**Earth, Life & Social Sciences**
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00

**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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| Date | 10 October 2016 |
| Author(s) | Veerle Heijne<br>Gerrit Kadijk<br>Norbert Ligterink<br>Peter van der Mark<br>Jordy Spreen<br>Uilke Stelwagen |
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# Samenvatting

Om negatieve effecten van de uitstoot van luchtverontreinigende stoffen en het broeikasgas $CO_2$ door het wegverkeer te verminderen zijn er Europese normen voor de uitlaatgasemissies van wegvoertuigen. Ook is er Nederlands beleid om de toepassing van schone en zuinige voertuigtechnieken te stimuleren. Om de effectiviteit van dit beleid te kunnen beoordelen voert TNO sinds 1987 in opdracht van het Nederlandse Ministerie van Infrastructuur en 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 werktemperatuur 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 dieselvoertuigen 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 dieselvoertuigen*

Het emissieonderzoek aan deze voertuigen bevestigt resultaten gevonden in eerdere studies: dieselauto's kunnen in het laboratorium aan de typekeuringsnorm voldoen maar in de praktijk ligt de $NO_x$-uitstoot vaak fors hoger. Onderzoek naar de oorzaak 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.

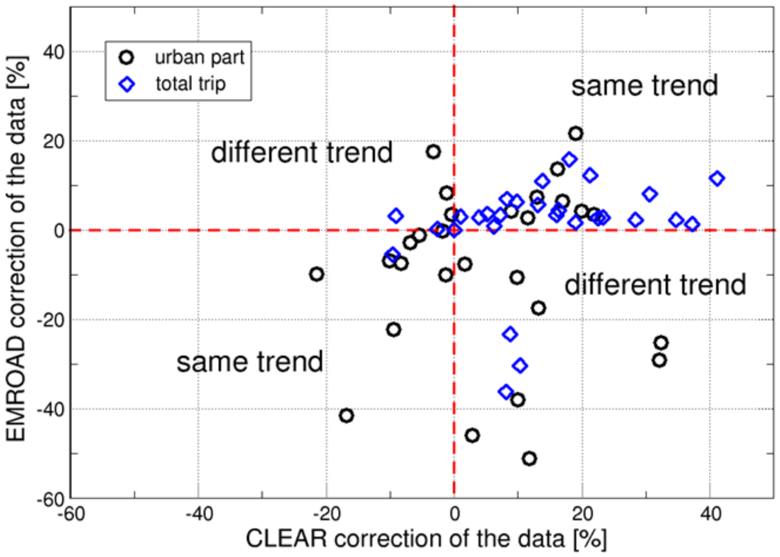
In het verleden waren verschillen tussen de typekeuringswaarde en de waarden in de praktijk deels te verklaren uit rijgedrag en rijomstandigheden. Deze testen en de uitgevoerde testen van de laatste jaren laten zien dat voor rijgedrag en gevraagde motorvermogens vergelijkbaar met de typekeurtest, de $NO_x$-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 $CO_2$ 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*(Genormaliseerde waarde – Actuele Waarde_TNO)/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 $CO_2$ 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.

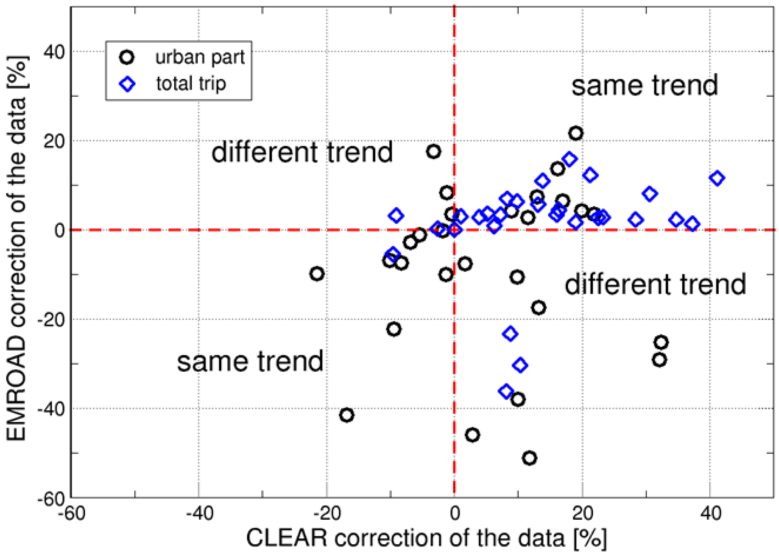


Figure S1 Relative correction of the $NO_x$ emissions on RDE compatible tests resulting from normalisation with EMROAD (y-axis) and CLEAR (x-axis), defined as 100*(Normalised_Value – Raw_Value_TNO)/Raw_Value_TNO %, for all 28 RDE trips.

# Contents

**Appendices**

# 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 $NO_2$ emitted, and because in the outside air NO is converted to $NO_2$, reducing $NO_x$ emissions of vehicles is important for bringing down the ambient air $NO_2$ concentration in cities. In the Netherlands, the ambient $NO_2$ concentration still exceeds European limits at numerous urban road-side locations[1].

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

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[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.

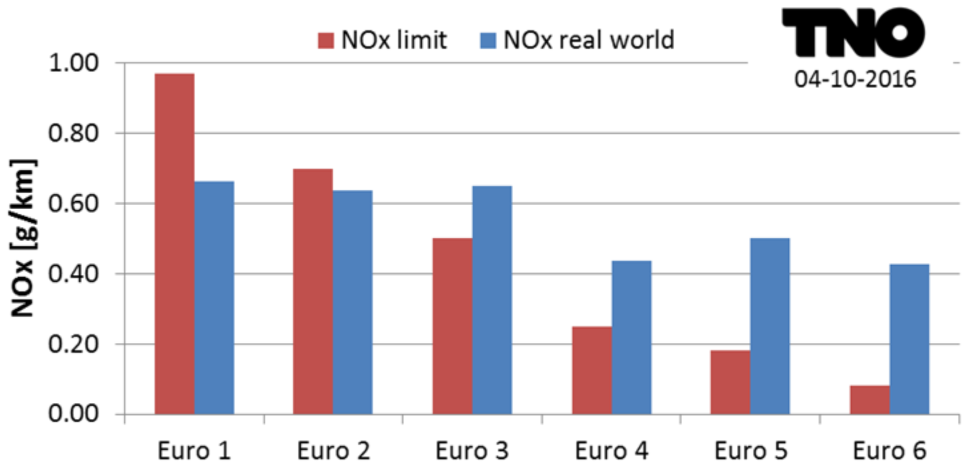


Figure 1 Emission limits and 2015 real-world emission factors for M1 class diesel passenger cars.

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 $CO_2$ emission measurements of SEMS deviate from the standard lab measurements by -2.4 to +0.8 g/km (-1.6% to +0.3%). For $NO_x$ emissions the deviation is -0.7 to +54.7 mg/km (-0.1 to +8.8%). The accuracy of the SEMS equipment relies 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].

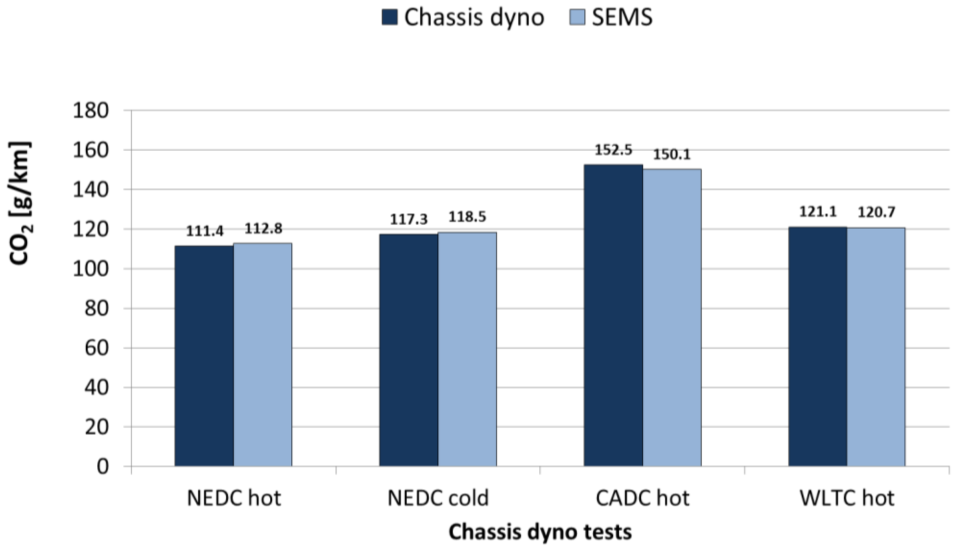


Figure 2 $CO_2$ emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS

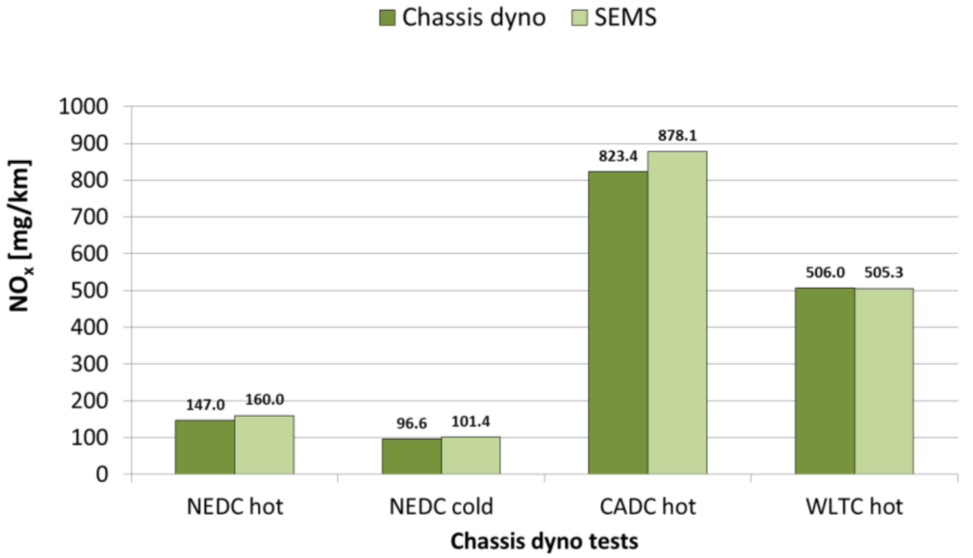


Figure 3 $NO_x$ emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS

# 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 | [-] | VF7OBBHYBFE559341 |
| 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 $CO_2$ 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 min/max/avg [°C] | | | $CO_2$ [g/km] | $NO_x$ [mg/km] | $NH_3$ [mg/km] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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.

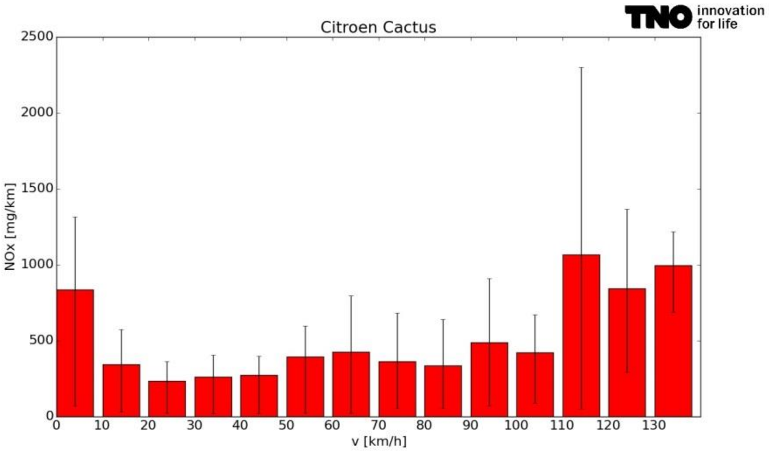


Figure 4 Average $NO_x$ emissions of a Citroen Cactus Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

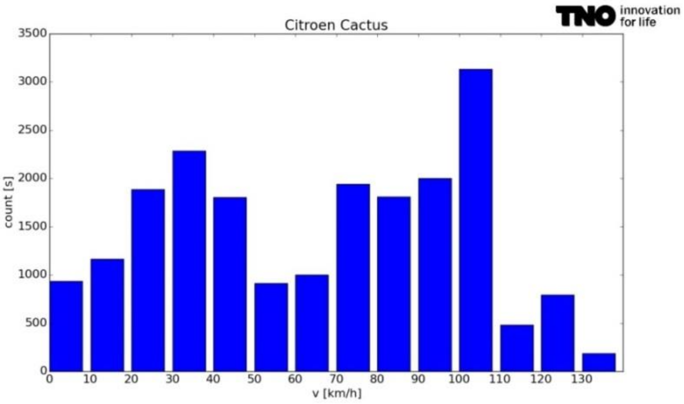


Figure 5 Number of seconds per velocity bin, over all trips. Idling is excluded.

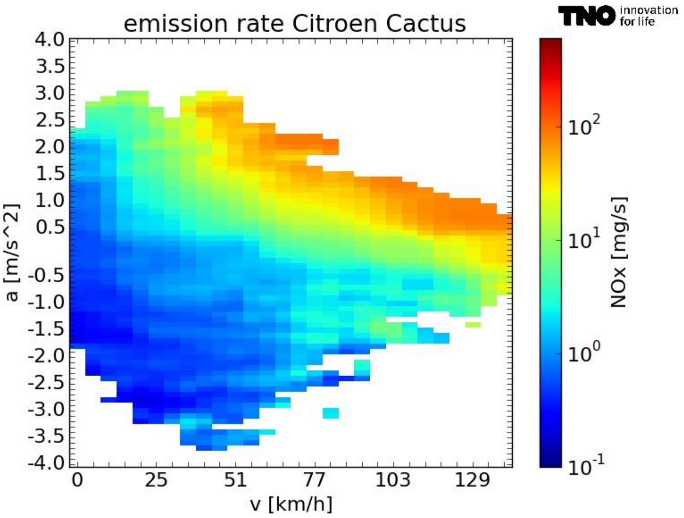


Figure 6 $NO_x$ emission rate [mg/s] of a Citroen Cactus Euro 6 diesel in bins of velocity and acceleration

### 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 $CO_2$ 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 min/max/avg [°C] | | | $CO_2$ [g/km] | $NO_x$ [mg/km] |
|---|---|---|---|---|---|---|---|---|---|---|
| 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.

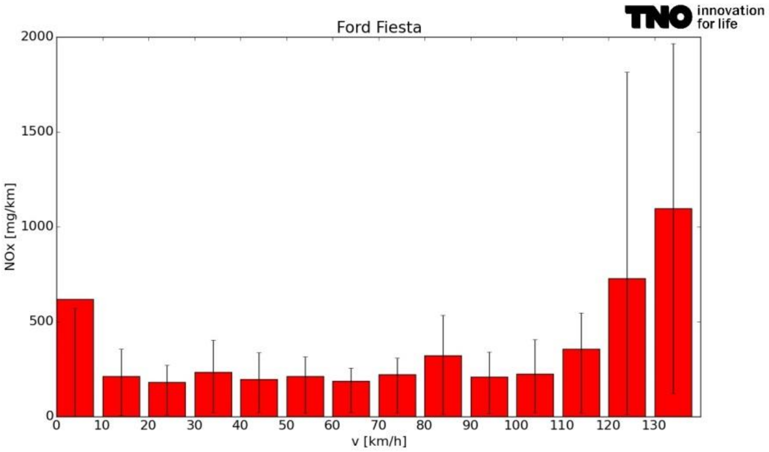


Figure 7 Average $NO_x$ emissions of a Ford Fiesta Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

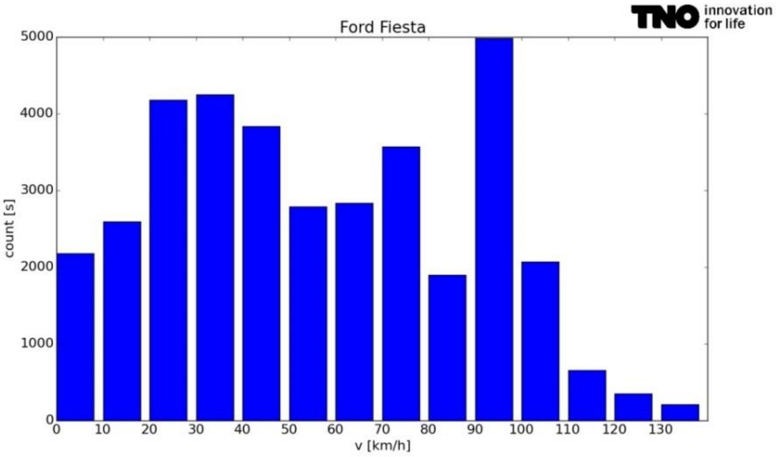


Figure 8 Number of seconds per velocity bin, over all trips. Idling is excluded.

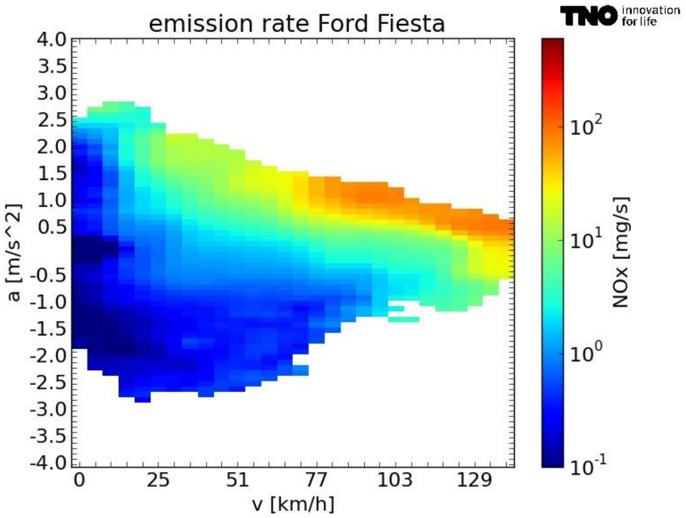


Figure 9 $NO_x$ emission rate [mg/s] of a Ford Fiesta Euro 6 diesel in bins of velocity and acceleration

### *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*<br>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 | CH4 | 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 $CO_2$ 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* min/max/avg [°C] | | | $CO_2$ [g/km] | $NO_x$ [mg/km] |
|---|---|---|---|---|---|---|---|---|---|---|
| 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).

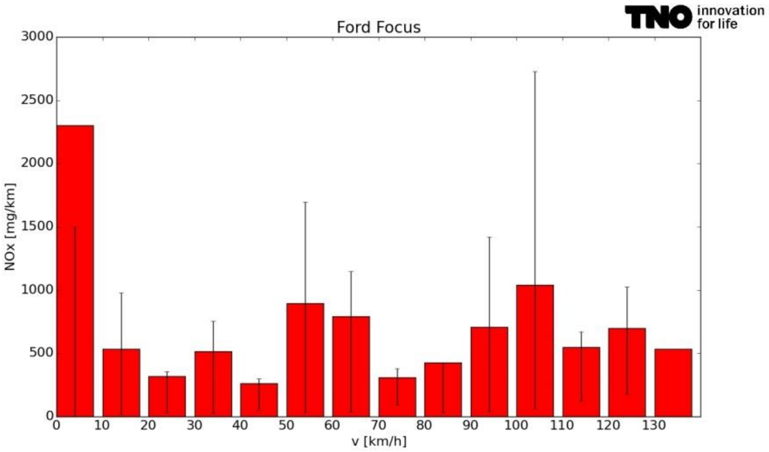


Figure 10 Average $NO_x$ emissions of a Ford Focus Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

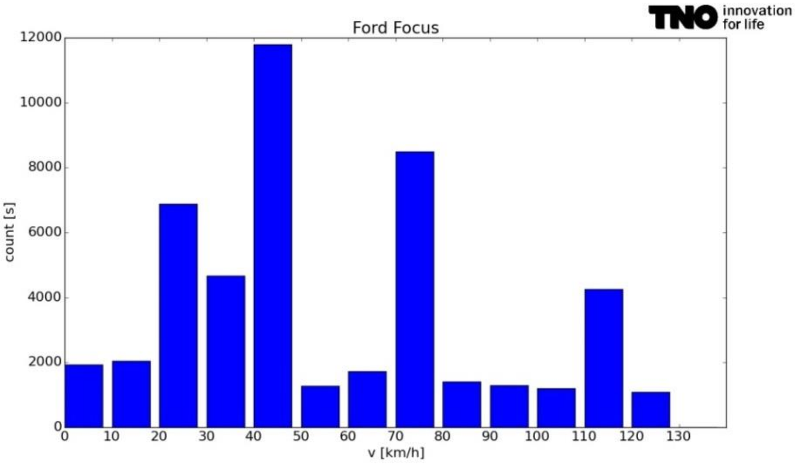


Figure 11 Number of seconds per velocity bin, over all trips. Idling is excluded.

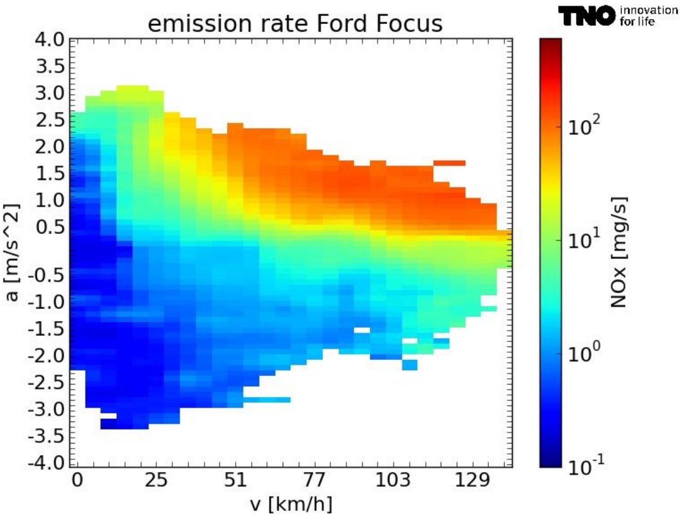


Figure 12 $NO_x$ emission rate [mg/s] of a Ford Focus Euro 6 diesel in bins of velocity and acceleration

### 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 $CO_2$ 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 min/max/avg [°C] | | | $CO_2$ [g/km] | $NO_x$ [mg/km] | $NH_3$ [mg/km] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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).

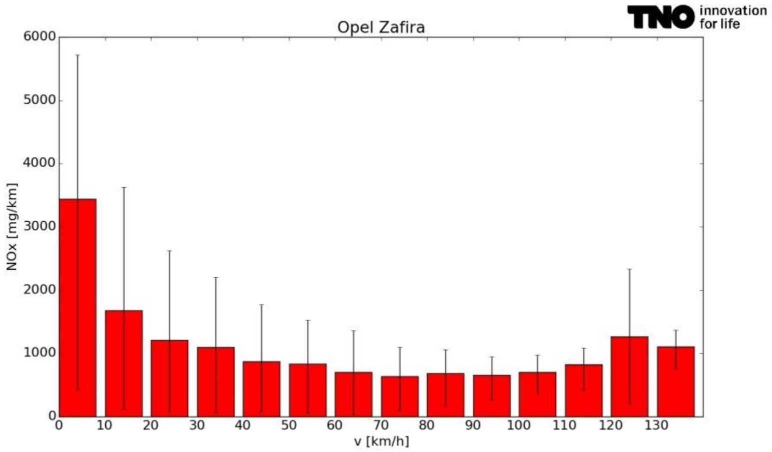


Figure 13 Average $NO_x$ emissions of an Opel Zafira Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

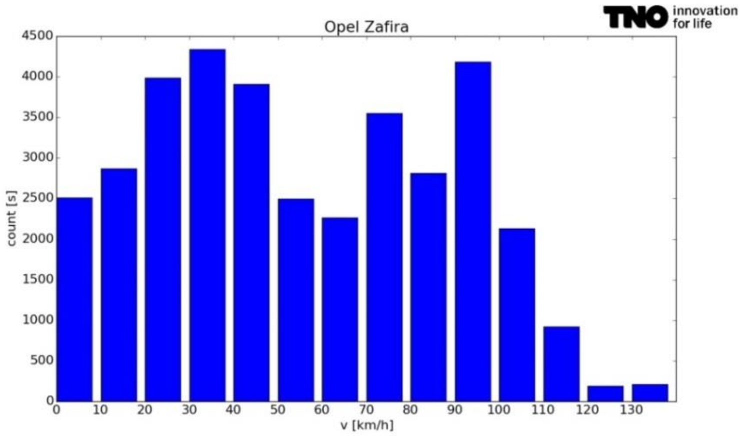


Figure 14 Number of seconds per velocity bin, over all trips. Idling is excluded.

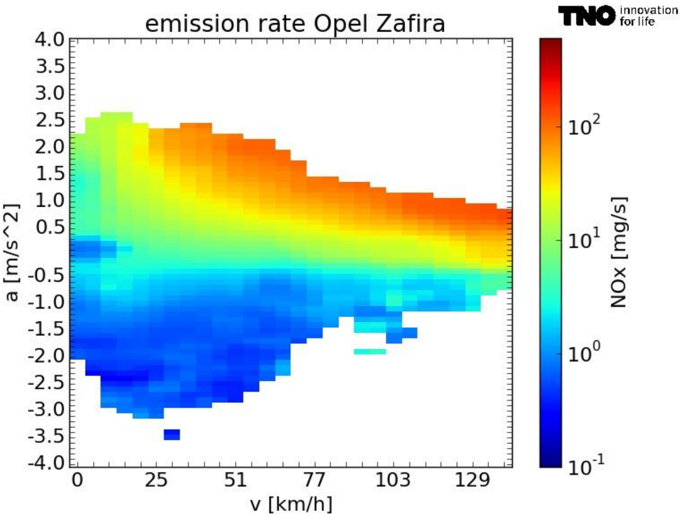


Figure 15 $NO_x$ emission rate [mg/s] of an Opel Zafira Euro 6 diesel in bins of velocity and acceleration

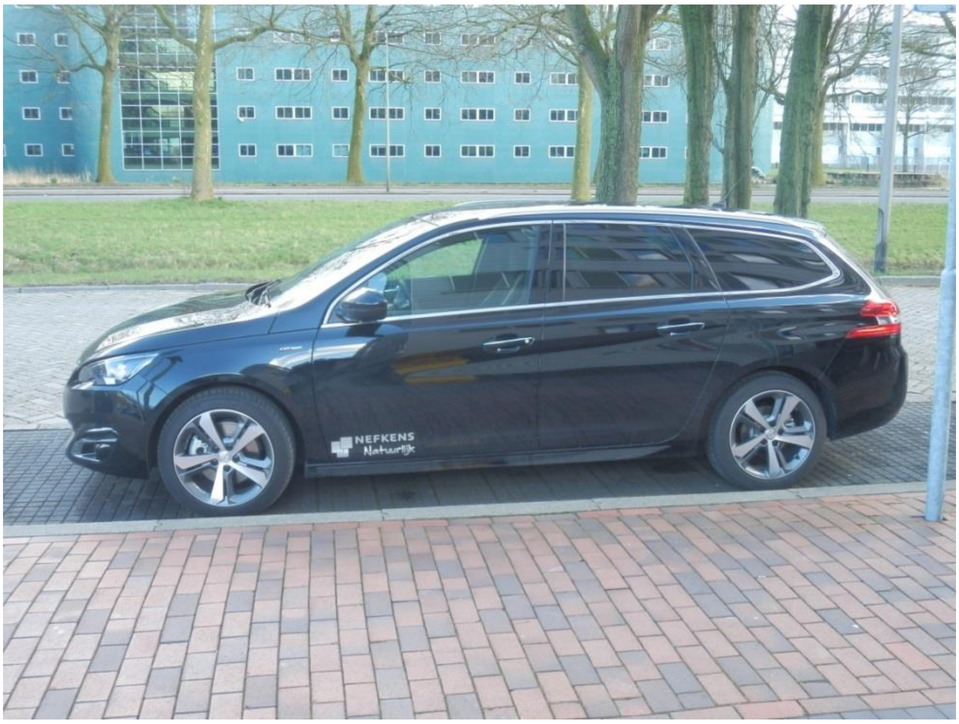
### 3.1.5 *Peugeot 308 (110 kW)*

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 $CO_2$ 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 min/max/avg [°C] | | | $CO_2$ [g/km] | $NO_x$ [mg/km] | $NH_3$ [mg/km] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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).

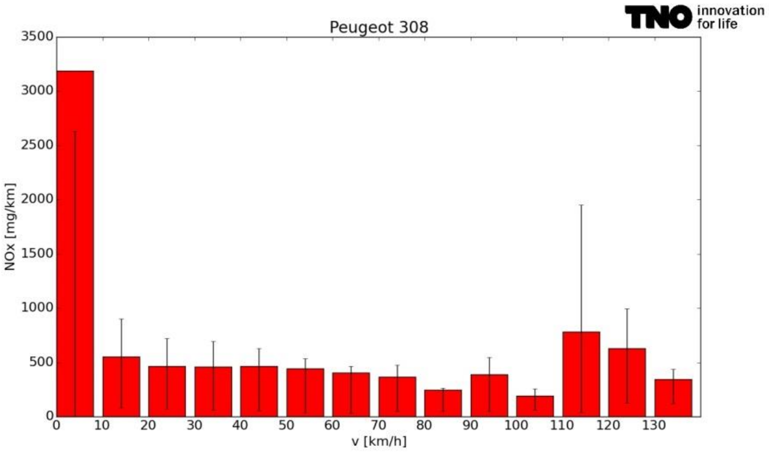


Figure 16 Average $NO_x$ emissions of a Peugeot 308 (110 kW) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

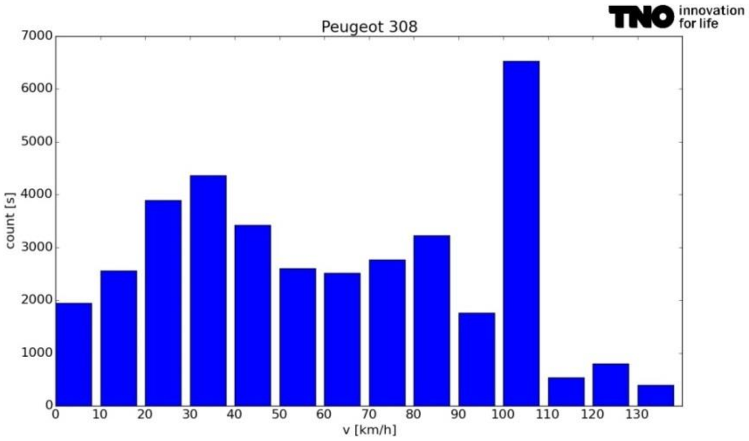


Figure 17 Number of seconds per velocity bin, over all trips. Idling is excluded.

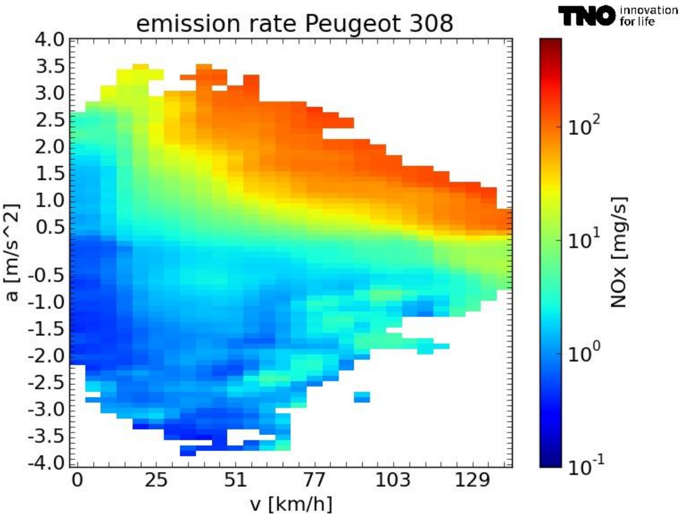


Figure 18 $NO_x$ emission rate [mg/s] of a Peugeot 308 (110 kW) Euro 6 diesel in bins of velocity and acceleration

### 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 $CO_2$ 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.

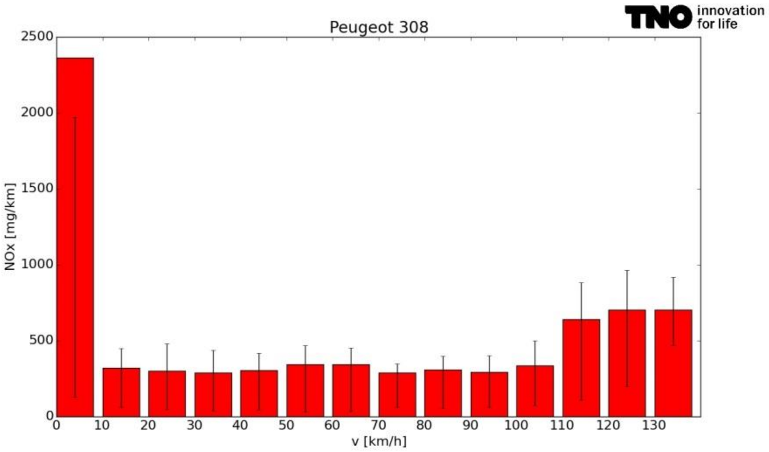


Figure 19 Average $NO_x$ emissions of a Peugeot 308 (88 kW) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

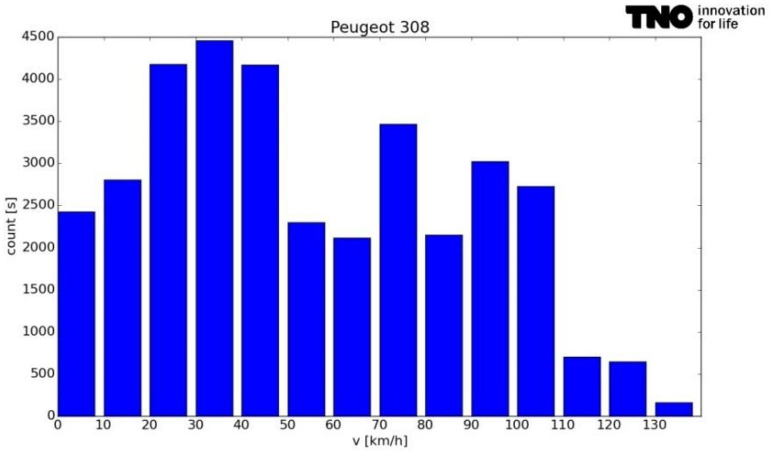


Figure 20 Number of seconds per velocity bin, over all trips. Idling is excluded.

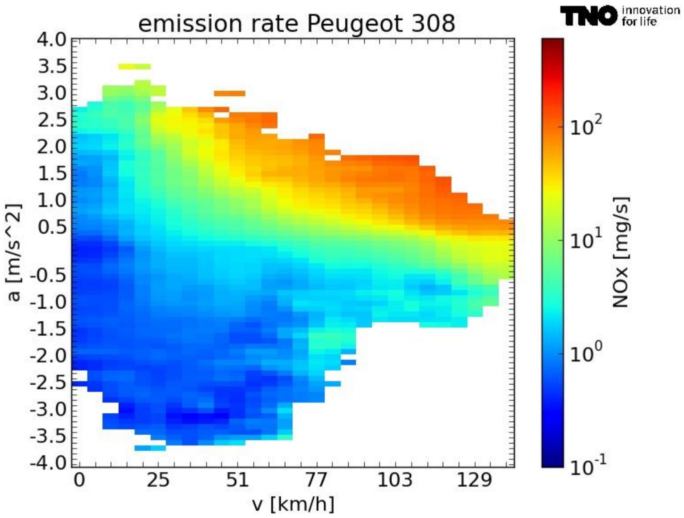


Figure 21 $NO_x$ emission rate [mg/s] of a Peugeot 308 (88 kW) Euro 6 diesel in bins of velocity and acceleration

### 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 $CO_2$ 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

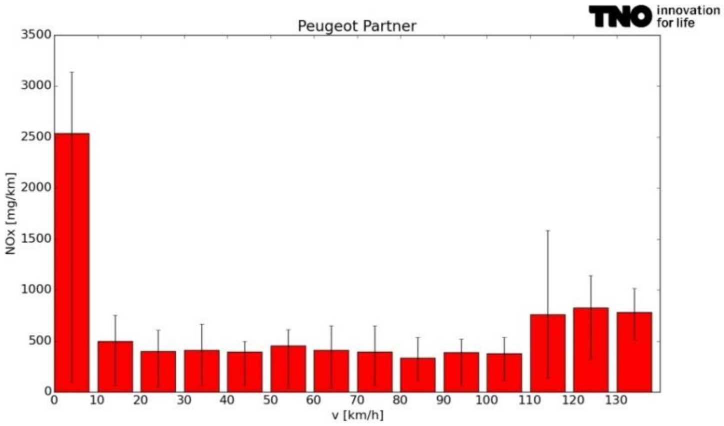


Figure 22 Average $NO_x$ emissions of a Peugeot Partner Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

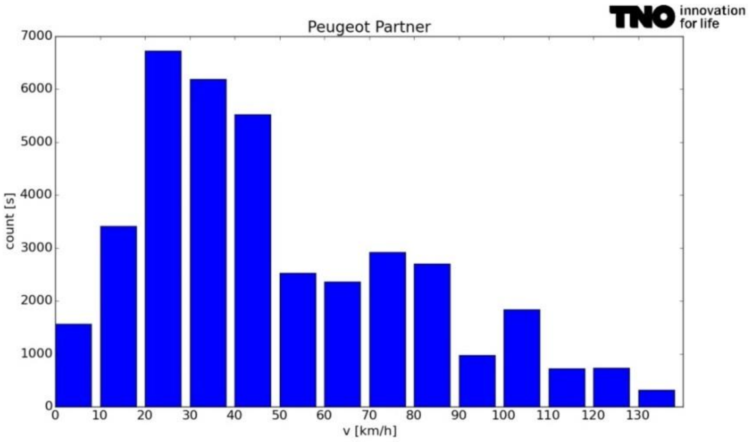


Figure 23 Number of seconds per velocity bin, over all trips. Idling is excluded.

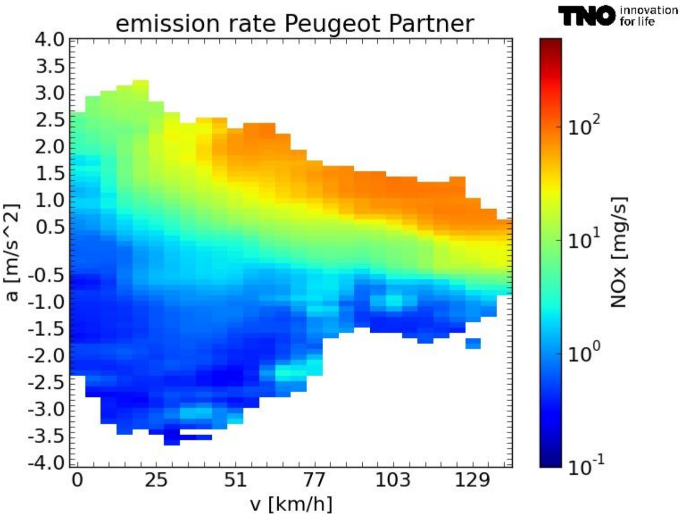


Figure 24 $NO_x$ emission rate [mg/s] of a Peugeot Partner Euro 6 diesel in bins of velocity and acceleration

### *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 $CO_2$ 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

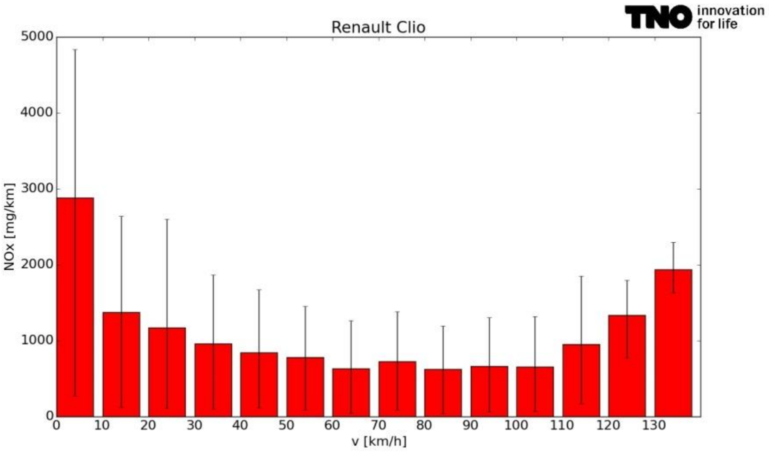


Figure 25 Average $NO_x$ emissions of a Renault Clio Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

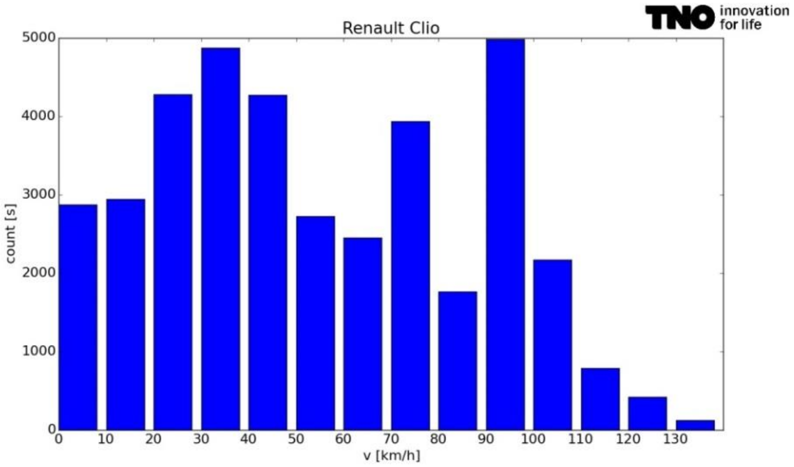


Figure 26 Number of seconds per velocity bin, over all trips. Idling is excluded.

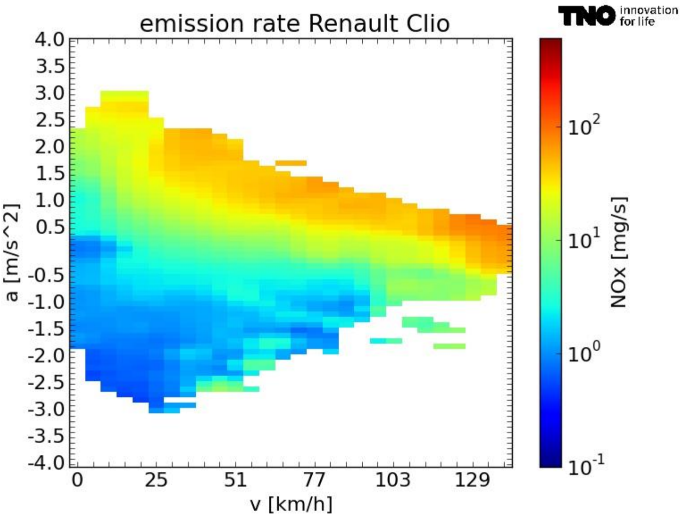


Figure 27 $NO_x$ emission rate [mg/s] of a Renault Clio Euro 6 diesel in bins of velocity and acceleration

### *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 $CO_2$ 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).

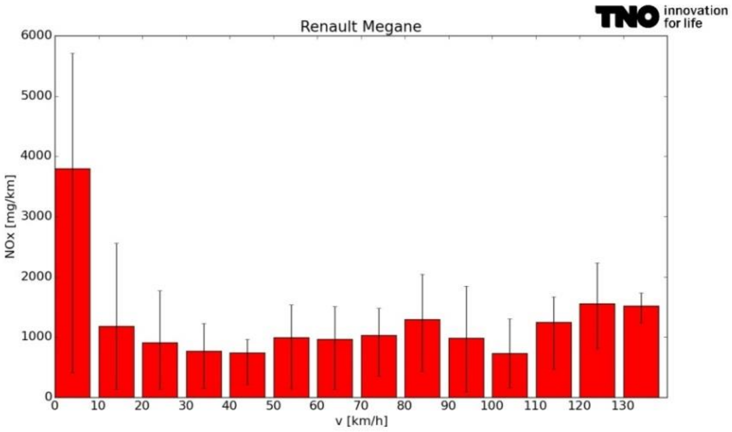


Figure 28 Average $NO_x$ emissions of a Renault Megane (a) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

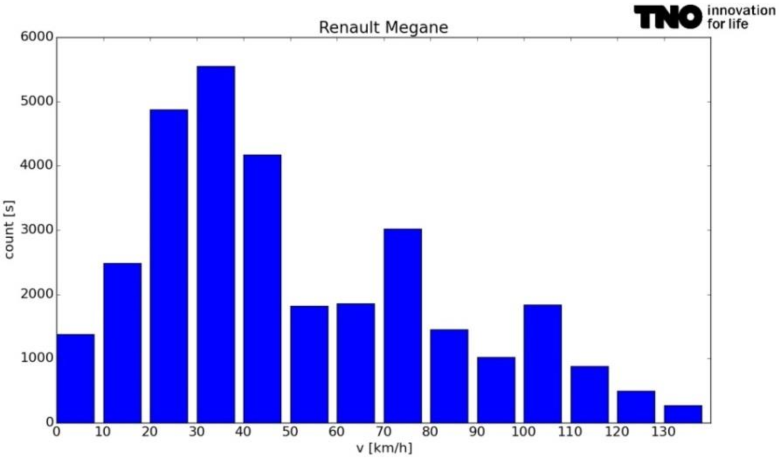


Figure 29 Number of seconds per velocity bin, over all trips. Idling is excluded.

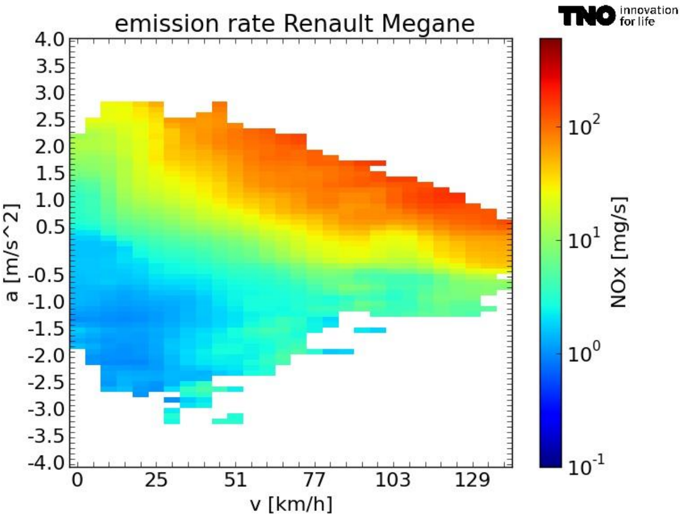


Figure 30 $NO_x$ emission rate [mg/s] of a Renault Megane (a) Euro 6 diesel in bins of velocity and acceleration

### *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 $CO_2$ emission is 117.3 g/km, which exceeds the specified type approval value of 93 g/km. This $CO_2$ 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 | CH4 | 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 $CO_2$ 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 |

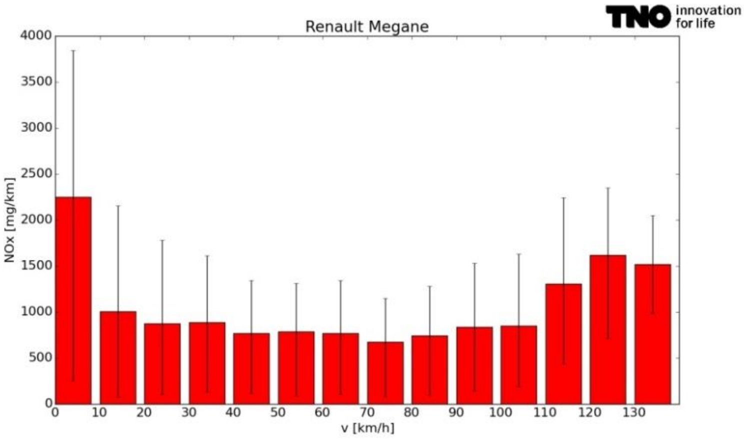


Figure 31 Average $NO_x$ emissions of a Renault Megane (b) Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

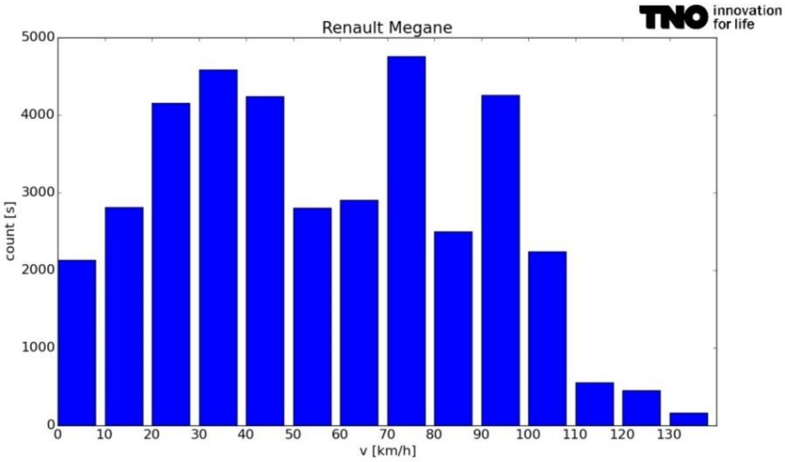


Figure 32 Number of seconds per velocity bin, over all trips. Idling is excluded.

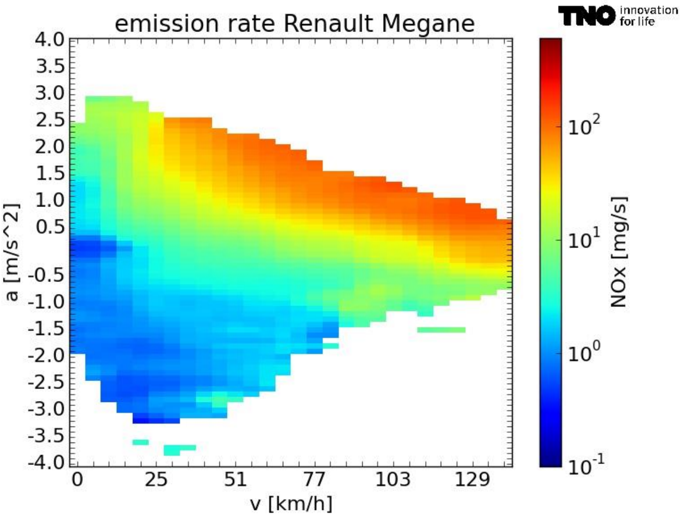


Figure 33 $NO_x$ emission rate [mg/s] of a Renault Megane (b) Euro 6 diesel in bins of velocity and acceleration

### *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 $CO_2$ 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.

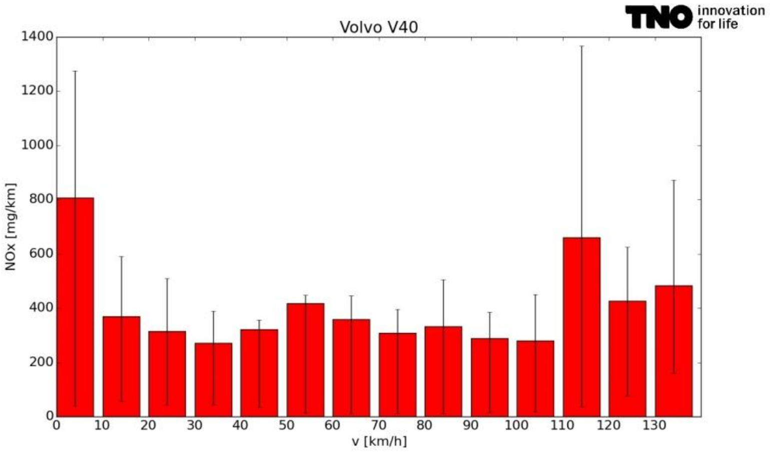


Figure 34 Average $NO_x$ emissions of a Volvo V40 Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

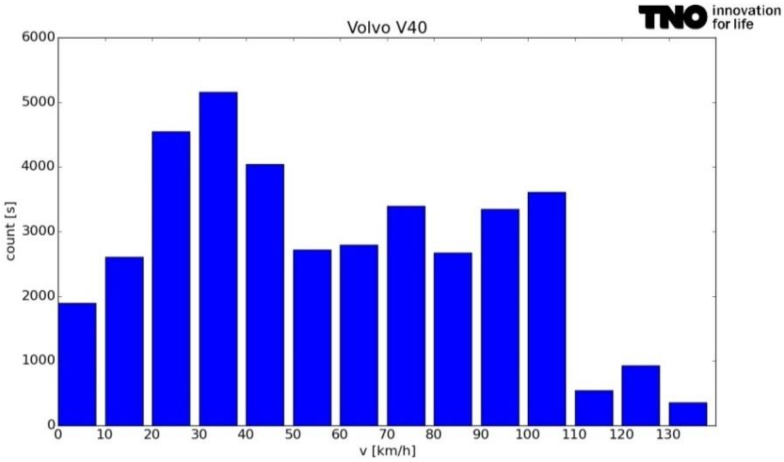


Figure 35 Number of seconds per velocity bin, over all trips. Idling is excluded.

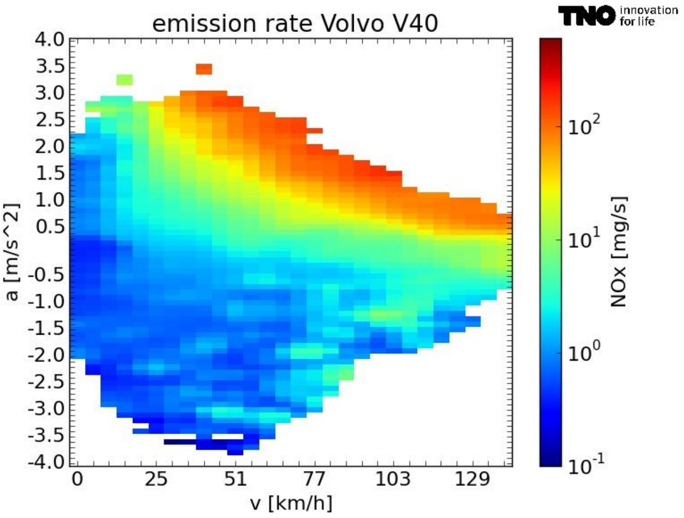


Figure 36 $NO_x$ emission rate [mg/s] of a Volvo V40 Euro 6 diesel in bins of velocity and acceleration

### *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 $CO_2$ emission is 118.3 g/km, which exceeds the specified type approval value of 96 g/km. This $CO_2$ 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 | CH4 | 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 | 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 $CO_2$ 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).

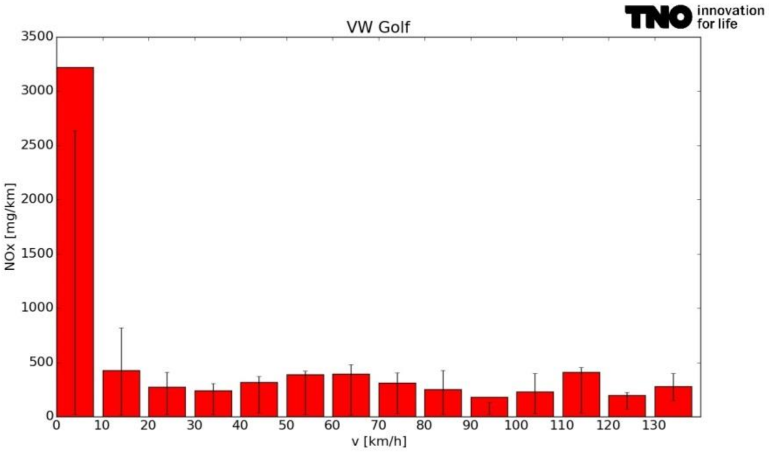


Figure 37 Average $NO_x$ emissions of a VW Golf Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

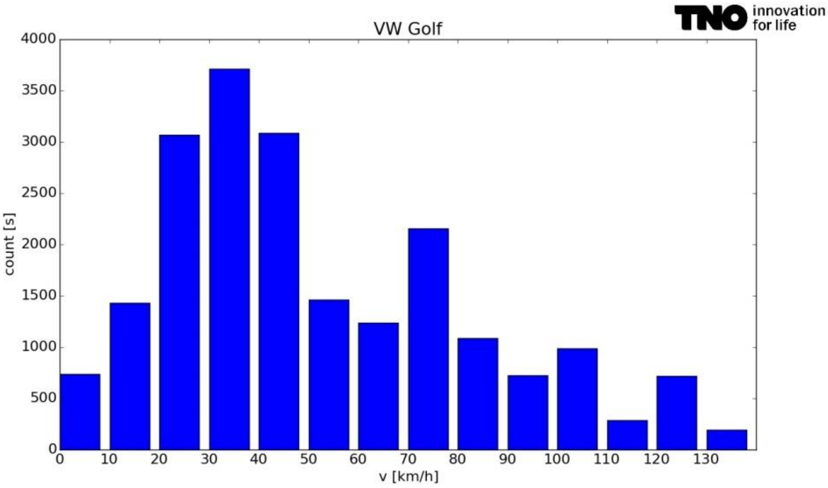


Figure 38 Number of seconds per velocity bin, over all trips. Idling is excluded.

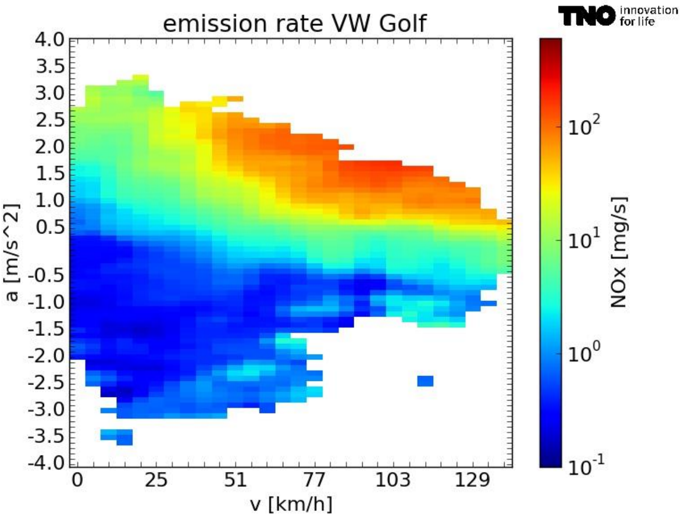


Figure 39 $NO_x$ emission rate [mg/s] of a VW Golf Euro 6 diesel in bins of velocity and acceleration

### *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 $CO_2$ 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 min/max/avg [°C] | | | $CO_2$ [g/km] | $NO_x$ [mg/km] |
|---|---|---|---|---|---|---|---|---|---|---|
| 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

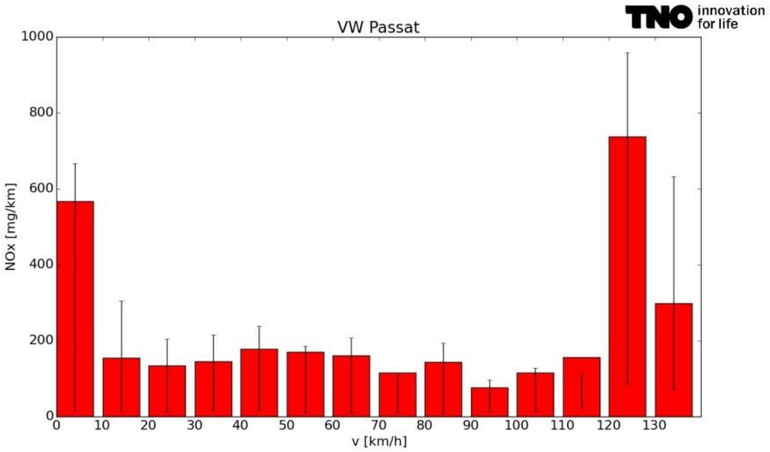


Figure 40 Average $NO_x$ emissions of a VW Passat Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

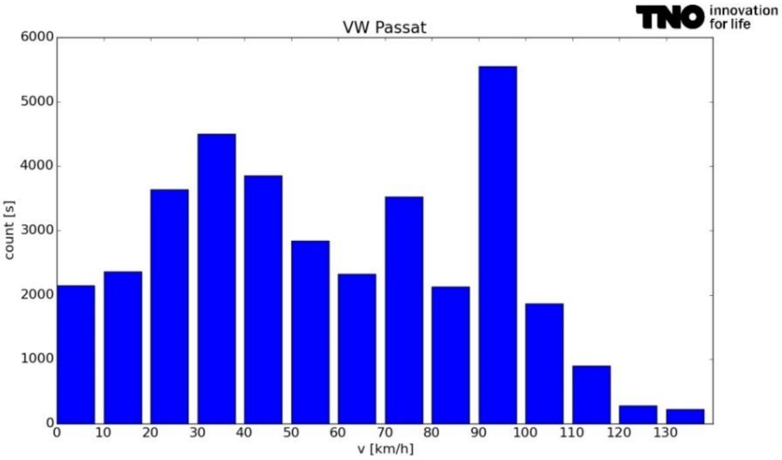


Figure 41 Number of seconds per velocity bin, over all trips. Idling is excluded.

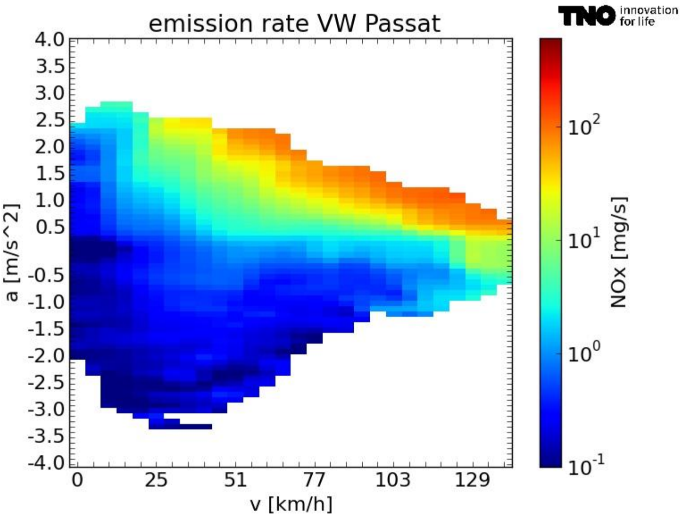


Figure 42 $NO_x$ emission rate [mg/s] of a VW Passat Euro 6 diesel in bins of velocity and acceleration

### *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<br>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 $CO_2$ 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

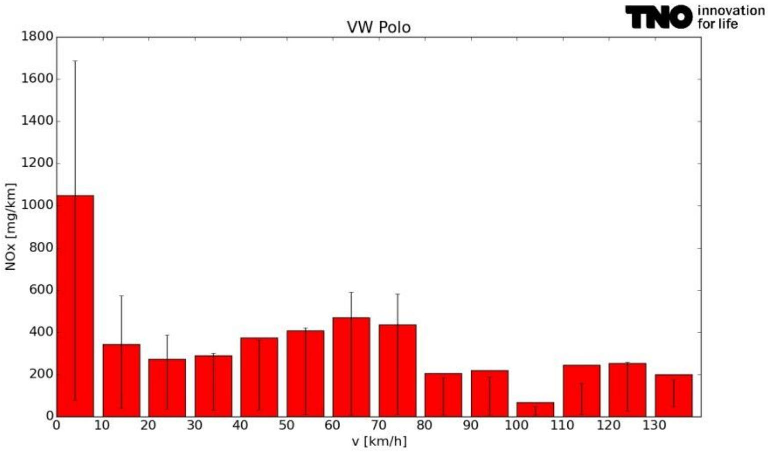


Figure 43 Average $NO_x$ emissions of a VW Polo Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

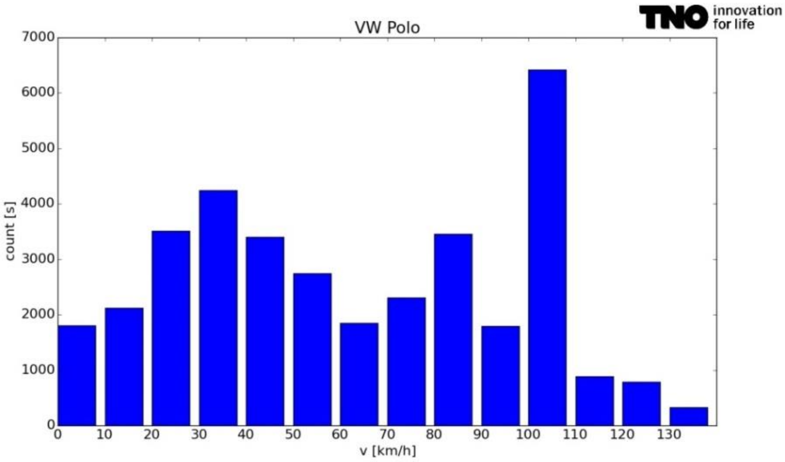


Figure 44 Number of seconds per velocity bin, over all trips. Idling is excluded.

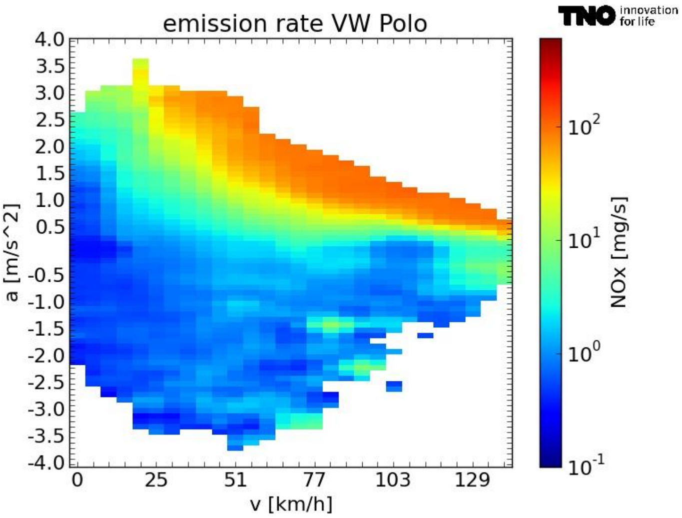


Figure 45 $NO_x$ emission rate [mg/s] of a VW Polo Euro 6 diesel in bins of velocity and acceleration

### *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 $CO_2$ 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 | $CO_2$ | $NO_x$ | NH3 |
|---|---|---|---|---|---|---|---|---|---|
| | [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].

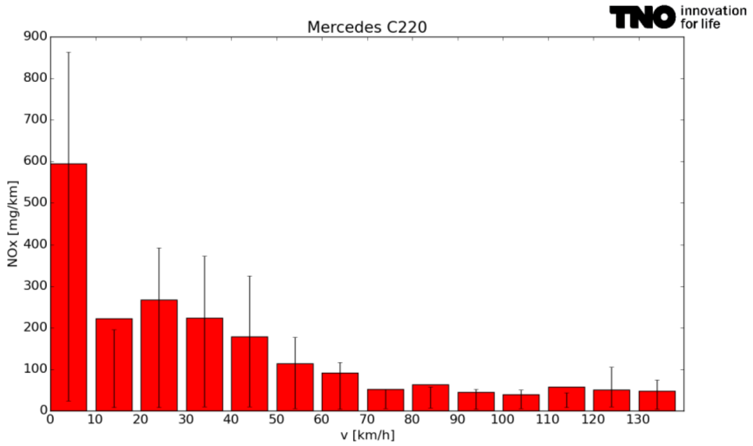


Figure 46 Average $NO_x$ emissions of a Mercedes C220 Euro 6 diesel per velocity bin for all trips. The error bars represent +/- one standard deviation from the median. Idling is excluded.

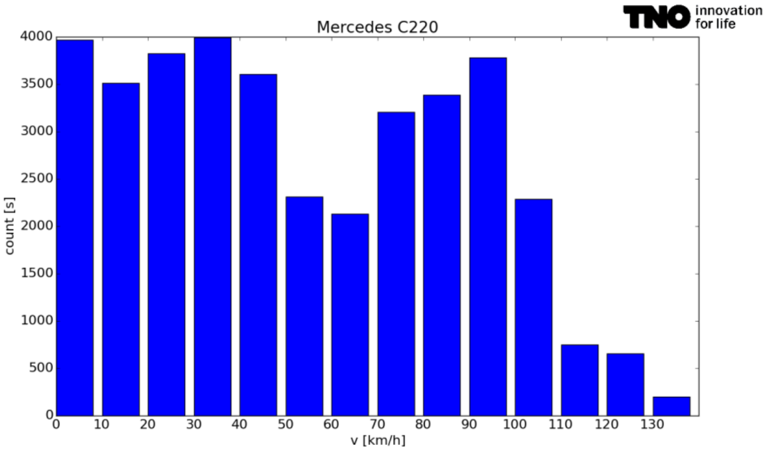


Figure 47 Number of seconds per velocity bin, over all trips. Idling is excluded.

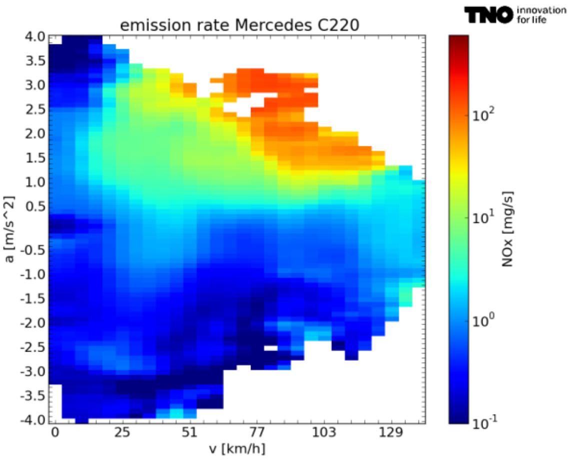


Figure 48 $NO_x$ emission rate [mg/s] of a Mercedes C220 Euro 6 diesel in bins of velocity and acceleration

## 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

| | | Normalised $NO_x$ emissions [mg/km] | | | |
|---|---|---|---|---|---|
| | Test temperature Range | 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 Meganes 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** | **Motorway** |
| **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 $v*a_{pos}$ and the average RPA. The parameter $v*a_{pos}$, 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 determined[2] 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.

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

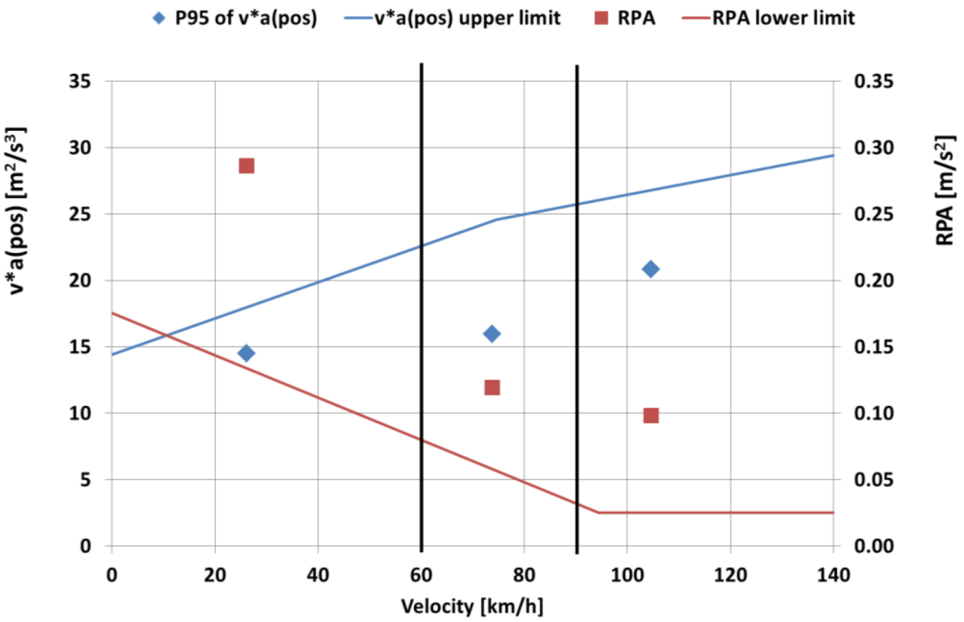

Figure 49 Values of driving dynamics parameters P95 of v*$a_{pos}$ and average RPA from one of the RDE trip performed at TNO compared to the RDE limits for P95 of v*$a_{pos}$ and average RPA.

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 ≤ v < 90 km/h) and motorway (v ≥ 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 $CO_2$ 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 $CO_2$ emission (in g/km) calculated from one of the many windows which are moved along the instantaneous $CO_2$ emission signal (in g/s). The black line represents the so called vehicle *$CO_2$ 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 $CO_2$ 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.

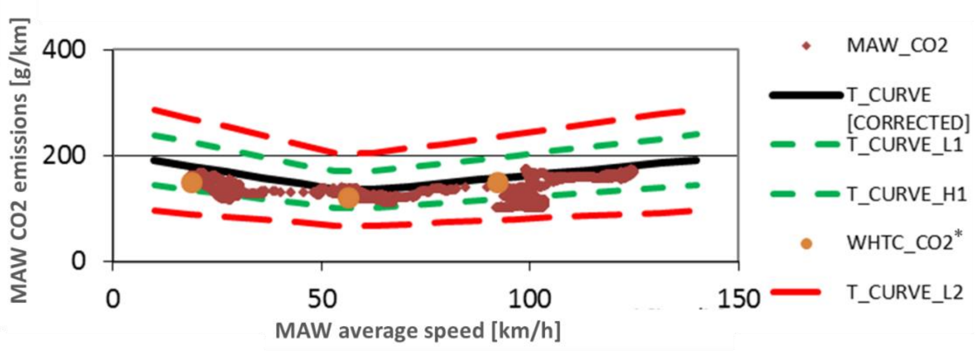

Figure 50 MAW $CO_2$ emission results (in g/km) for an RDE trip evaluated with EMROAD.
*) In output of EMROAD these points are incorrectly labelled. The correct label is WLTC_CO2.

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 software[3].

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%.

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[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.

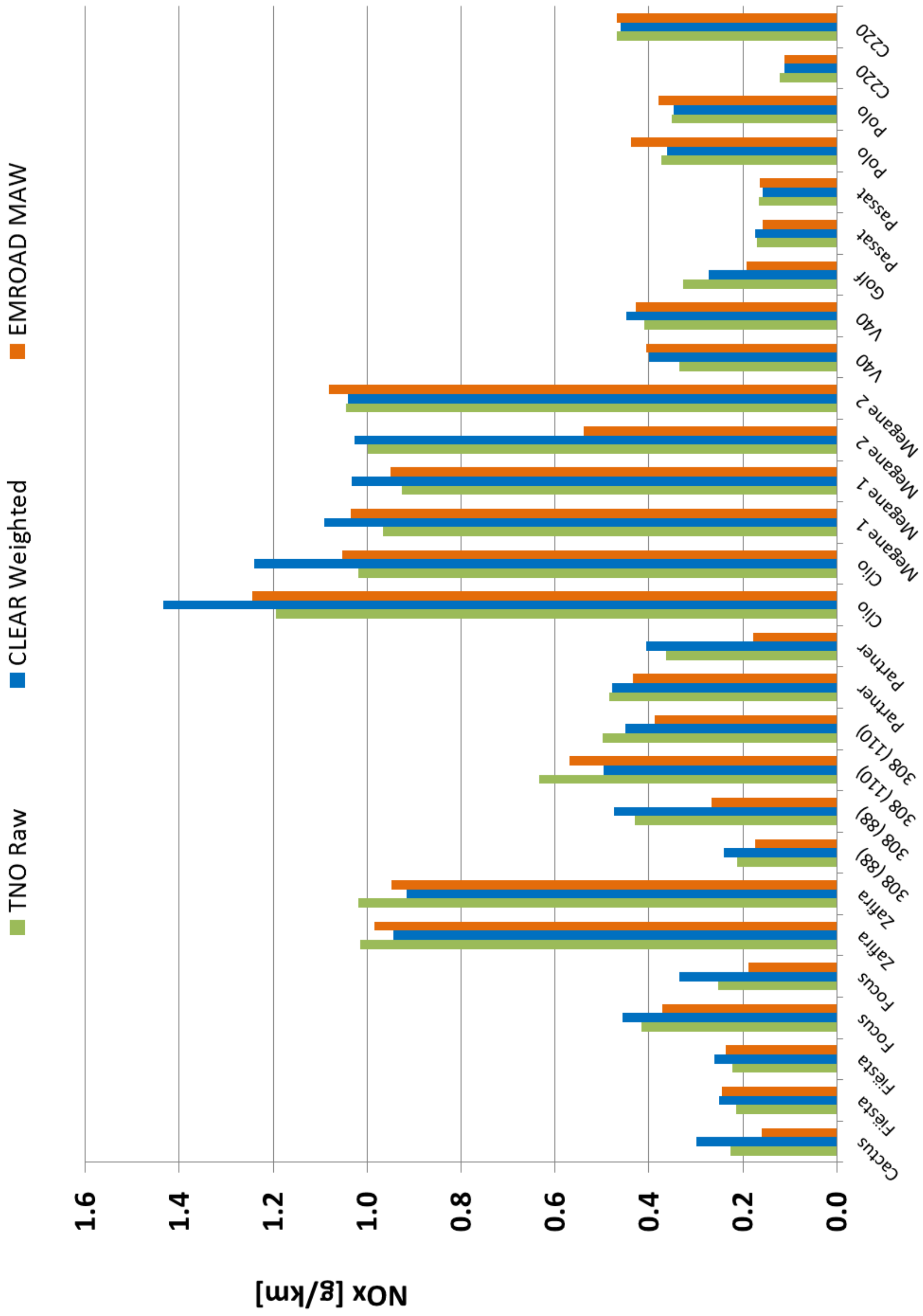


Figure 51 Raw and normalised (CLEAR Weighted and EMROAD MAW) **urban** $NO_x$ emissions (in g/km) for all 28 RDE trips.

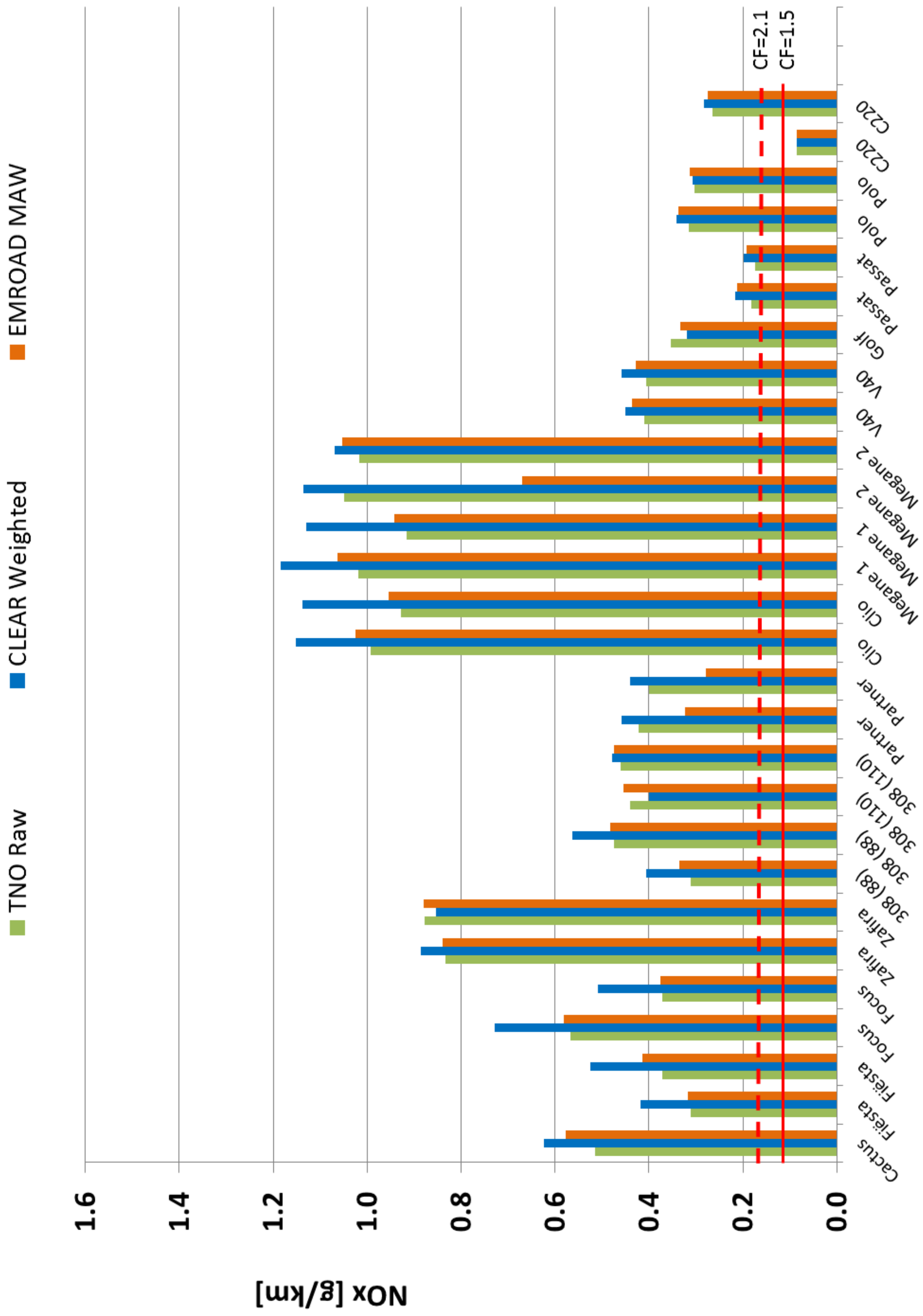


Figure 52 Raw and normalised (CLEAR Weighted and EMROAD MAW) **total trip** $NO_x$ emissions (in g/km) for all 28 RDE trips.

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%.

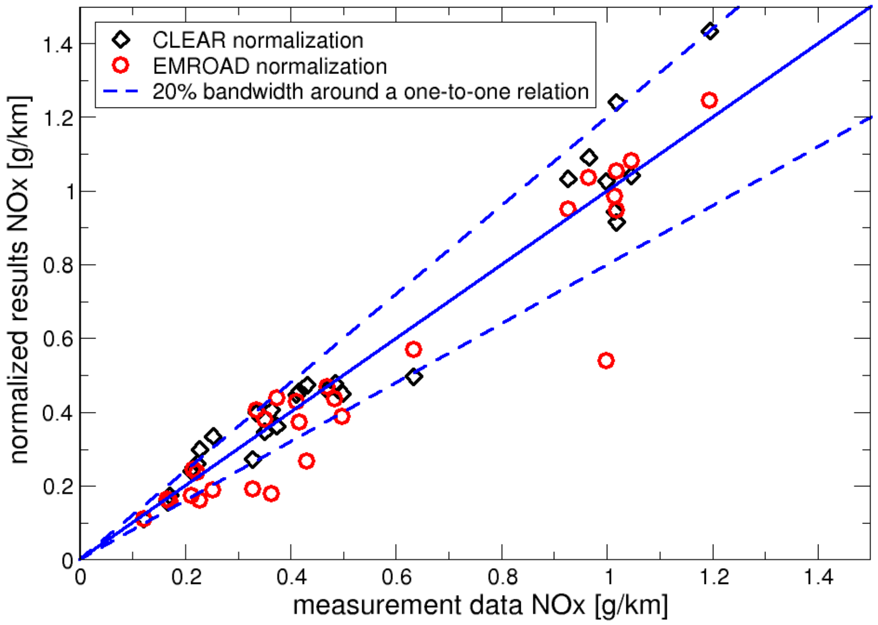


Figure 53 **Urban** $NO_x$ **emissions** (in g/km) after normalisation with CLEAR and EMROAD, as function of the raw $NO_x$ emission result (TNO values in g/km), for all 28 RDE trips.

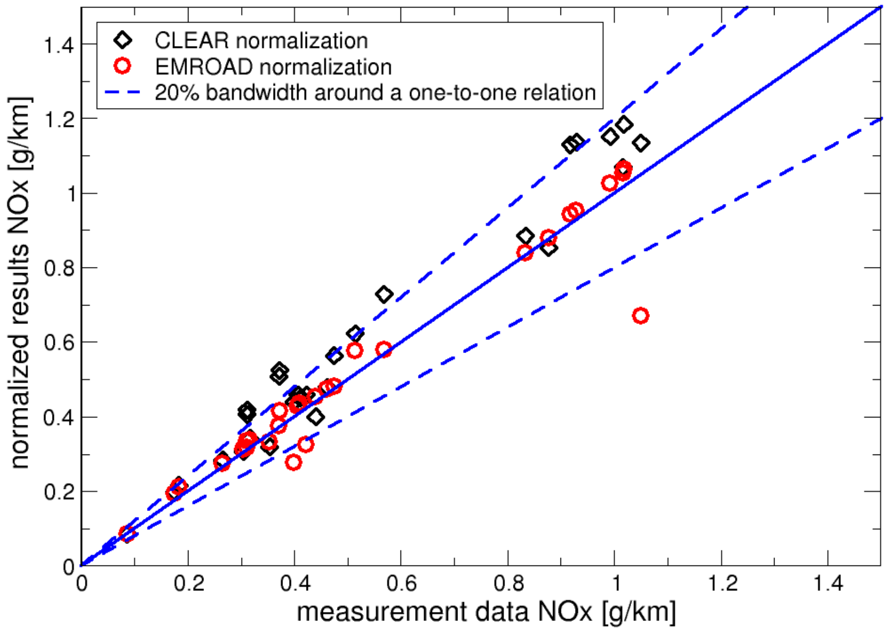


Figure 54 **Total trip** $NO_x$ emissions (in g/km) after normalisation with CLEAR and EMROAD, as function of the raw $NO_x$ emissions (TNO values in g/km), for all 28 RDE trips.

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.

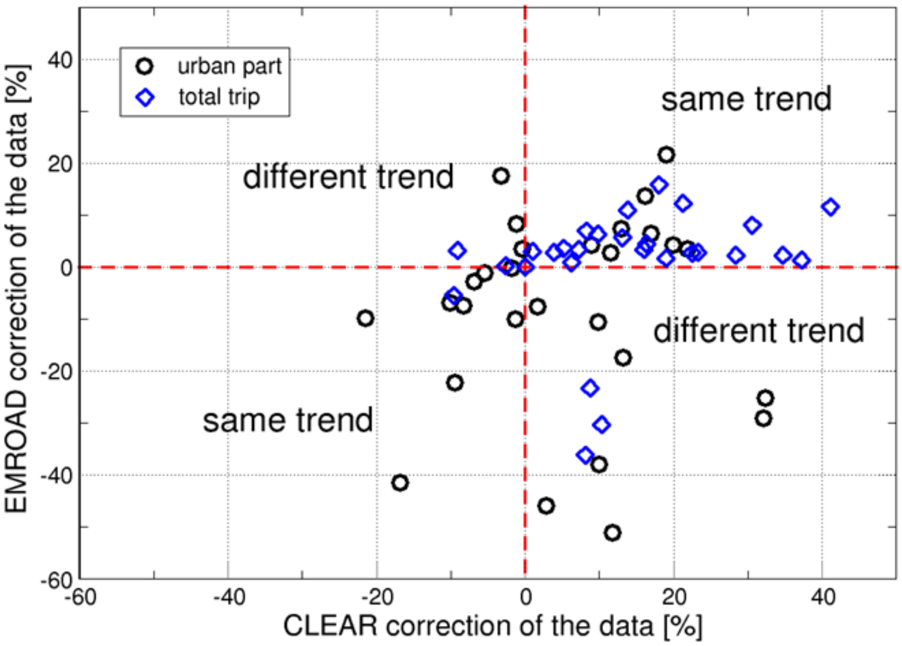


Figure 55 Relative correction of the $NO_x$ emissions as a result of normalisation with EMROAD (y-axis) and with CLEAR (x-axis), defined as 100*(Normalised_Value – Raw_Value_TNO)/Raw_Value_TNO %, for all 28 RDE trips.

# 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.

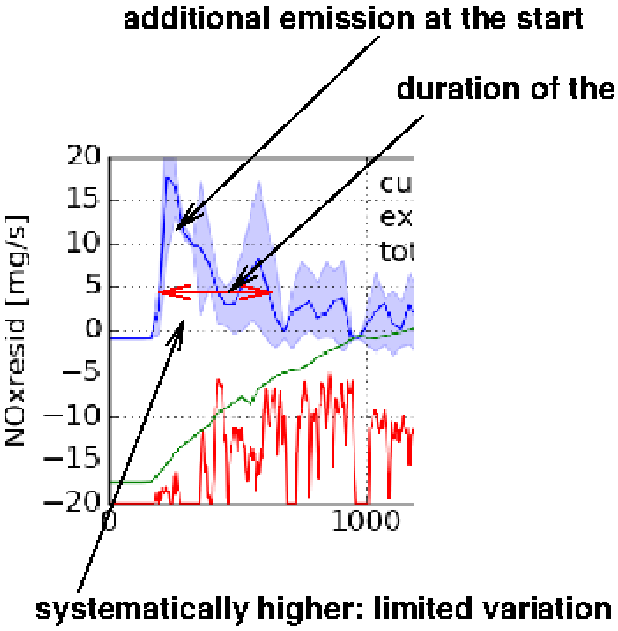
For the larger part, emissions are the result of the instantaneous driving behaviour: the velocity and acceleration of the vehicle and the required power demand from the engine. Emission models and emission legislation rely somewhat on this basic assumption. Different emission control strategies and 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.


**additional emission at the start**

**duration of the cold start**

**systematically higher: limited variation**

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.

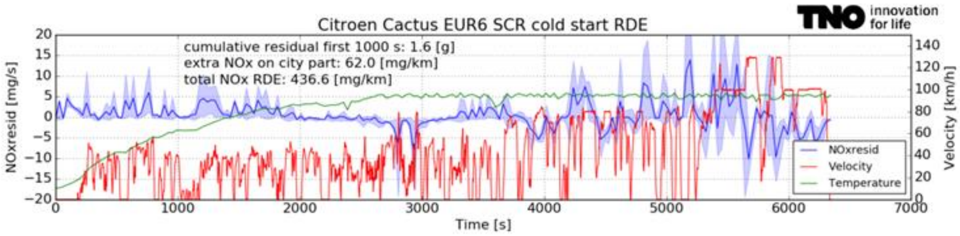
Table 38 The RDE trips with a cold start, with the additional emissions over 1000 s due to the cold start separated from the emissions associated with warm engine operation. In standard assumption the cold start last for 5 minutes. This yields a larger effect and different trends than the residual analysis.

| 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.


Citroen Cactus EUR6 SCR cold start RDE
TNO innovation for life
cumulative residual first 1000 s: 1.6 [g]
extra NOx on city part: 62.0 [mg/km]
total NOx RDE: 436.6 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
20
15
10
5
0
−5
−10
−15
−20
140
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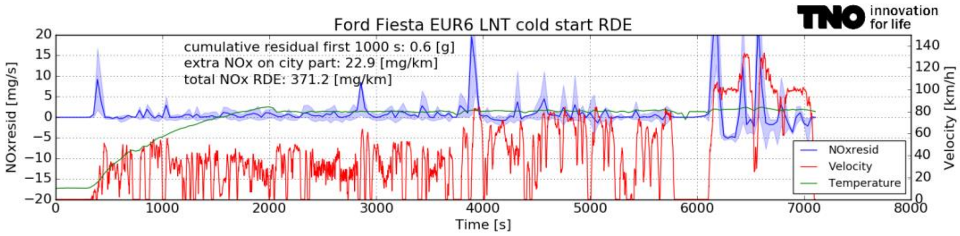
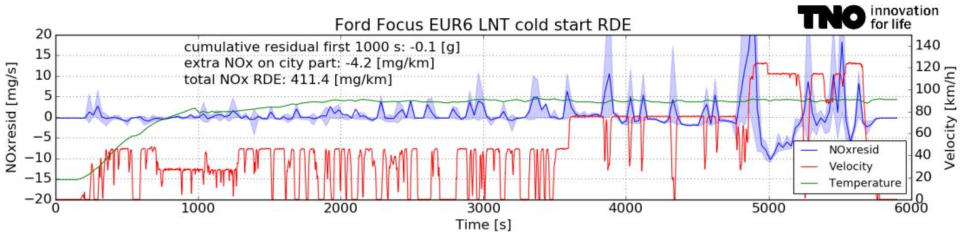
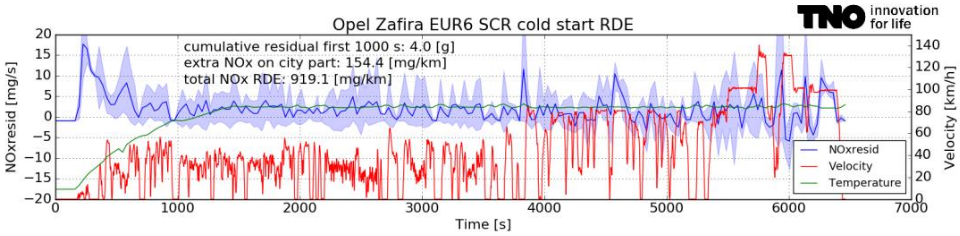
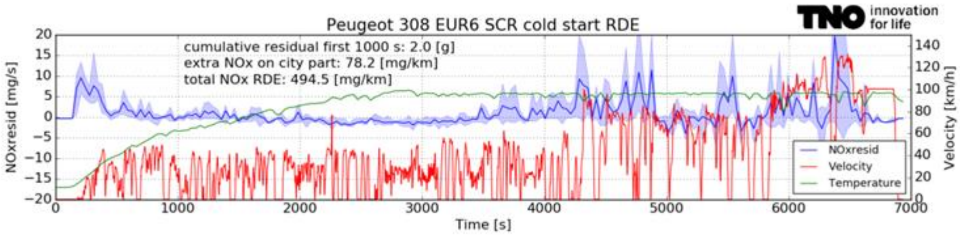
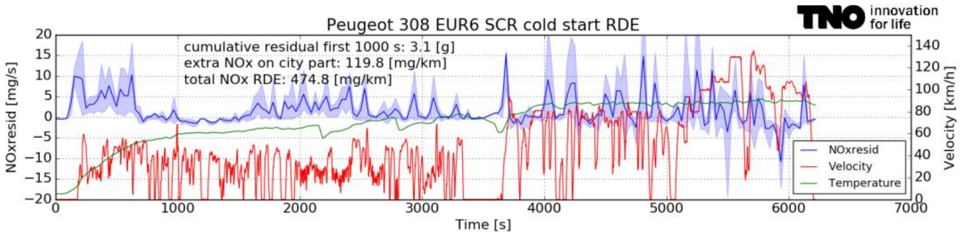
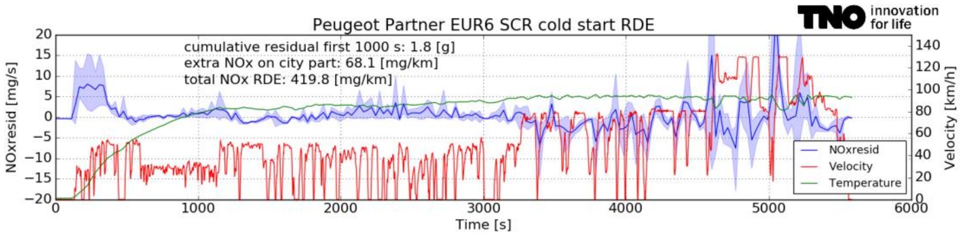

Ford Fiesta EUR6 LNT cold start RDE
TNO innovation for life
cumulative residual first 1000 s: 0.6 [g]
extra NOx on city part: 22.9 [mg/km]
total NOx RDE: 371.2 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
0
1000
2000
3000
4000
5000
6000
7000
8000

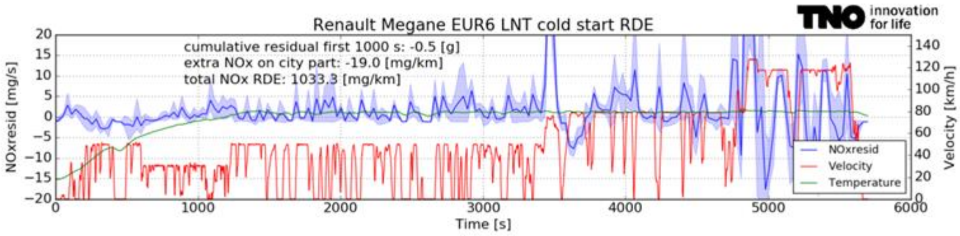

Ford Focus EUR6 LNT cold start RDE
TNO innovation for life
cumulative residual first 1000 s: -0.1 [g]
extra NOx on city part: -4.2 [mg/km]
total NOx RDE: 411.4 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
0
1000
2000
3000
4000
5000
6000

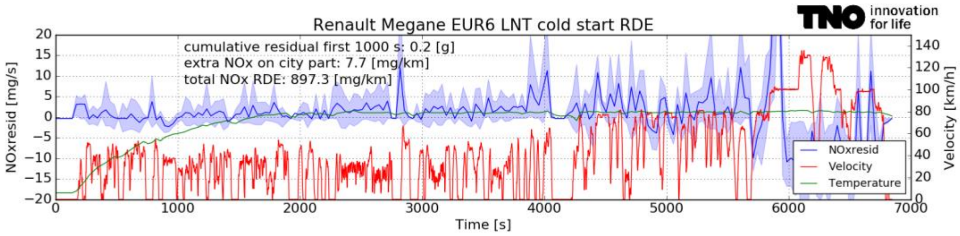

Opel Zafira EUR6 SCR cold start RDE
TNO innovation for life
cumulative residual first 1000 s: 4.0 [g]
extra NOx on city part: 154.4 [mg/km]
total NOx RDE: 919.1 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
0
1000
2000
3000
4000
5000
6000
7000

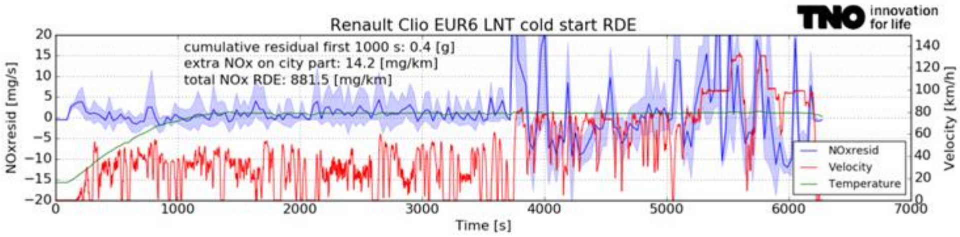

Peugeot 308 EUR6 SCR cold start RDE
TNO innovation for life
cumulative residual first 1000 s: 2.0 [g]
extra NOx on city part: 78.2 [mg/km]
total NOx RDE: 494.5 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
0
1000
2000
3000
4000
5000
6000
7000

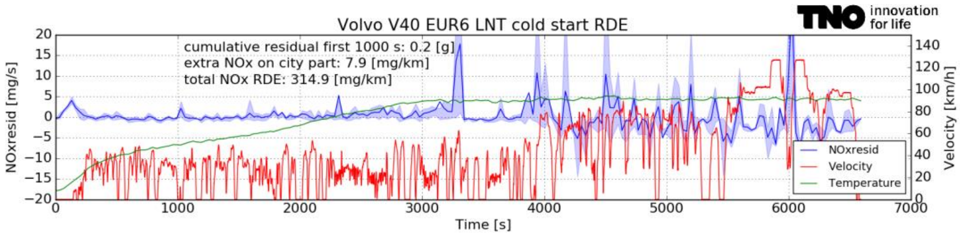

Peugeot 308 EUR6 SCR cold start RDE
TNO innovation for life
cumulative residual first 1000 s: 3.1 [g]
extra NOx on city part: 119.8 [mg/km]
total NOx RDE: 474.8 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
0
1000
2000
3000
4000
5000
6000
7000

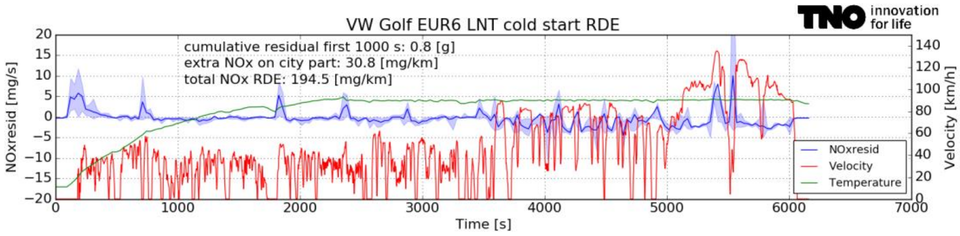

Peugeot Partner EUR6 SCR cold start RDE
cumulative residual first 1000 s: 1.8 [g]
extra NOx on city part: 68.1 [mg/km]
total NOx RDE: 419.8 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
20
15
10
5
0
−5
−10
−15
−20
140
120
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000


Renault Megane EUR6 LNT cold start RDE
cumulative residual first 1000 s: -0.5 [g]
extra NOx on city part: -19.0 [mg/km]
total NOx RDE: 1033.3 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
20
15
10
5
0
−5
−10
−15
−20
140
120
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000


Renault Megane EUR6 LNT cold start RDE
cumulative residual first 1000 s: 0.2 [g]
extra NOx on city part: 7.7 [mg/km]
total NOx RDE: 897.3 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
20
15
10
5
0
−5
−10
−15
−20
140
120
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000
7000


Renault Clio EUR6 LNT cold start RDE
cumulative residual first 1000 s: 0.4 [g]
extra NOx on city part: 14.2 [mg/km]
total NOx RDE: 881.5 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
20
15
10
5
0
−5
−10
−15
−20
140
120
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000
7000


Volvo V40 EUR6 LNT cold start RDE
cumulative residual first 1000 s: 0.2 [g]
extra NOx on city part: 7.9 [mg/km]
total NOx RDE: 314.9 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
20
15
10
5
0
−5
−10
−15
−20
140
120
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000
7000


VW Golf EUR6 LNT cold start RDE
cumulative residual first 1000 s: 0.8 [g]
extra NOx on city part: 30.8 [mg/km]
total NOx RDE: 194.5 [mg/km]
NOxresid [mg/s]
Velocity [km/h]
Time [s]
NOxresid
Velocity
Temperature
20
15
10
5
0
−5
−10
−15
−20
140
120
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000
7000

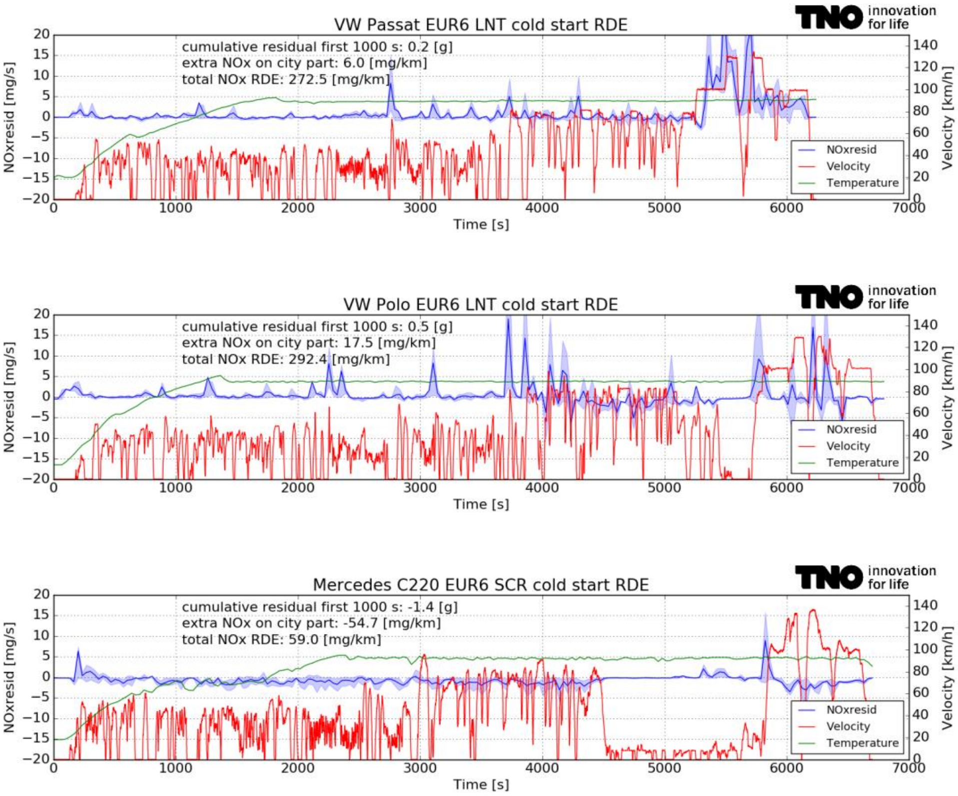


Figure 57 Plots of residual cold start analysis of fifteen tested vehicles

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 or their environmental performance. The current test temperatures lies well within the range of the most common ambient temperatures in the Netherlands. Hence it I 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 $CO_2$ 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 $CO_2$ and $NO_x$ emission results from SEMS with results obtained with the chassis dynamometer measuring equipment yields typical deviations of less than 2% for the accumulated $CO_2$ and up to 0-8% for $NO_x$ over a few trips.

It can therefore be concluded that the observed deviations between on-road and type approval $NO_x$ emissions of the tested Euro 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 $CO_2$ 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 $O_2/NO_x$ 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

[BDT 2016] Vehicle Emissions Testing Programme, Department of Transport, Cm 9252, April 2016.

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[EU 2016b] RDE-wetgeving Pakket-2, (CELEX_32016R0646_EN_TXT).pdf alias *“COMMISSION REGULATION (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)”*, pp. 22. URL: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0646&rid=3

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[ReFr 2016] Rapport final de la commission indépendante mise en place par la Ministre Ségolène Royal après la révélation de l’affaire Volkswagen, 29-07-2016.

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[TNO 2016b] Kadijk, Ligterink, and Smokers, *Preliminary insights into the relation between ambient temperature and* $NO_x$ *emissions of a Euro 6 Mercedes C220 with a diesel engine*, TNO report 2016 R11123.

[TNO 2016c] Cuelenaere and Ligterink, *Assessment of the strengths and weaknesses of the new Real Driving Emissions (RDE) test procedure*, TNO report 2016 R11227.

[TNO 2016d] Kadijk, Ligterink, van Mensch and Smokers, $NO_x$ *emissions of Euro 5 and Euro 6 diesel passenger cars – test results in the lab and on the road*, TNO report 2016 R10083.

# 9 Signature

Delft, 10 October 2016

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 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD | EMROAD |
| | Trade mark | Model | License | Speed | P95 VApos | P95 Valid | RPA | RPA Valid | Speed | P95 VApos | P95 Valid | RPA | RPA Valid | Speed | P95 VApos | P95 Valid | RPA | RPA Valid |
| | | | plate | km/h | m^2/s^3 | 0/1 | m/s^2 | 0/1 | km/h | m^2/s^3 | 0/1 | m/s^2 | 0/1 | km/h | m^2/s^3 | 0/1 | m/s^2 | 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 |

# B Normalised $NO_x$ emissions for all 28 RDE trips

| | | | | RDE NOx, Urban | | | | | RDE NOx, Total Trip | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | CLEAR | EMROAD | TNO | CLEAR | EMROAD | CLEAR | EMROAD | TNO | CLEAR | EMROAD |
| | Trade mark | Model | License | Raw | Raw | Raw | Weighted | MAW | Raw | Raw | Raw | Weighted | MAW |
| | 0 | | plate | g/km | g/km | g/km | g/km | g/km | g/km | g/km | g/km | g/km | g/km |
| | | | | | | | | | | | | | |
| 1 | CITROEN | Cactus | HG656N | 0.227 | 0.226 | 0.227 | 0.3 | 0.161 | 0.514 | 0.513 | 0.514 | 0.623 | 0.577 |
| 2 | FORD | Fiësta | GV011G | 0.216 | 0.215 | 0.215 | 0.25 | 0.244 | 0.312 | 0.311 | 0.311 | 0.419 | 0.318 |
| 3 | FORD | Fiësta | GV011G | 0.223 | 0.222 | 0.223 | 0.261 | 0.237 | 0.373 | 0.372 | 0.372 | 0.525 | 0.415 |
| 4 | FORD | Focus | GZ364X | 0.417 | 0.412 | 0.416 | 0.457 | 0.372 | 0.568 | 0.567 | 0.568 | 0.729 | 0.581 |
| 5 | FORD | Focus | GZ364X | 0.253 | 0.252 | 0.253 | 0.335 | 0.189 | 0.371 | 0.37 | 0.371 | 0.509 | 0.376 |
| 6 | OPEL | Zafira | 1THN81 | 1.014 | 1.012 | 1.014 | 0.945 | 0.985 | 0.833 | 0.832 | 0.833 | 0.885 | 0.84 |
| 7 | OPEL | Zafira | 1THN81 | 1.018 | 1.017 | 1.018 | 0.916 | 0.948 | 0.877 | 0.875 | 0.877 | 0.854 | 0.879 |
| 8 | PEUGEOT | 308 (88) | HV027G | 0.212 | 0.211 | 0.212 | 0.24 | 0.175 | 0.311 | 0.31 | 0.311 | 0.406 | 0.336 |
| 9 | PEUGEOT | 308 (88) | HV027G | 0.431 | 0.43 | 0.431 | 0.474 | 0.267 | 0.474 | 0.473 | 0.474 | 0.564 | 0.482 |
| 10 | PEUGEOT | 308 (110) | JB670L | 0.633 | 0.633 | 0.633 | 0.497 | 0.57 | 0.44 | 0.44 | 0.44 | 0.4 | 0.454 |
| 11 | PEUGEOT | 308 (110) | JB670L | 0.498 | 0.497 | 0.498 | 0.451 | 0.387 | 0.462 | 0.461 | 0.461 | 0.479 | 0.474 |
| 12 | PEUGEOT | Partner | VR134G | 0.484 | 0.484 | 0.484 | 0.478 | 0.435 | 0.422 | 0.421 | 0.422 | 0.459 | 0.324 |
| 13 | PEUGEOT | Partner | VR134G | 0.364 | 0.363 | 0.364 | 0.407 | 0.178 | 0.399 | 0.398 | 0.399 | 0.44 | 0.278 |
| 14 | RENAULT | Clio | HT999B | 1.195 | 1.193 | 1.195 | 1.434 | 1.245 | 0.992 | 0.991 | 0.992 | 1.151 | 1.025 |
| 15 | RENAULT | Clio | HT999B | 1.019 | 1.017 | 1.018 | 1.241 | 1.053 | 0.93 | 0.928 | 0.929 | 1.138 | 0.954 |
| 16 | RENAULT | Megane 1 | HH808B | 0.966 | 0.962 | 0.966 | 1.091 | 1.036 | 1.018 | 1.016 | 1.018 | 1.184 | 1.064 |
| 17 | RENAULT | Megane 1 | HH808B | 0.926 | 0.924 | 0.926 | 1.033 | 0.951 | 0.917 | 0.916 | 0.917 | 1.13 | 0.943 |
| 18 | RENAULT | Megane 2 | HH809B | 0.998 | 0.997 | 0.998 | 1.027 | 0.539 | 1.05 | 1.048 | 1.05 | 1.135 | 0.671 |
| 19 | RENAULT | Megane 2 | HH809B | 1.046 | 1.045 | 1.046 | 1.042 | 1.082 | 1.016 | 1.015 | 1.016 | 1.069 | 1.053 |
| 20 | VOLVO | V40 | HP449L | 0.335 | 0.334 | 0.335 | 0.399 | 0.407 | 0.41 | 0.409 | 0.41 | 0.45 | 0.436 |
| 21 | VOLVO | V40 | HP449L | 0.41 | 0.41 | 0.411 | 0.448 | 0.428 | 0.405 | 0.405 | 0.406 | 0.459 | 0.429 |
| 22 | VOLKSWAGEN | Golf | GZ910G | 0.328 | 0.327 | 0.328 | 0.273 | 0.192 | 0.353 | 0.353 | 0.353 | 0.319 | 0.334 |
| 23 | VOLKSWAGEN | Passat | 9ZLR55 | 0.171 | 0.171 | 0.171 | 0.174 | 0.158 | 0.183 | 0.183 | 0.183 | 0.216 | 0.212 |
| 24 | VOLKSWAGEN | Passat | 9ZLR55 | 0.166 | 0.165 | 0.166 | 0.157 | 0.164 | 0.174 | 0.174 | 0.174 | 0.198 | 0.193 |
| 25 | VOLKSWAGEN | Polo | 6ZGV28 | 0.374 | 0.374 | 0.374 | 0.362 | 0.439 | 0.316 | 0.316 | 0.316 | 0.342 | 0.338 |
| 26 | VOLKSWAGEN | Polo | 6ZGV28 | 0.352 | 0.351 | 0.351 | 0.347 | 0.38 | 0.304 | 0.303 | 0.304 | 0.307 | 0.313 |
| 27 | MERCEDES | C220 | 9TJS12 | 0.123 | 0.123 | 0.121 | 0.111 | 0.112 | 0.086 | 0.086 | 0.086 | 0.086 | 0.086 |
| 28 | MERCEDES | C220 | 9TJS12 | 0.469 | 0.469 | 0.469 | 0.461 | 0.468 | 0.265 | 0.264 | 0.265 | 0.284 | 0.274 |