen	Cactus	SCR	0.44	0.34	10.7	31.4	0.7	2.1	0.31	1.6
Ford	Fiesta	LNT	0.37	0.26	9.3	35.9	0.6	0.7	0.81	0.6
Ford	Focus	LNT	0.41	0.36	10.7	29.7	0.6	2.0	0.30	-0.1
Opel	Zafira	SCR	0.92	1.18	37.4	31.7	3.6	1.0	3.77	4.0
Peugeot	308 110 kW	SCR	0.49	0.49	16.3	33.0	2.1	1.6	1.31	2.0
Peugeot	308 88 kW	SCR	0.48	0.50	15.8	31.7	2.5	2.7	0.93	3.1
Peugeot	Partner	SCR	0.42	0.40	12.9	31.9	1.8	1.4	1.27	1.8
Renault	Megane	LNT	1.03	0.80	24.5	30.7	1.6	1.9	0.82	-0.5
Renault	Megane	LNT	0.90	0.94	31.1	33.2	2.0	2.2	0.88	0.2
Renault	Clio	LNT	0.88	0.90	29.2	32.5	1.8	1.7	1.08	0.4
Volvo	V40	LNT	0.32	0.37	11.7	32.1	0.7	2.0	0.33	0.2
Volkswagen	Golf	LNT	0.20	0.25	8.0	31.6	0.9	2.3	0.36	0.8
Volkswagen	Passat	LNT	0.27	0.18	5.6	31.9	0.3	1.7	0.19	0.2
Volkswagen	Polo	LNT	0.29	0.31	10.2	33.4	0.5	1.6	0.30	0.5
Mercedes	C220	SCR	0.06	0.10	3.0	30.8	0.7	2.3	0.31	-1.4

The plots of the different residual analyses are shown below in Figure 57. In the motorway section at the end of the trip the residuals are generally higher. The absolute emission rates in mg/s are also higher. This explains in part the large variation in the motorway part. However, in many cases the variation, indicated by the shaded area is also large. In some cases longer periods of constant driving at higher velocity may lead to reduced emissions, which are not captured by the emission average based on the instantaneous driving.

This residual analyses show a clear distinction between the LNT-equipped and the SCR-equipped vehicles. Moreover, the cold start effect for these vehicles is much smaller than estimated based on the average mg/km emissions based on the first 5 minutes, probably related to the initial idling and driving after the engine start. The effect has little relation to the magnitude of the warm emissions of the vehicles. From the first 5 minutes the high emissions of the Renault vehicles may be mistaken for cold start effects, but from the residual analyses it is clear these emissions are characteristic for the warm engine operation.

Finally, the window of 1000 seconds for the integrated cold-start effect is based on the residues themselves. Both the Opel Zafira and both Peugeot 308 show a decreasing effect from the start to about 800 to 1000 seconds into the test. On the other hand, the SCR-equipped Mercedes C220 has low overall emissions and no discernible cold-start effect from these tests. The average emission data, used to determine the residues, of this vehicle may have generated some bias by tests at different ambient temperatures.





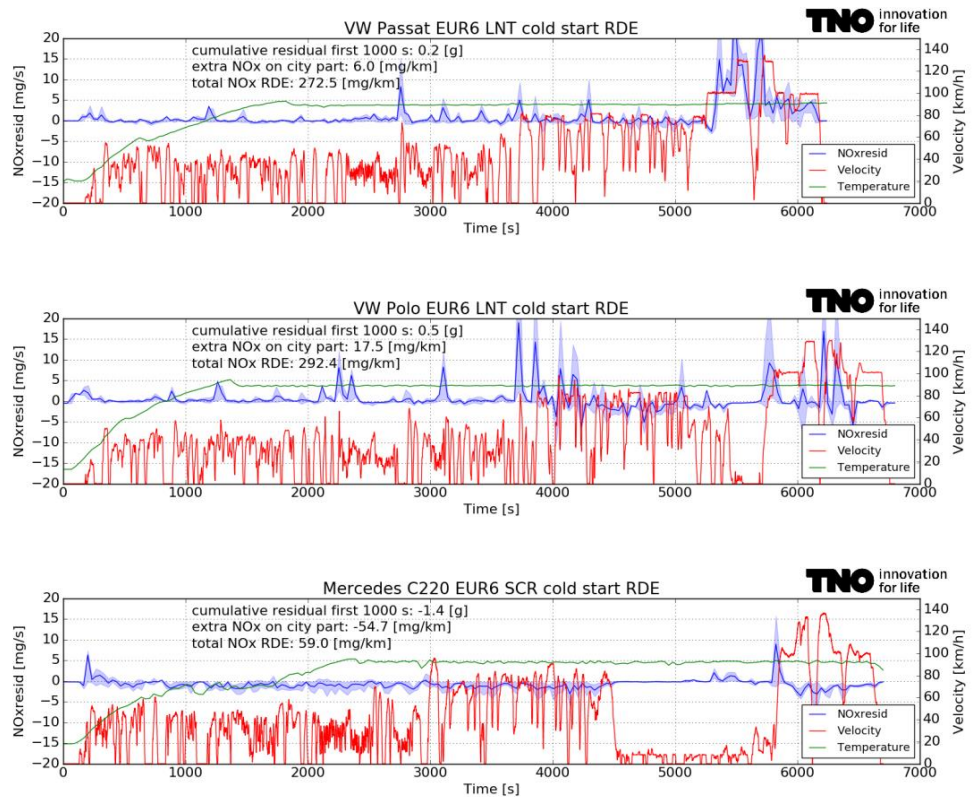


Figure 57 Plots of residual cold start analysis of fifteen tested vehicles

From the plots it is clear that the emission peaks with dynamic rural driving of LNT peaks are compensated by lower than average emissions by the constant driving at higher velocity. Many vehicles show a lower than average emissions in the last part of the RDE trip on the motorway, not visible in the first part of the motorway driving. It seems a longer period of constant motorway driving is beneficial for the emission performance of many LNT-equipped Euro-6 diesel vehicles.

6 Discussion

6.1 Insights into the emission behaviour of Euro 6 diesel passenger cars

There is a large spread in the on-road NO_x emission performance of the tested Euro-6 vehicles. Both groups of vehicles (with SCR and LNT technology) have normalized NO_x emissions in the same range (SCR: 202 to 1306 mg/km; LNT: 140 to 1227 mg/km). 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 in 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. As the vehicles in this report were all tested on comparable or even identical RDE-compliant routes, and as results are further normalized using the TNO VERSIT+ approach, the impact of differences in driving patterns on the comparability of results as presented in Table 36 is strongly reduced. As a consequence, differences in ambient temperature during the tests remain as one of the main factors that limit the comparability of results for different vehicles.

In this test programme most vehicles were tested on the road at ambient temperatures between 0 and 18 °C. It is expected that the emission behavior 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 of their environmental performance. The current test temperatures lies well within the range of the most common ambient temperatures in the Netherlands. Hence it is expected the test results are representative, also in this aspect.

In order to get more insight in the temperature dependence of emission behavior one vehicle was tested on a chassis dynamometer in an NEDC-test with cold start with two different ambient temperatures (soak and test cell at 23 and 15 °C). Due to this temperature drop of 8 °C the NO_x emission increased from 71 to 488 mg/km. In the near future TNO will pay more attention to temperature related emission behavior of vehicles. One vehicle type was further investigated at different temperatures on the road, the results are published in a separate report [TNO 2016b].

6.3 RDE testing

Starting in 2008 with heavy-duty vehicles and in 2010 with light-duty vehicles TNO has gained a broad experience in on-road testing of vehicles. In general on-road testing is complicated and therefore a trained team is needed to produce reliable test results. From 2008 onwards several reference trips were developed and used for on-road testing. From November 2015 to May 2016 TNO has developed specific

Real Driving Emission tests (routes + accompanying procedures) at two locations (Helmond and Delft).

RDE testing requires a highly qualified test team

The construction of a robust RDE-trip which meets all criteria is challenging and requires a process of iteration (trial and error). First of all the three road types (urban/rural/motorway) must be available in a certain sequence with a certain length/duration. Then during execution, certain vehicle speed profiles must be reached and finally a certain repeatability must be realized. Moreover, the driver must be trained to create certain driving styles which meet the criteria of the trip dynamics. Finally, the data processing, check of trip parameters, normalization, interpretation and validation of the test results require a high level of understanding of the emission behavior of vehicles, the measurement technologies, and the evaluation methods.

The normalization tools EMROAD and CLEAR yield different results

The two methods for normalization of the test results produce very different results. For the fifteen tested vehicles the results do not show a clear relationship between the CLEAR and EMROAD normalization: the data points are quite widely scattered. This means that the CLEAR and EMROAD normalization results not only are quite uncorrelated but also may largely differ, in spite of being calculated from the same data for the same purpose (i.e., normalization). This might create an incentive for selective use of these tools for deriving type approval results and validating compliance with the RDE legislation. A more detailed analysis of the RDE testing methodology is reported in [TNO 2016d].

With current high levels of NO_x emissions of light-duty diesel vehicles the cold start effects are in many cases only minor contributions to the total emissions, even for the urban emissions. However, from current testing significant levels of the cold start magnitude and duration are only observed for SCR-equipped vehicles. If the average emissions decrease the relative effect of cold start may become larger. However, the cold-start RDE test with the Mercedes C220 shows that low emissions are possible.

7 Conclusions

7.1 General caveats with regard to 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 in Table 36 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 in Table 36 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 after treatment and control systems.

Numbers and bandwidths mentioned in the conclusions below are based on the data as presented in Table 36.

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

In the on-road measurement method with SEMS, as used in this project, the NO_x and CO₂ mass emission rates are calculated on the basis of measured concentrations, fuel parameters, and the mass-air-flow (MAF) signal from the vehicle's CAN bus. The air mass flow signals of the vehicles may deviate from actual values (i.e. +/- 10%), leading to inaccuracies in the overall test result. However, a comparison of the CO₂ 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 CO₂ 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 6 diesel cars 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 CO₂ emission performance of fourteen Euro 6 compliant diesel passenger vehicles M1 legislative class and one Euro 6 commercial N1 class II vehicle have 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 O₂/NO_x sensor. Combined with CAN bus data of the vehicle and a dedicated emission calculation method, the mass emission rates were determined. Three vehicles were tested in greater detail on a chassis dynamometer in a test laboratory.

Real-world NO_x emission levels

On the road the tested vehicles showed NO_x emission levels that are 2 to 16 times higher than the type approval emission limit of 80 mg/km. Their average NO_x emissions in urban traffic ranged from 162-1306 mg/km. These measurement results confirm findings in another studies ([BDT 2016], [ReFr 2016], [BMVI 2016]) which reported comparable real-world NO_x emissions in RDE tests.

When subjected to a type approval test, the three vehicles that were tested on the chassis dynamometer had NO_x emissions below or near the type approval limit of 80 mg/km. Tests on the chassis dynamometer under different conditions, e.g. starting with a hot engine, with a different road load or on a different test cycle, generally caused far higher NO_x emissions, ranging from 77 to 823 mg/km. Testing the same vehicles on the road has shown NO_x emission levels of 185 up to as much as 1050 mg/km.

Despite of the continuous tightening of the NO_x type approval limit values from Euro 1 to Euro 6 real-world NO_x emission factors have stabilized on average at around 300-500 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 80 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 [TNO 2016d] 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 across different tests, while other vehicles have very different emissions in different tests.

Rural velocity profile

The average measured velocity profile at rural roads is much more dynamic than previously assumed. This is mainly due to congestion, roundabouts and other obstacles. The recent update in driving behavior underlying the emission factors also suggested that Dutch rural driving behavior has changed significantly in recent years.

SCR and LNT technologies and emission controls

The 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 indicates application of different control strategies of the emission control technologies (EGR/LNT/SCR) in real-world operation.

Execution of the RDE test procedure

The current RDE test procedure and especially the execution of the tests is reasonably complex but feasible. It must be carried out by a well-trained and skilled test team.

Normalization tools

For many of the obtained on-road test results, application of the two normalization tools (EMROAD and CLEAR) produced quite different results. This might create an incentive for selective use of these tools for deriving type approval results and validating compliance with the RDE legislation.

Cold start emissions

Currently the RDE regulation prescribes that an RDE test trip has a hot start. In order to get a view on cold start emissions all tested vehicles were subjected to (RDE) tests with a cold start. From current Euro 6 diesel vehicles (model year 2016) the amount of additional NO_x emission during a cold start is found to be related to the applied after treatment technology. In the first 300 seconds of the urban part of RDE trips with a cold start the nine tested vehicles with a LNT have an average NO_x emission of 0.56 g/km and the six tested vehicles with a SCR have an average NO_x emission of 1.31 g/km. 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. It is expected that a large share of the Euro 6c diesel vehicles will be equipped with SCR technology and therefore it might be considered to add a cold start to the current RDE test trip.

8 References

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9 Signature

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TNO

Peter van der Mark
Project Leader

Gerrit Kadijk
Author

A v^*a_{pos} and RPA values for all 28 RDE trips

RDE test	Vehicle		Driving behaviour, Urban				Driving behaviour, Rural				Driving behaviour, Motorway							
	Trade mark	Model	License plate	EMROAD Speed km/h	EMROAD P95 VAp05 m²/s³	EMROAD P95 Valid 0/1	RPA m/s²	EMROAD RPA Valid 0/1	EMROAD Speed km/h	EMROAD P95 VAp05 m²/s³	EMROAD P95 Valid 0/1	RPA m/s²	EMROAD RPA Valid 0/1	EMROAD Speed km/h	EMROAD P95 VAp05 m²/s³	EMROAD P95 Valid 0/1	RPA m/s²	EMROAD RPA Valid 0/1
1	CITROEN	Cactus	HG656N	24.7	13.6	1	0.253	1	74.9	26.2	0	0.151	1	110.5	26.6	1	0.089	1
2	FORD	Fiësta	GV011G	25.6	13.5	1	0.25	1	72.8	20.3	1	0.115	1	106.5	21	1	0.062	1
3	FORD	Fiësta	GV011G	25.5	12.9	1	0.235	1	72.4	20.2	1	0.128	1	105.3	20.1	1	0.076	1
4	FORD	Focus	GZ364X	25.1	14.3	1	0.201	1	77.5	23.8	1	0.069	1	106.7	26.9	1	0.118	1
5	FORD	Focus	GZ364X	25.9	12.9	1	0.172	1	74	23.4	1	0.051	0	109.9	22.3	1	0.075	1
6	OPEL	Zafira	1THN81	27.5	14	1	0.257	1	73.2	19.2	1	0.119	1	103.6	18.5	1	0.053	1
7	OPEL	Zafira	1THN81	27.4	14.6	1	0.266	1	74.2	21.4	1	0.124	1	103.8	24.4	1	0.078	1
8	PEUGEOT	308 (88)	HV027G	25.5	12.7	1	0.231	1	73.7	25	0	0.141	1	106.9	31.9	0	0.077	1
9	PEUGEOT	308 (88)	HV027G	26.4	14.2	1	0.26	1	75.1	21.5	1	0.12	1	107.1	23.4	1	0.071	1
10	PEUGEOT	308 (110)	JB670L	27.3	19.5	0	0.301	1	76.3	26.1	0	0.152	1	103.9	16.2	1	0.06	1
11	PEUGEOT	308 (110)	JB670L	26.1	15.1	1	0.252	1	74.9	31.4	0	0.122	1	107.5	41.8	0	0.073	1
12	PEUGEOT	Partner	VR134G	26.6	13.5	1	0.237	1	73.3	20.9	1	0.095	1	107.6	29.7	0	0.088	1
13	PEUGEOT	Partner	VR134G	22.8	13.5	1	0.197	1	74.6	17.8	1	0.099	1	109.9	23	1	0.082	1
14	RENAULT	Clio	HT999B	27	14.4	1	0.264	1	74.7	17.6	1	0.122	1	105.5	17.2	1	0.048	1
15	RENAULT	Clio	HT999B	27.4	14.5	1	0.248	1	72.7	20.1	1	0.116	1	106.8	18.1	1	0.046	1
16	RENAULT	Megane 1	HH808B	25.2	14.7	1	0.261	1	73.4	23.7	1	0.128	1	105.9	24.5	1	0.053	1
17	RENAULT	Megane 1	HH808B	25.8	13.2	1	0.256	1	74.5	20.9	1	0.109	1	103.2	21.4	1	0.067	1
18	RENAULT	Megane 2	HH809B	25.2	15.3	1	0.241	1	75.7	22.8	1	0.105	1	110.4	25.1	1	0.085	1
19	RENAULT	Megane 2	HH809B	25.9	15.8	1	0.232	1	73.4	24.3	1	0.1	1	107.8	21	1	0.047	1
20	VOLVO	V40	HP449L	24.1	11.9	1	0.221	1	72.6	28.1	0	0.133	1	113.1	28	0	0.077	1
21	VOLVO	V40	HP449L	25.3	12.1	1	0.251	1	71.7	20.7	1	0.135	1	106.8	24.8	1	0.06	1
22	VOLKSWAGEN	Golf	GZ910G	25.7	16.8	1	0.247	1	75.7	29.2	0	0.097	1	109.6	37.8	0	0.094	1
23	VOLKSWAGEN	Passat	9ZLR55	25.5	14.5	1	0.24	1	74.4	21.8	1	0.104	1	106	31.7	0	0.052	1
24	VOLKSWAGEN	Passat	9ZLR55	25.6	14.2	1	0.255	1	72.9	22.5	1	0.116	1	105.1	24.3	1	0.049	1
25	VOLKSWAGEN	Polo	6ZGV28	27.2	16.3	1	0.283	1	76.8	29	0	0.145	1	110.5	24.4	1	0.072	1
26	VOLKSWAGEN	Polo	6ZGV28	28.5	16.3	1	0.281	1	74.4	26.1	0	0.145	1	111.1	25.7	1	0.065	1
27	MERCEDES	C220	9TJS12	20.9	12.2	1	0.269	1	74.9	17.6	1	0.124	1	103.8	18.7	1	0.07	1
28	MERCEDES	C220	9TJS12	27.7	13.6	1	0.217	1	76.5	14.7	1	0.096	1	103.7	9.5	1	0.035	1

