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TNO report

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Emissions of five Euro 6d-Temp Light Duty diesel vehicles

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Samenvatting

Van emissiemetingen naar emissiemonitoring

In de afgelopen jaren zijn de eisen aan voertuigemissies en brandstofverbruik steeds verder aangescherpt. Hierdoor zijn de voertuigtechnologieën steeds complexer worden. De emissieprestaties van een voertuig zijn sterk afhankelijk van de werking van deze technologieën. Mede in het licht van dieselgate, zijn er in de loop der tijd nieuwe methoden ontwikkeld om de emissies van voertuigen op de weg te bepalen. De meest recente voertuigen, de zogenaamde Euro 6d-Temp (vanaf 2017) en Euro 6d[1] (vanaf 2020) voertuigen moeten zowel emissietests op de rollenbank als op de weg, de zogenaamde "Real Driving Emission" of RDE-test, doorstaan. De RDE-test is ingevoerd vanaf 2017; vanaf 2021 moeten alle nieuw ingeschreven voertuigen voldoen aan de Euro 6d emissiegrenswaarden voor RDE. De huidige RDE-methode bestaat uit een relatief kort emissietestprogramma dat in totaal enkele dagen in beslag neemt.

Emissiemonitoring kan worden gebruikt om een breder scala van normaal emissiegedrag van voertuigen te onderzoeken. Emissiemonitoring wordt gedefinieerd als het meten van emissies tijdens normaal gebruik, over een langere periode. Hierdoor kunnen ook langetermijneffecten, zoals seizoensgebonden effecten en onderhoudsintervallen, worden meegenomen. Het TNO ‘Smart Emission Measurement System’ (SEMS) is speciaal ontwikkeld voor emissiemonitoring.

In dit project zijn de werkelijke emissieprestaties op de weg (de ‘praktijkemissies’) van vijf dieselvoertuigen met Euro 6d-Temp technologieën onderzocht, zowel met de huidige RDE-methodologie als via emissiemonitoring.
Euro 6d wetgeving geldt vanaf 1 januari 2020, Euro 6d voertuigen waren daarom ook nog niet beschikbaar[2] voor dit meetprogramma dat grotendeels in 2019 en begin 2020 is uitgevoerd. De geteste Euro 6d-Temp voertuigen werden gedurende een periode van weken/maanden gemonitord en reden ca. tussen 2.300 en 6.400 km, voornamelijk in Nederland.

Hoewel de NO_x-emissies het belangrijkste aandachtspunt waren in deze studie, zijn ook CO_2-, NH_3- en N_2O emissies gemeten. De CO_2 emissies zijn, in het licht van deze studie, met name relevant omdat deze een goede indicator zijn voor de motorbelasting. NH_3- en N_2O-emissies zijn geen onderdeel van de huidige emissiewetgeving voor licht wegverkeer, maar hebben een belangrijke impact op het milieu. NH_3-emissies kunnen worden bepaald met SEMS maar N_2O-emissies kunnen alleen in het laboratorium betrouwbaar worden gemeten. Hiervoor zijn metingen uitgevoerd op een ‘chassis dynamometer’ (rollenbank) met één voertuig.

De resultaten van de emissietests zijn gedeeld met de betreffende fabrikanten en TNO heeft om terugkoppeling gevraagd. Indien ontvangen, en waar dit van invloed is op de interpretatie van de meetresultaten, zijn opmerkingen of aanvullende voertuiginformatie opgenomen in dit rapport.

[1] Euro 6d voertuigen moeten o.a. voldoen aan een strengere NO_x RDE-emissienorm vergeleken met Euro 6d-Temp

Resultaten en conclusies:
De meetresultaten die binnen het uitgevoerde testprogramma zijn verzameld, resulteren in de volgende hoofdconclusies:

De gemiddelde NO_x-emissieniveaus van de geteste Euro 6d temp voertuigen zijn laag, maar er worden grote variaties waargenomen.
De totale gemiddelde praktijk NO_x-uitstoot van alle geteste Euro 6d-Temp voertuigen bedroeg 35 tot 125 mg/km. Deze waarden liggen ruim onder de RDE NO_x-grenswaarden van (afhankelijk van de voertuig categorie) 168 of 262,5 mg/km. Tijdens korte ritten, harde acceleraties, hoge snelheden en DPF (roetfilter) regeneraties (die tijdens normaal gebruik plaatsvonden) konden emissies aanzienlijk hoger zijn. Zo lag bij één van de geteste voertuigen de NO_x emissie, gemeten tijdens een RDE rit waarbij ook een DPF regeneratie plaatsvond, 24% boven de emissielimiet voor dit voertuig.

RDE-ritten hebben een lage gemiddelde NO_x-emissie per rit in vergelijking met ritten bij normaal gebruik.
Voor alle voertuigen geldt dat een groot deel van de gereden ritten een hogere gemiddelde NO_x-emissie liet zien dan tijdens de geldige RDE-ritten. Bovendien werden grote variaties in de emissies op verschillende wegtypen niet altijd weerspiegeld in de RDE-gemiddelden. Voor sommige voertuigen waren de emissies als gevolg van langdurig stationair draaien significant, terwijl langdurig stationair draaien niet is toegestaan tijdens de RDE test.

RDE-ritten geven geen nauwkeurige weergave van hoe deze voertuigen kunnen presteren in normale rijsituaties op de weg.
Er zijn grote verschillen in de gemiddelde NO_x-emissies tussen de verschillende normale ritten die in het kader van het emissiecontroleprogramma zijn gereden. Onduidelijk is wat de redenen voor deze verschillen zijn. Tijdens 'RDE'-ritten werden geen buitensporige NO_x-emissieniveaus gemeten. Verschillende beladingen in combinatie met economische/normale/sportieve rijstijlen in 'RDE'-tests resulteerden in NO_x-emissies van 5 tot 159 mg/km voor alle geteste voertuigen. Ter vergelijking: het maximum van de NO_x-emissies van alle ritten, bij normaal gebruik, varieerde per voertuig van 250 tot meer dan 1.000 mg/km.

Vier van de vijf geteste voertuigen vertoonden een lage NH_3-emissie.
De gemiddelde NH_3-emissies van vier geteste voertuigen lagen tussen 0,9 en 1,5 mg/km, maar het vijfde voertuig had een gemiddelde NH_3-emissie van 21,7 mg/km. De gemeten NH_3-emissies laten duidelijk zien dat een lage NH_3-emissie mogelijk is met SCR-technologieën omdat de technologie beschikbaar en effectief is. Bovendien geven de cijfers aan dat NH_3-emissiegrenswaarden (zoals in de wetgeving inzake zware bedrijfswagens) nodig zijn om het risico van overmatige NH_3-emissies te vermijden.

N_2O meetresultaten verkregen tijdens metingen op de chassis dynamometer geven een indicatie voor verder onderzoek.
Bij het chassis dynamometer testprogramma van een Peugeot 308 zijn twee typen testcycli gebruikt, de WLTC (huidige test voor typegoedkeuring) en vier achtereenvolgende UDCs (de UDC is het stadsgedeelte uit de oudere NEDC typekeuringstest). Tijdens de UDC werd een N_2O-emissie van 77,3 mg/km gemeten.

Dit is het CO_2-equivalent van 23,0 g/km (+18% extra in de totale GHG-uitstoot, naast CO_2). Opgemerkt moet worden dat er slechts één dynamometer resultaat beschikbaar is. Gemiddeld bedroeg de N_2O-emissie voor de WLTC-tests ongeveer 3,8 g/km, CO_2-equivalent (+3%). De variatie in deze resultaten, inclusief de onverwacht hoge emissies in de stadstest, geeft aan dat er meer onderzoek nodig is met betrekking tot N_2O.

Met SEMS verkregen testresultaten zijn in lijn met die verkregen met de rollenbank (chassis dynamometer) in het laboratorium.
Een vergelijking van meetresultaten verkregen met het ‘Smart Emission Measurement System’ (SEMS) en die van rollenbank in het laboratorium toonde aan dat testresultaten zeer goed overeenkomen.

<u>Wat gebeurt er met de testresultaten?</u>
De resultaten worden doorgestuurd naar de Nederlandse typegoedkeurings-instantie (RDW). Verder zullen de testresultaten worden gebruikt voor een update van de Nederlandse emissiefactoren van wegvoertuigen.
Emissiefactoren worden gebruikt voor het modelleren van de luchtkwaliteit, het berekenen van stikstofdepositie en voor de internationale emissieregistraties. Emissiefactoren zijn op gegevens gebaseerde, gemiddelde, berekende emissies van specifieke voertuigcategorieën onder specifieke gemiddelde verkeersomstandigheden. De werkgroep Verkeer en Vervoer van de nationale emissieregistratie werkt deze emissiefactoren jaarlijks bij.
Tot slot worden de uit meetprogramma’s verkregen inzichten gebruikt om in Europees verband wetgeving en testprocedures met betrekking tot voertuigemissies verder te verbeteren.

Summary

From emission measurements towards emission monitoring

In recent years, the requirements on vehicle emissions and fuel consumption have become increasingly stringent. As a result, vehicle technologies are becoming increasingly complex. The emission performance of a vehicle is highly dependent on the operation of these technologies. Partly in the light of diesel-gate, new methods have been developed over time to determine on-road vehicle emissions. The most recent vehicles, so called Euro 6d-Temp (from 2017) and Euro 6d (from 2020) vehicles must pass both chassis dynamometer and on-road emission tests, the so called 'Real Driving Emission' or RDE test. The RDE test was implemented from 2017; from 2021 all new registered vehicles must comply with the Euro 6d final RDE emission limits. The current RDE methodology consists of a relatively short emission test programme that takes a total of several days.

Emission monitoring can be used to investigate a wider range of normal vehicle emission behaviour. Emission monitoring is defined as measuring emissions during normal use, over a longer period. This can also incorporate long term effects like seasonal effects and maintenance intervals. The TNO Smart Emission Measurement System (SEMS) has been specifically developed for emission monitoring.

During this project the real-world on-road emission performance of five diesel vehicles with Euro 6d-Temp technologies, using both the current RDE methodology, as well as via emission monitoring, has been investigated. Euro 6d legislation will apply from 1 January 2020, therefore Euro 6d vehicles were not yet available[3] for this measurement programme, which was largely carried out in 2019 and early 2020.The vehicles were monitored over a period of weeks/months and drove approx. between 2,300 and 6,400 km, mainly in the Netherlands.

Although NO_x emissions were the main focus of this study, CO_2, NH_3 and N_2O emissions were also measured. The CO_2 emissions are, in the light of this study, particularly relevant because they are a good indicator of engine load. NH_3- and N_2O-emissions are not part of the current emission legislation for light road traffic, but have an important impact on the environment. NH_3 emissions can be determined with SEMS but N_2O emissions can only be reliably measured in the laboratory. For this purpose, measurements have been carried out with a single vehicle, on a chassis dynamometer.

The emission test results were shared with the relevant manufacturers and TNO has asked for feedback. If received, and where it affects the interpretation of the measurement results, comments are included in this report.

[3] Euro 6d vehicles must, inter alia, comply with a more stringent NOx RDE emission standard compared to Euro 6d-Temp.

Results and conclusions:
The measurement results gathered within the performed test programme result in the following main conclusions:

Average NO_x emission levels are low, but large variations are observed.
The total average real-world NO_x emissions of all tested Euro 6d-Temp vehicles were 35 to 125 mg/km and well below the RDE NO_x limit values of (depending on the vehicle category) 168 or 262.5 mg/km. During short trips, hard accelerations, high velocities, and DPF regenerations (which occurred during normal use), emissions could be substantially higher. For example, for one of the vehicles tested, the NO_x emissions measured during a RDE trip that included a DPF regeneration was 24% above the emission limit for this vehicle.

RDE trips have low average NO_x emissions per trip compared to normal-use trips.
For all vehicles a large proportion of the trips driven had higher average NO_x emissions than the valid RDE trips .Furthermore, large variations in emissions on different road types were not always reflected in RDE averages. For some vehicles, emissions due to extended idling were significant, while extended idling is not tested for within RDE.

'RDE' trips are not an accurate representation of how these vehicles can perform in normal on-road driving situations.
There are large differences in average NO_x emissions between the various normal trips made under the emission monitoring programme. It is unclear what the reasons for these differences are. During 'RDE' trips, no excessive NO_x emission levels were measured: different loads combined with economic/regular/sportive driving styles in 'RDE' tests resulted in NO_x emissions of 5 to 159 mg/km for all tested vehicles. For comparison, the maximum NO_x emission of all normal-use trips ranged from 250 to over 1,000 mg/km per vehicle.

Four out of five tested vehicles showed low NH_3 emission levels.
The average NH_3 emissions of four tested vehicles were in the range of 0.9 to 1.5 mg/km but the fifth vehicle had an average NH_3 emission of 21.7 mg/km. The measured NH_3 emissions clearly show that low NH_3 emissions are possible with SCR technologies because the technology is available and effective. Furthermore, the numbers indicate that NH_3 emission limit values (like in heavy-duty emission legislation) are needed to avoid the risk of excessive NH_3 emissions.

N_2O measurements on chassis dynamometer signpost need for further investigation.
During the chassis dynamometer test programme of a Peugeot 308 two types of test cycles were applied, the WLTC (current type approval test) and four consecutive UDCs (the UDC is the urban part from the older NEDC type approval test). During the UDC test a N_2O emission of 77.3 mg/km was measured. This is the CO_2 equivalent of 23.0 g/km (+18% extra in the total GHG emissions next to CO_2). It should be noted that only one UDC result was available.
On average for the WLTC tests, N_2O emissions were around 3.8 g/km, CO_2 equivalent (+3%). The variation in these results, including the unexpectedly high emissions in the urban test, indicates that more research is needed with regards to N_2O.

SEMS test results in line with chassis dynamometer test results.
The comparison of measurement results obtained with the Smart Emission Measurement System (SEMS) and those obtained with the chassis dynamometer in the laboratory showed that test results match very well.

What happens with the test results?
The results will be forwarded to the Dutch Type Approval Authority (RDW). Furthermore the test results will be implemented in an update of the Dutch emission factors of vehicles which are used for modelling of air quality and the international emission registrations. Emission factors are data based, average calculated, emissions of specific vehicle categories under specific average traffic conditions. The taskforce Traffic and Transport of the national emission registration updates these emission factors yearly. Finally, the insights gained from measurement programmes will be used to further improve legislation and test procedures relating to vehicle emissions at European level.

Contents

1 Introduction

This report presents results of emission tests carried out by TNO in the period spring 2019 - spring 2020. The tests focussed on emissions of in-use, Euro 6d-Temp and Euro 6d diesel vehicles. The emission tests were carried out as part of an in-use-compliance light duty project for the Dutch Ministry of Infrastructure and Water Management.

With this report TNO intends to provide clarity and understanding on the measured data and what the results do and do not imply. TNO and the Dutch Ministry of Infrastructure and Water Management aspire to provide maximum transparency on the information that feeds into policy decisions regarding air quality and emission legislation.

Results of the emission measurements with two Euro 6b vehicles were published in an earlier stage [TNO 2020]. It was decided to test an additional set of Euro 6d-Temp diesel vehicles. The current report presents the measurement results of these five Euro 6d-Temp vehicles.

1.1 Context

1.1.1 Euro emission standards

The European Commission introduced the Euro emission standards in 1992 to minimize air pollutant emissions of light-duty vehicles. These standards have become more stringent over the years. Currently produced light duty vehicles of categories M and N must comply with the Euro 6d-Temp standard.
The Euro 6d-Temp standard was implemented from 01-09-2017, and has had several iterations (see Figure 1-1 and Figure 1-2). The Euro 6d final standard, that further lowers emission limits, was implemented from 01-01-2020 and will become mandatory for all registered M1 class vehicles in 2021. It is likely that as of 2025 a new Euro standard will be introduced, but the details of what this shall entail is still under consultation.

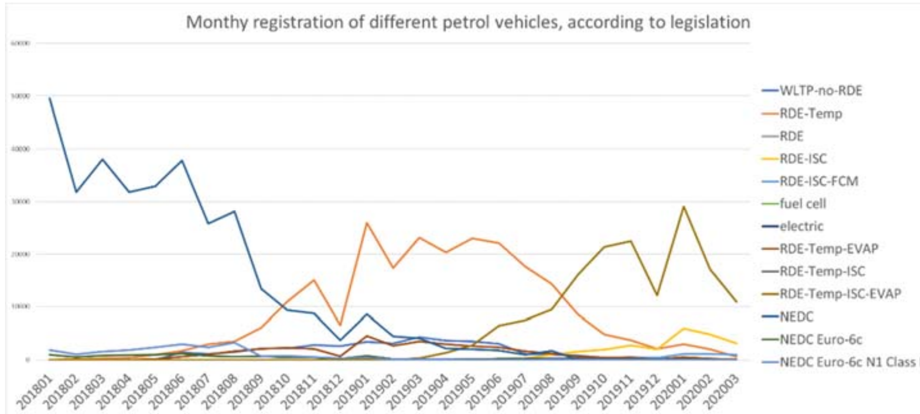

Figure 1-1: Evolution of the Dutch vehicle fleet as indicated via monthly registrations of Euro 6 petrol passenger cars. The separate iterations of Euro 6 are prefixed by their testing regime in the caption. Three main features can be observed: the decrease in the number of registrations of Euro 6 vehicles based on NEDC type approval, the increase and subsequent decrease of the first iteration of Euro 6d-Temp based on RDE (RDE-Temp), then the increase (and probable decrease) of 6d-Temp-ISC-EVAP (RDE-Temp-ISC-EVAP). In yellow, the increasing share of 6d-ISC (RDE-ISC) is shown from July 2019.

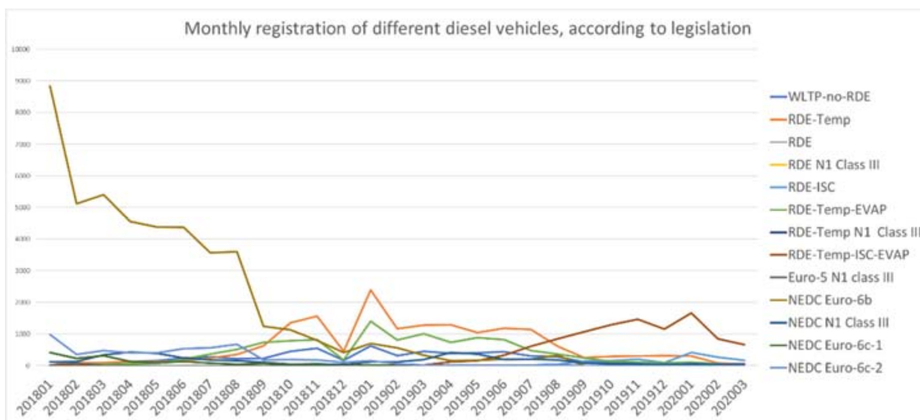

Figure 1-2: Evolution of the Dutch vehicle fleet as indicated via monthly registrations of Euro 6 diesel passenger cars and vans. The separate iterations of Euro 6 are prefixed by their testing regime in the caption. As for petrol vehicles, three main features can be observed: the decrease in the number of registrations of Euro 6 vehicles based on NEDC type approval (NEDC Euro-6b), the increase and subsequent decrease of the first iteration of Euro 6d-Temp based on RDE (RDE-Temp and RDE-Temp-EVAP), then the increase (and probable decrease) of 6d-Temp-ISC-EVAP (RDE-Temp-ISC-EVAP). In light blue, the share of 6d-ISC (RDE-ISC) is shown, which has a small initial increase per 01-01-2020.

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

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

As a result of the Euro emission standards, the pollutant emissions of light-duty vehicles, passenger cars and vans, as observed in type approval tests have reduced significantly over the past decade. However, under real driving conditions some emissions substantially deviate from their type approval values.

1.1.2 *6d-Temp vehicles are the first to be tested within RDE legislation*

The Real Driving Emission (RDE) test procedure was introduced with the Euro 6d-Temp standard. This procedure was developed as a response to increasing differences between vehicle emissions as indicated by laboratory tests, and real-world vehicle emissions. RDE is performed on-road, and includes urban, rural and motorway sections, which allows for a much larger range of driving conditions. However there are still a number of driving situations that are not accounted for within RDE (Figure 1-3), including common situations such as short trips and aggressive acceleration. Furthermore, the mileage limit for in-service conformity within RDE is only 100 000 km (i.e., conformity to emission limits is only required for the first 100 000 km of use) and does not account for different levels of maintenance. Typical total lifetime distance of a diesel vehicle are 300,000 kilometres or more.

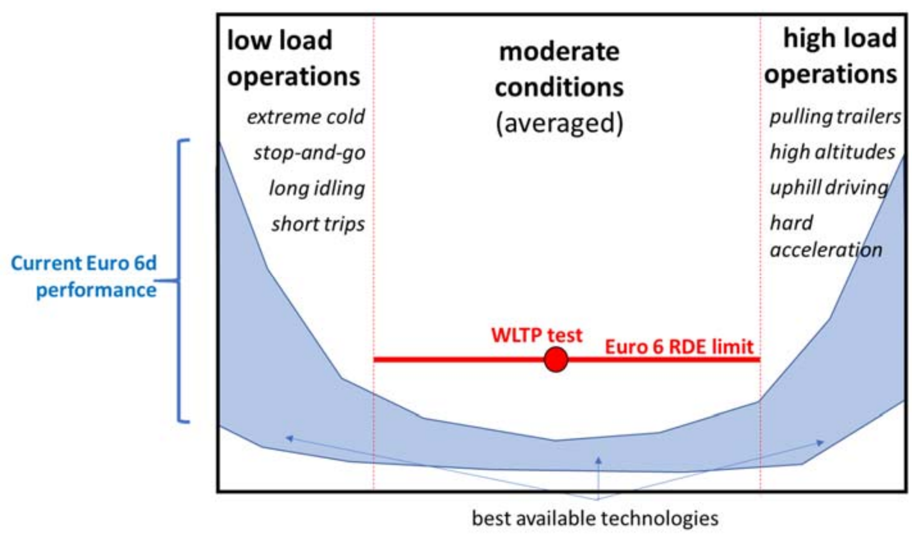

Figure 1-3: Graphic representation of current Euro 6d vehicle performance (blue band) in the context of RDE testing. The WLTP laboratory test is a very specific subset of moderate driving conditions (as indicated by the red dot). Comparatively, the RDE test addresses a much wider range of driving conditions (as shown by the red line), though these conditions could still, on average, be described as moderate. The current RDE testing procedure does not test for low load (such as extreme cold, stop-and-go traffic, long periods of idling, or short trips) or high load (e.g. pulling trailers, driving at high altitude, driving uphill, or hard acceleration) operations.

1.1.3 *High levels of nitrogen-based emissions are mainly due to poor real-world vehicle performance*

The real driving emissions of nitrogen oxides, or NO_x, from diesel vehicles are the most important issue with regard to pollutant emissions, as many cities fail, or long failed, to satisfy the NO_2 air-quality standards mainly through the poor real-world performance of diesel cars.[4] As NO_x represents the sum of NO and NO_2 emitted, and much of the NO is converted to NO_2 in ambient conditions, reducing NO_x emissions of vehicles is important for bringing down the ambient air NO_2 concentration in cities.

In the Netherlands, the ambient NO_2 concentration still exceeded European limits at 26 urban road-side locations monitored by the National Air Quality Cooperation Programme (NSL) in 2019[5]. NO_2 also contributes to the nitrogen deposition in nature, leading to eutrophication. The Council of State ruled that there is insufficient care to prevent and reduce eutrophication in designated nature areas. This is based on a combined effect of NH_3 and NO_2 emissions. TNO has taken this problem on board and has been measuring NH_3 emissions during monitoring for SCR equipped vehicles for several years now.

Even though they can contribute significantly to environmental problems, neither NH_3 nor the greenhouse gas N_2O are accounted for within current RDE legislation.

1.1.4 *Annual in-use compliance emission measurements performed by TNO have been the foundation of Dutch emission factors since 1987*

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

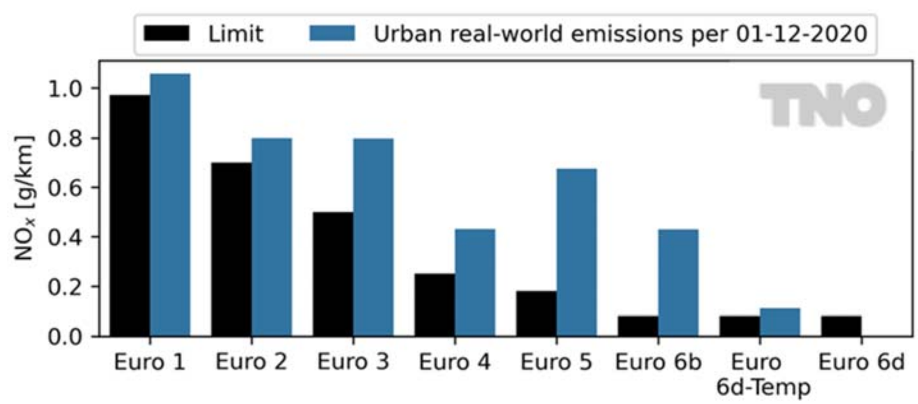

Figure 1-4: NO_x Emission factors for urban traffic and type approval limit values of Euro 1-6 diesel M1 & N1 Class 1 vehicles for the Dutch air-quality assessments (Euro 6d emission factors are not yet available).

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[4] http://www.platformparticipatie.nl/projecten/alle-projecten/projectenlijst/aanpassing-nationaal-samenwerkingsprogramma-luchtkwaliteit-2018/index.aspx
[5] http://atlasleefomgeving.nl/en/meer-weten/lucht/stikstofdioxide

The urban real-world emission factors, or average emissions for real world use of this group of vehicles are typically above the type-approval limit. The current 2020 emission factors are given in Figure 1-4. One should note that urban emissions are substantially higher than rural and motorway emissions. This is partially due to cold start contributions. For urban driving it is estimated that for every 7 kilometres of driving one cold start occurs.[6]

TNO is one of the few institutes in Europe that performs independent emission tests. Based on the results of performed emission tests, TNO develops, and annually updates, Dutch vehicle emission factors that represent the average real-world emissions data for specific various vehicle types categories under different driving and traffic conditions.

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

1.2 Aim and approach

The aim of the project was to assess the real-world emission performance of diesel vehicles with Euro 6d-Temp technologies and to provide input for generating emission factors for this vehicle category.

Four weaknesses of the RDE procedure were mentioned earlier:

1. only moderate driving conditions, in a long, ordered trip, with limited idling
2. a low mileage limit for in-service conformity
3. no allowance for various quality levels of maintenance and replacement parts
4. the pollutants NH_3 and N_2O are not yet included.

We address two of these weaknesses in our assessment of real-world emission performance by investigating driving styles that fall outside the boundaries of “moderate”, as well as NH_3 and N_2O emissions. The effects of Points 2 and 3 still form significant knowledge gaps.

In order to achieve the aim, emissions of five Euro 6d-Temp vehicles (Volvo XC60, Peugeot 308, Skoda Octavia, Mercedes B180, Renault Master) were measured on-road. Measurements were also taken on a chassis dynamometer with one of these vehicles. Particulates and N_2O emissions can now only be measured reliably in a laboratory.

[6] See report: CBS Methods for calculating emissions of transport in the Netherlands, 2017.

1.3 TNO policy with respect to publication of data

TNO takes the care in generating reliable data and in communication on the findings of its studies to the various stakeholders. Great care has been taken in carrying out the tests and in solving any problems that may have arisen.

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

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

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 present test results with references to makes and models. This decision also meets a desire expressed by the Dutch Ministry of Infrastructure and Water Management.
By presenting results from the complete sample of vehicle models tested, covering a wide range of makes and models, and by providing the necessary background information on test procedures and test conditions as well as caveats with respect to what can be concluded from these data, the test results on individual vehicle models are presented in a context that allows a well-balanced interpretation of the meaning of the results.

Finally, 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 Structure of the report

Further information with regards to the Real Driving Emission testing procedure is given in Chapter 2. A discussion of the measured real-world driving emissions with respect to on-road driving conditions is given in Chapter 3.

Chapter 4 presents an overview of NH_3 and N_2O emissions, followed by conclusions and discussion in Chapter 5. Chapter 6 gives further recommendations, and closing remarks are given in Chapter 7.

The measurement programme and its results are described and analysed in detail in Appendix A. All test results of the individual vehicles as well as the specification of the chassis dynamometer as used during the tests with one of the vehicles are also part of the Appendices.

2 RDE legislation

2.1 The paradigm shift of RDE legislation

With RDE legislation the first step is taken from self-certification of the manufacturer witnessed by the type-approval authority (the old-fashioned approach to type-approval) to independent control of emission performance. Key elements therein are the possibility, and in some cases obligation, of a) independent parties to test a car, and b) the Granting Type Approval Authority (GTAA) to investigate issues with non-compliance. The freedom to test on the road is central to this control. RDE testing is restricted by boundaries; by design the RDE test represents a supposed “average” of vehicle use.

2.2 Restrictions of the RDE test

The type-approval legislation is based on a lack of trust and the possibility of appeal, audit, or jurisprudence. Therefore, the legislation is intended to cover all possibilities and to be fair to all parties. The result is hundreds of pages of protocols and restrictions, forcing the RDE test to follow a very strict procedure. This strict procedure limits the original intention of freedom to test on-road. Some limitations have been removed in later stages, as it turned out it was quite difficult to meet all the criteria set in the regulation [TNO 2017c] but executing a valid RDE test is still not simple, and therefore vehicle operation relevant to normal driving may be limited.

However, more important are the restrictions of the RDE test hard-wired into the current procedure: [TNO 2016c, TNO 2017b]

1. An RDE test is very long, typically 90 - 120 minutes.
2. An RDE test is prescribed with urban, rural and motorway shares, each with a minimum distance of 16 kilometres and defined minimum or maximum speeds or a speed interval.
3. An RDE test cannot contain longer periods of idling.
4. The amount of hard accelerations is limited. This restricts the amount of overtaking on rural roads and accelerating onto the motorway.
5. The pulling of trailers, uphill driving, high velocities above 145 km/h, are all restricted or excluded.
6. The fuel consumption on parts of the tests needs to approximately meet the fuel consumption in the laboratory WLTP test.
7. Only the urban part and the whole trip averages are reported and evaluated.

All these elements generate a gap between normal vehicle use and vehicle operation in the RDE test.

In the RDE legislation there is much attention for driving style and vehicle weight as key elements affecting the emission performance. It was intended that robust NO_x emission control would include an SCR system; the lessons learnt from heavy duty vehicles suggest that driving style and vehicle weight are the wrong focus with SCR on board.

A focus on high engine load was needed to ensure appropriate technology for emission control for the high engine loads not covered by the NEDC and the WLTP. However, with SCR now generally included in Euro 6d-Temp vehicles, the problems with NO_x emissions shift, for example, to low load and situations with a lot of idling.

2.3 RDE test results are not real-world emission performance

Many laboratories do only RDE tests and observe low NO_x emissions. This, in part, is used in the emission factors and air-quality prognoses that are therefore overly optimistic. Since RDE legislation is also the basis of vehicle design and optimization, this will naturally give a lower result than normal operation. Of course one can execute tests intended to generate high emissions, but for the moment the most important question for air-quality is the difference between RDE and real-world emission in normal use. This has been central to the approach of TNO.

Vehicles with NO_x emission monitoring devices were used in normal use to provide an indication of the emissions in normal use. This provides an answer to the differences between RDE tests and real-world emission, but not necessarily an explanation of this difference. The explanation can be any of the items discussed above, or any other that are implicit in the differences between normal use and RDE tests.

With more, and more complex, emission control technology, the emission behaviour moves further away from the deterministic relation with underlying driving parameters, like engine torque and speed. The need to have representative vehicle use, or monitoring, rather than only representative driving in emission testing, is great. This has been an ongoing trend, in which TNO has taken the lead for many years. It does not necessarily provide much technical understanding of the problems with modern vehicles, but it sets the real-world emissions in an appropriate coverage of representative usages central to the impact of vehicles on the environment.

3 Real-world emissions can vary greatly dependent on driving situations

The RDE testing procedure was set up to form a better representation of how vehicles are used on-road than previously used chassis dynamometer tests in the laboratory. However, as outlined in Chapter 2, there are several boundary conditions which must be met when driving a true RDE test. The on-road testing programme performed by TNO consisted of two parts: an emission test on defined routes, and emission monitoring phase (for full details see Appendix A). Note that most emission tests did not meet RDE boundary conditions due to starting with a warm engine, for this reason they are collectively referred to 'RDE' (RDE between quotes) trips in the text. The distinction is made between the valid (meeting all RDE boundary conditions) and invalid RDE trips where relevant.

In this section the real-world emission performance are examined of the five 6d-Temp diesel vehicles in the context of driving conditions and driving style. It is also highlighted how the 'RDE' trips relate to the trips driven during the monitoring phase. For further details, such as total distances driven with each vehicle and total average emissions, see Section A.2.1 in the Appendix.

The following five 6d-Temp diesel vehicles are tested, see Appendix A for more detailed information:

- Volvo XC 60
- Peugeot 308
- Skoda Octavia
- Mercedes B180
- Renault Master.

3.1 Emission monitoring allows for emission measurements during normal vehicle use

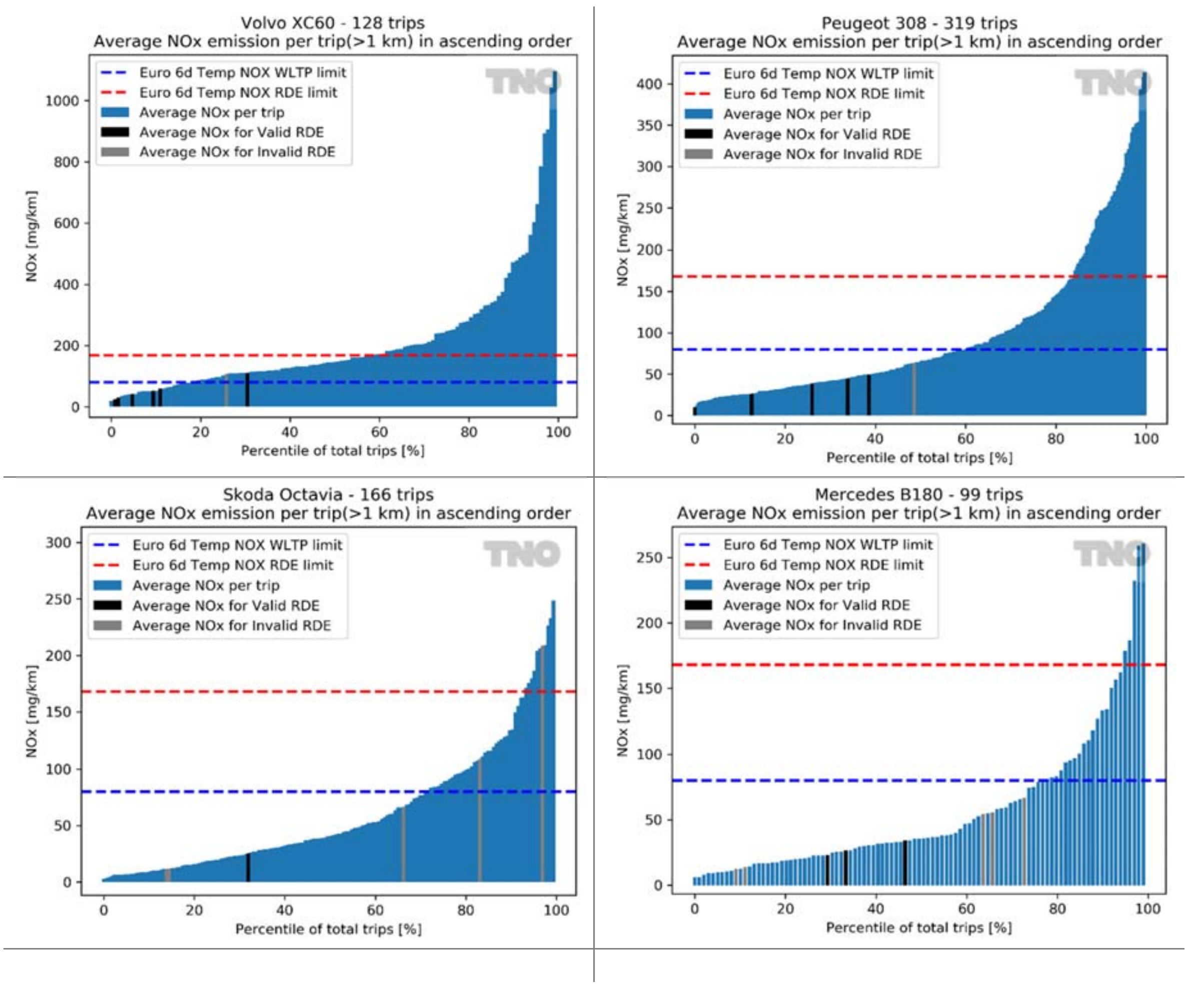
During the emission monitoring phase, vehicle emissions were measured during normal on-road use. This included both short and long trips, throughout the Netherlands and abroad. Note that this did not include any extreme driving; all trips were performed by TNO employees taking part in surrounding traffic.
The measurement methods used during the on-road testing programme are described in detail in the TNO methodology report [TNO 2016a]. A comparison between the on-road measurement system Smart Emission Measurement System (SEMS) with chassis dynamometer (Section A.2.3.3 in the Appendix) further corroborates the validity of SEMS as an accurate on-road measurement system.

3.2 RDE trips do not significantly challenge modern passenger vehicles

In Figure 3-1 the average NO_x emissions for every trip longer than 1 km are shown, for each vehicle. These trips are sorted by their average NO_x emissions, such that the lowest average NO_x is the 0^{th} percentile, and the trip with the highest NO_x the 100^{th} percentile. Most of the trips by the five vehicles have average NO_x emissions lower than the Euro 6d-Temp RDE limit: in the case of the Volvo XC60 around 40% of trips have higher average emissions, while for the Peugeot 308 a little less than 20% of trips have higher average emissions.

Please note that the ‘RDE’ trips do not appear to significantly challenge the vehicles measured here. For example, in the case of the Volvo XC60, we see that the both valid and invalid RDE trips are in the bottom third with respect to average emissions. Two-thirds of all the trips driven with this vehicle have higher average NO_x emissions, of which around 10% have an average NO_x higher than 400 mg/km.

For all vehicles a large proportion of the trips driven have higher average NO_x emissions than the valid RDE trips. In other words, for these vehicles, the RDE trips are not an accurate representation of how these vehicles can perform in normal on-road driving situations. This could indicate a certain degree of optimisation for RDE, but also reinforces that RDE tests are largely representative of ‘moderate’ driving conditions and not *all* driving conditions. We do note that RDE trips are also relatively long, and in a certain order, which can lead to a lower average emission value.



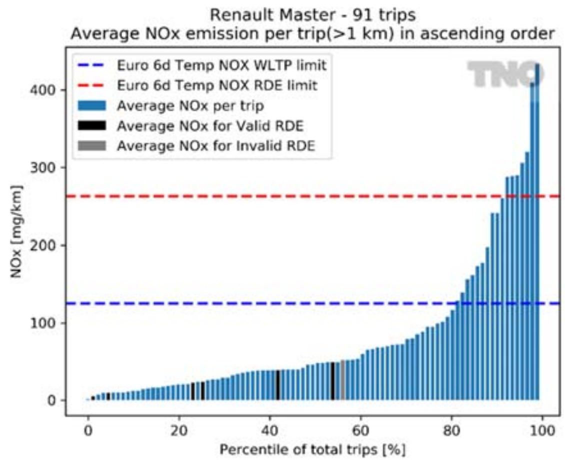


Figure 3-1: Average NOx emissions per trip for every trip driven by the five 6d-Temp vehicles, as sorted by increasing average NOx. The valid RDE trips are indicated by the black bars, while the invalid RDE trips are grey. The invalid RDE trips include, for example, the RDE trips with DPF regenerations, especially in the case of the Skoda (see also Appendix A). The WLTP and RDE limit are indicted by the blue and red dashed lines respectively.

3.2.1 Large variations in emissions on different road types may not be reflected in RDE averages

Because of the length of RDE trips, higher emissions in certain environments can be averaged out over the length of the trip. Although a vehicle has high emissions in rural areas, this could be compensated by low emissions in urban and motorway driving. An RDE test can be divided into three speed segments: urban, rural and motorway (see also Section A.1.3). This segmentation is done based on speed. However, based on Open Street Map data, most roads driven on throughout the test programs can be linked with their respective speed limit. This allows for a more detailed illustration of where high emissions are occurring.

For example, in Figure 3-2, in the case of the Volvo XC60 the NO_x emissions in the urban RDE speed segment are significantly higher for all monitoring data (‘normal use’, blue bars) than during the valid RDE trips (black bars). This can be further nuanced by looking at the emissions on roads with a certain speed limit (green bars). Here we see that for the Volvo XC60, the emissions are higher in 30 km/h zones than 50 km/h zones. For all vehicles monitored the NO_x emissions in 30 km/h zones were higher than in 50 km/h zones, but this disparity is especially evident in the case of the Renault Master. The Renault Master has an average NO_x emission on 30 km/h speed limit roads that is more than three times the emissions on 50 km/h roads.

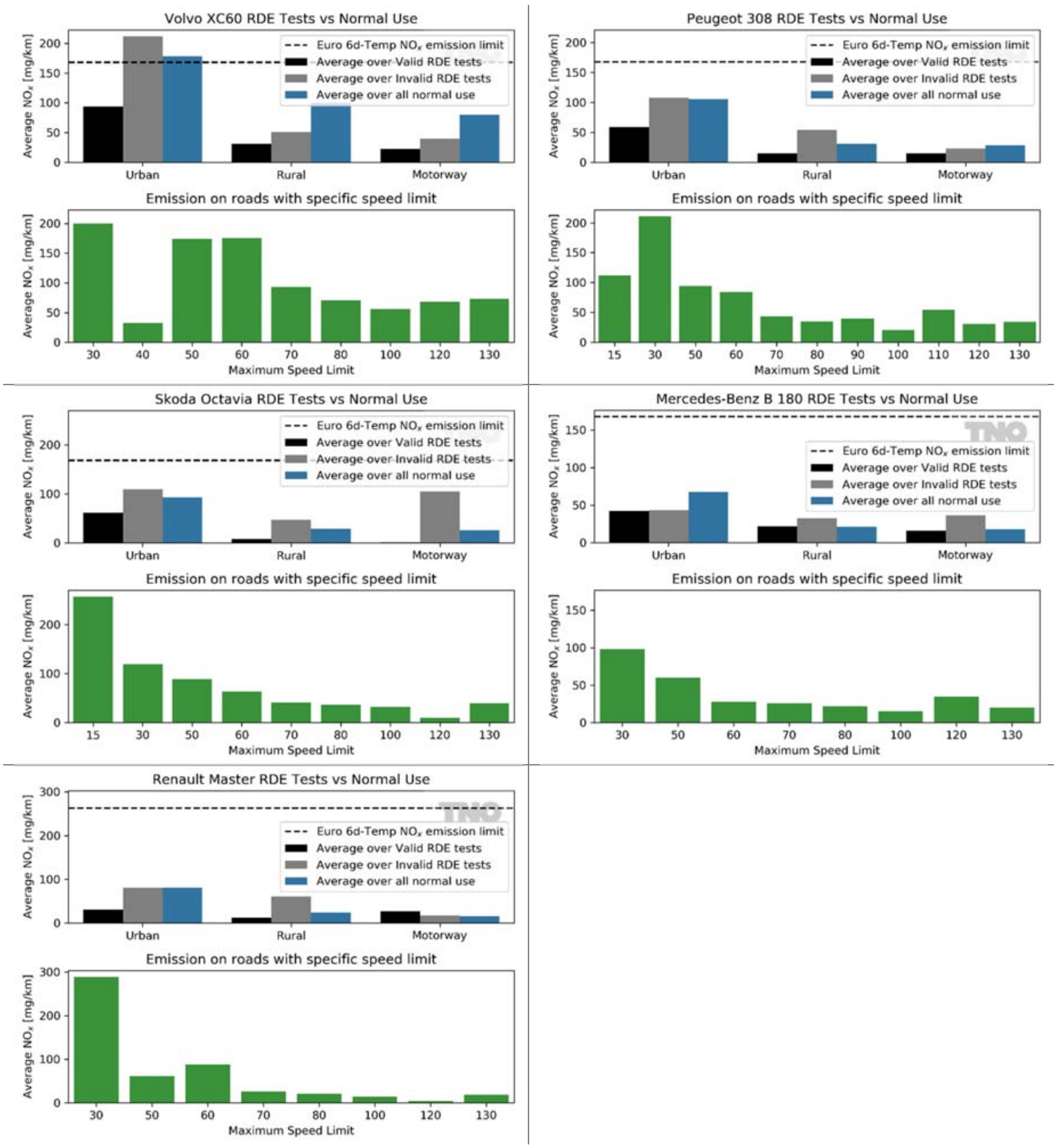


Figure 3-2: Average NO_x emissions per RDE speed section for the valid and invalid RDE trips (black and grey bars) and for all normal use/monitoring (blue bars), as compared to emissions on roads with specific speed limits (green bars). Note that speed limits are only shown if the respective vehicle has spent more than 15 min on roads with that limit.

3.2.2 *Emissions due to extended idling can be significant, but aren't tested for within RDE*

One of the few elements of special testing that was included in the test program, was the longer periods of idling, as the RDE boundaries are quite restrictive on idling, and it can be simply checked if manufacturers optimized the vehicle to meet only this boundary.

Idling and stop-and-go traffic are situations which one could consider 'non-moderate' driving conditions yet occur frequently in urban settings. Although RDE tests do allow for some idling, there is a maximum time allowed of 300 seconds. In Figure 3-3, two specific trips are shown with periods of extended idling. In the case of the Renault Master (Figure 3-3, left) initially lower NO_x emissions are followed by an increase of emissions that stabilise around 2.2 mg/s. The Skoda Octavia (Figure 3-3, right) also demonstrates similar behaviour in the trip shown: idling emissions increase to a stable level which is relatively high. Given the fact that a vehicle takes in urban conditions about 150 seconds to drive 1 kilometre, an emission rate of 2 mg/s would result in 300 mg/km. This is well above any RDE limit.

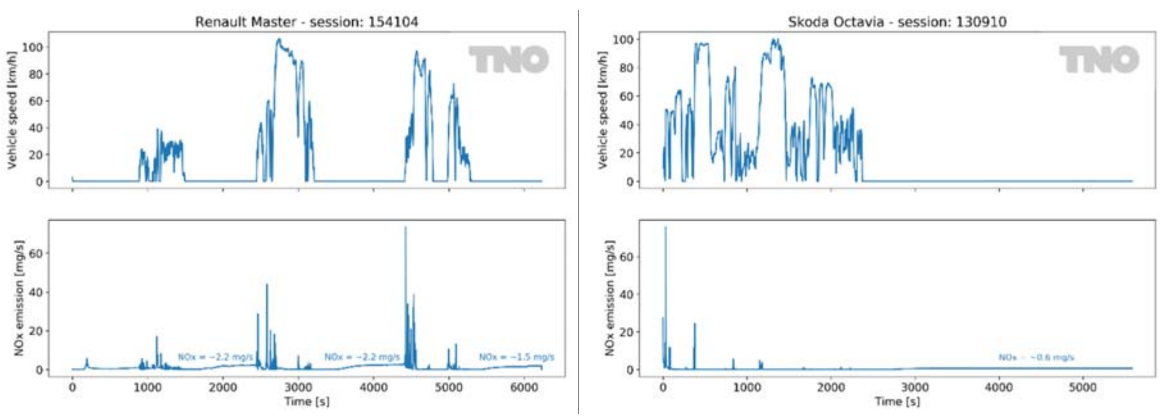


Figure 3-3: The instantaneous vehicle speed and NO_x emissions for a specific trip including extended idling for (left) the Renault Master and (right) the Skoda Octavia. Approximate NO_x levels during idling are shown via the blue annotation.

Although the two trips in Figure 3-3 show similar increasing emission behaviour, across all periods of idling there is a variety of different behaviours (Figure 3-4). In some cases, emissions increase then plateau, but the rate of increase varies, as does the moment when these increases start. The cause of this variation is an open question.

The variations in idling behaviour can also be seen in the frequency distribution of the instantaneous emissions (Figure 3-5). One could assume that the emissions while idling could decrease exponentially with higher values. However, this is not the case for any of the vehicles tested. All show secondary peaks at higher NO_x emissions. To once again take the example of the Volvo XC60, there is a relatively substantial amount of time in which the vehicle emits 4 – 5 mg/s of NO_x while idling. Comparing the five vehicles, there is a range of idling emission distributions.

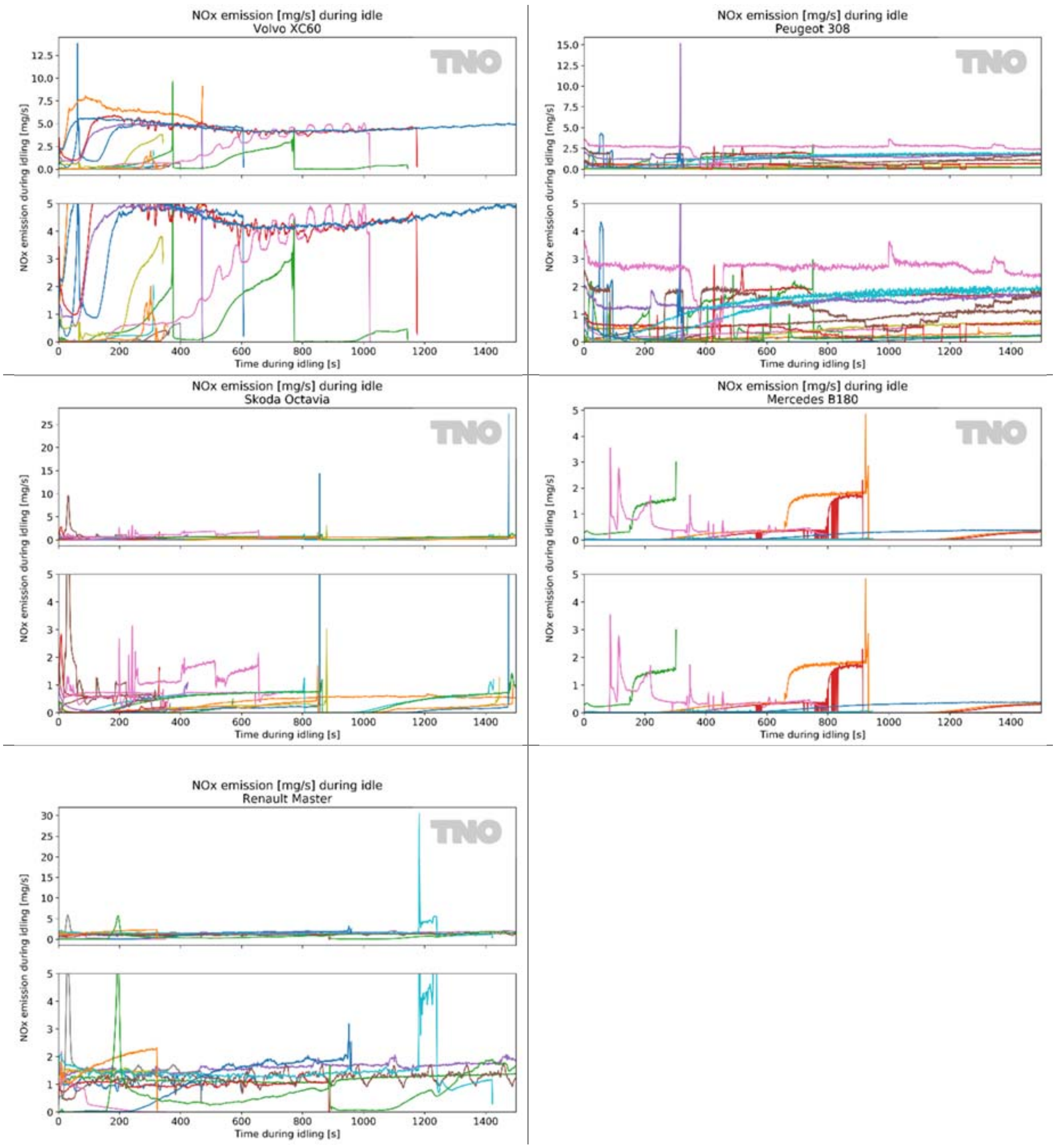


Figure 3-4: Instantaneous NO_x emissions after idling has started, for all periods of extended idling. These periods are defined as when the vehicle speed is less than 5 km/h for at least 300 s. The y-axis in the top frame per vehicle is scaled automatically to show all data, while the bottom frame per vehicle shows emissions 0 – 5 mg/s.

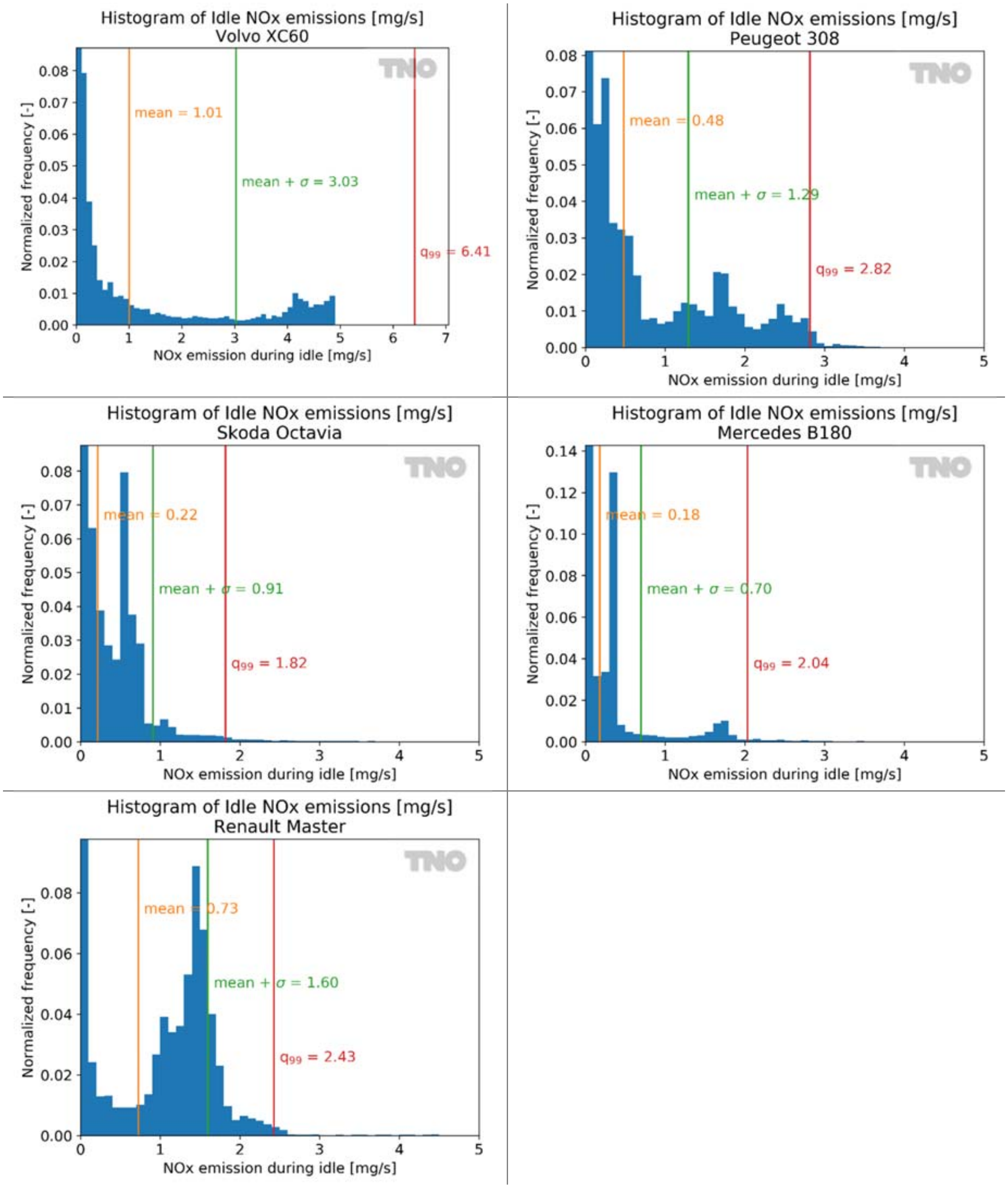
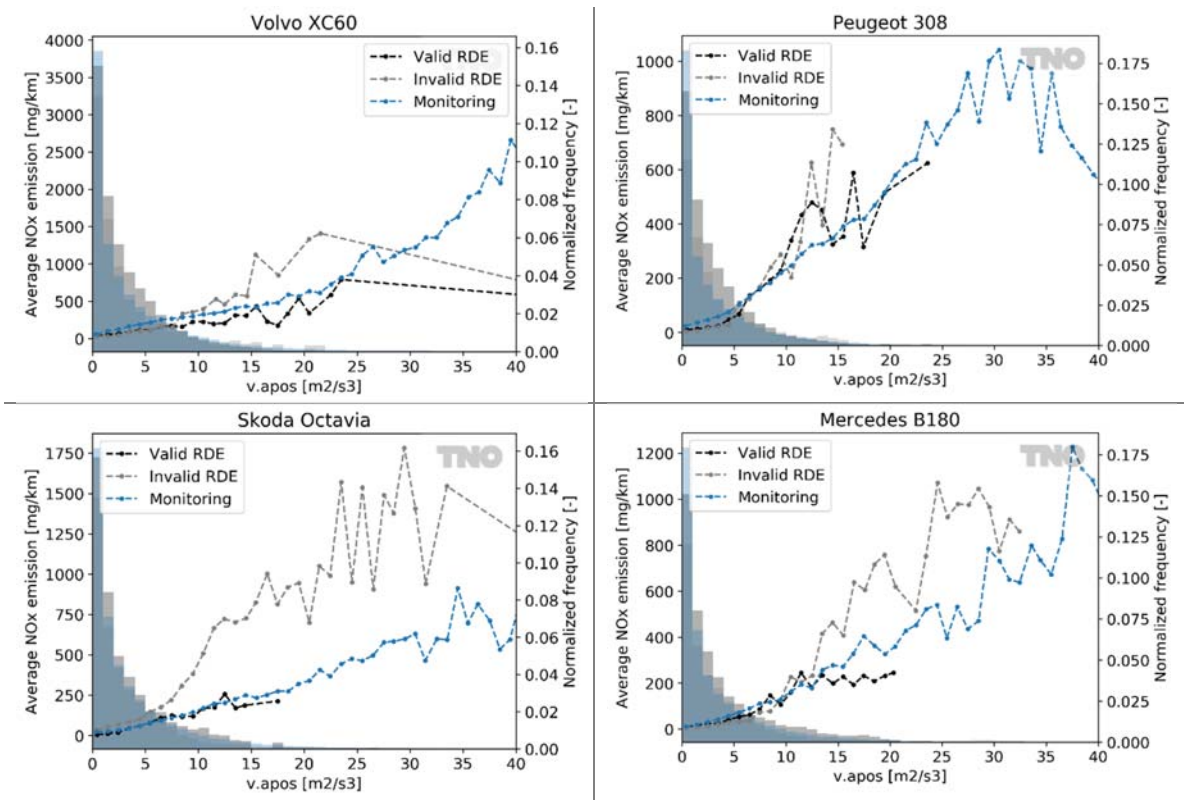


Figure 3-5: Frequency distribution of the instantaneous NO_x emissions for all periods of extended idling. Idling periods are defined as when the vehicle speed is less than 5 km/h for at least 300 s. The y-axis is truncated to show the details of the emission distribution; the mean, mean + standard deviation, and 99th quantile are annotated to give an quantified indication of the distribution.

3.3 Dynamic driving leads to higher NO_x emissions

So-called aggressive driving is parametrized by the parameter $v \cdot a_{pos}$. It is an indication of the amount of power used to accelerate. High values of $v \cdot a_{pos}$ can be considered aggressive driving but also occurs naturally when accelerating onto a motorway or overtaking vehicles.

The parameter $v \cdot a_{pos}$, the product of vehicle speed and positive acceleration, is commonly used as an indicator for the driving dynamics during a trip. $v \cdot a_{pos}$ is also used to define the parameters of how the RDE trip is evaluated. We compare the emissions at different $v \cdot a_{pos}$ values for the 'RDE' trips and monitoring data in Figure 3-6. For four out of five vehicles, the emissions are higher during monitoring for the $v \cdot a_{pos}$ values that occur most frequently. Emissions increase substantially for higher values of $v \cdot a_{pos}$.



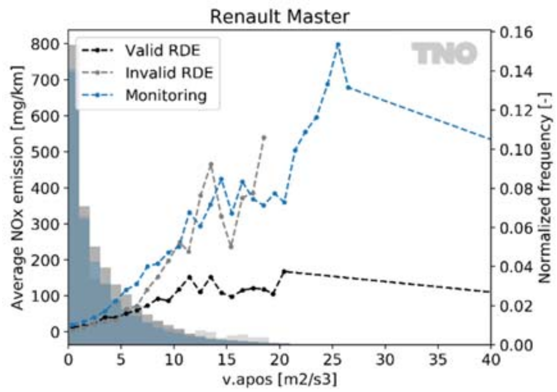
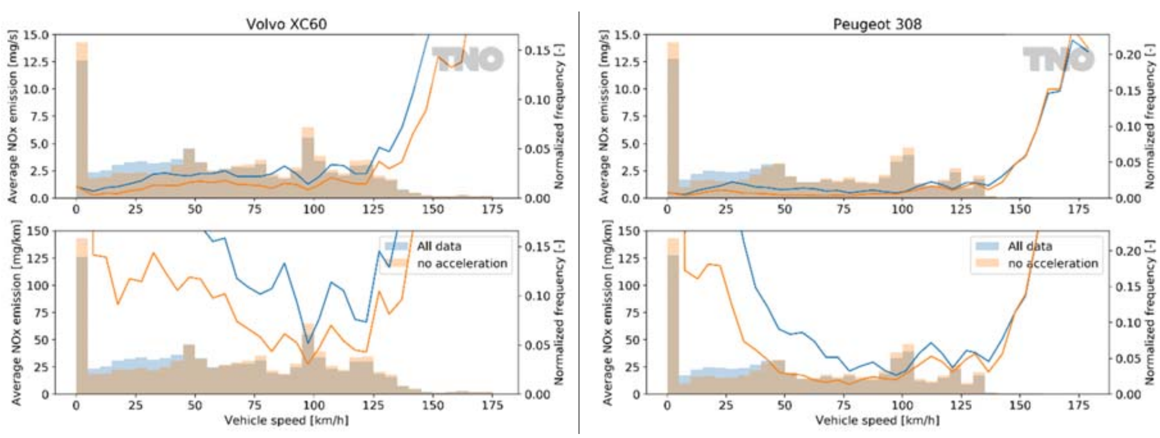


Figure 3-6: Average NOx (dashed lines with points) and frequency distribution (bars) per v · apos bin for both valid and invalid RDE (black and grey) and monitoring (blue) data. Data is binned per 1 m2/s3 and is only shown if the bin has more than 20 seconds of data.

Vehicle emissions do increase with little bounds as v · a_{pos} increases. There does not seem to be a clear change in emission levels at the RDE boundary. The black line indicates where the driving behaviour is limited in the RDE test, while in normal use, also with more data available, the data extends to much higher values (the Peugeot 308, Skoda Octavia and Mercedes B180 show clear examples of this).

The influence of dynamic driving can also be observed when comparing the average NO_x emissions per speed bin for all data, and for data excluding accelerations (where 'no' acceleration is defined as driving where the acceleration is less than 0.5 m/s^2). For all vehicles tested (Figure 3-7), constant speed driving (i.e. without acceleration greater than 0.5 m/s^2) has lower average NO_x emissions per vehicle speed bin.



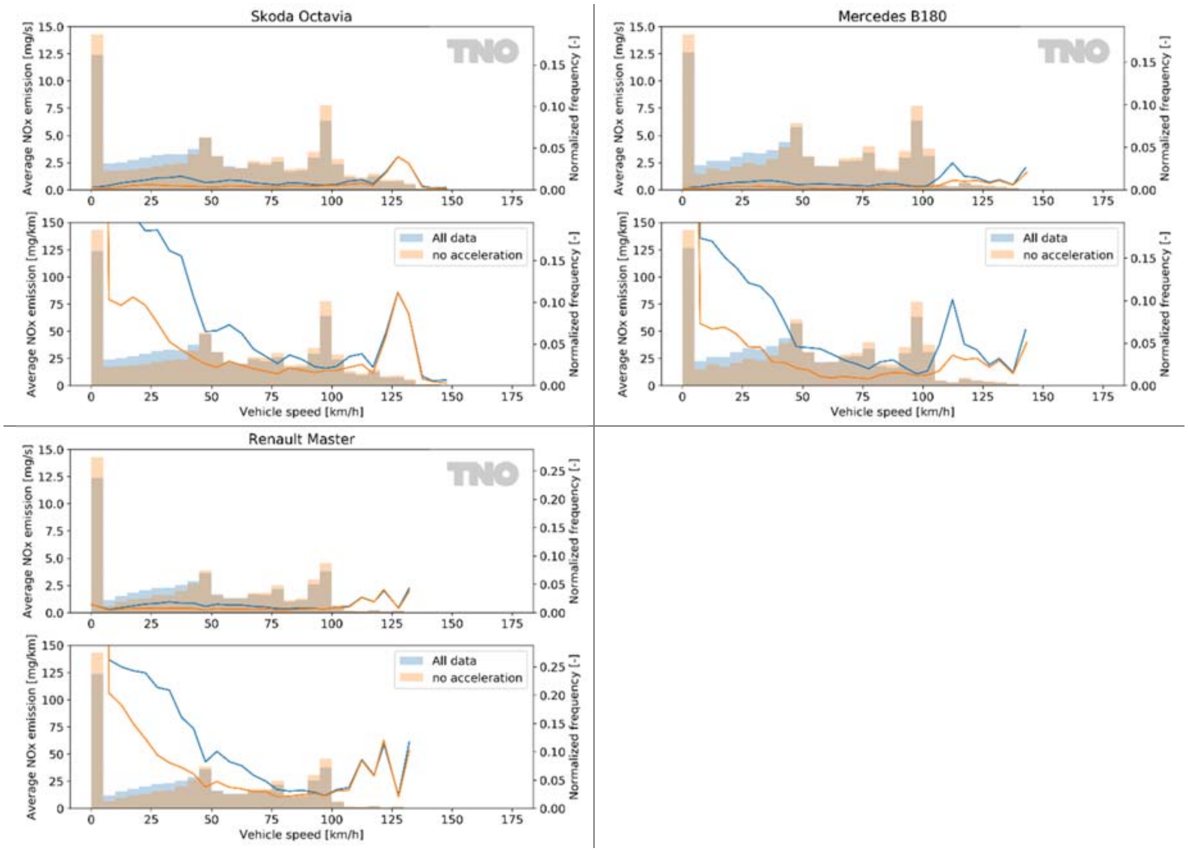


Figure 3-7: Average NO_x (lines) and frequency distribution (bars) per speed bin for all data and data excluding acceleration (acceleration less than 0.5 m/s^2, equivalent to 1.8 km/h per second).

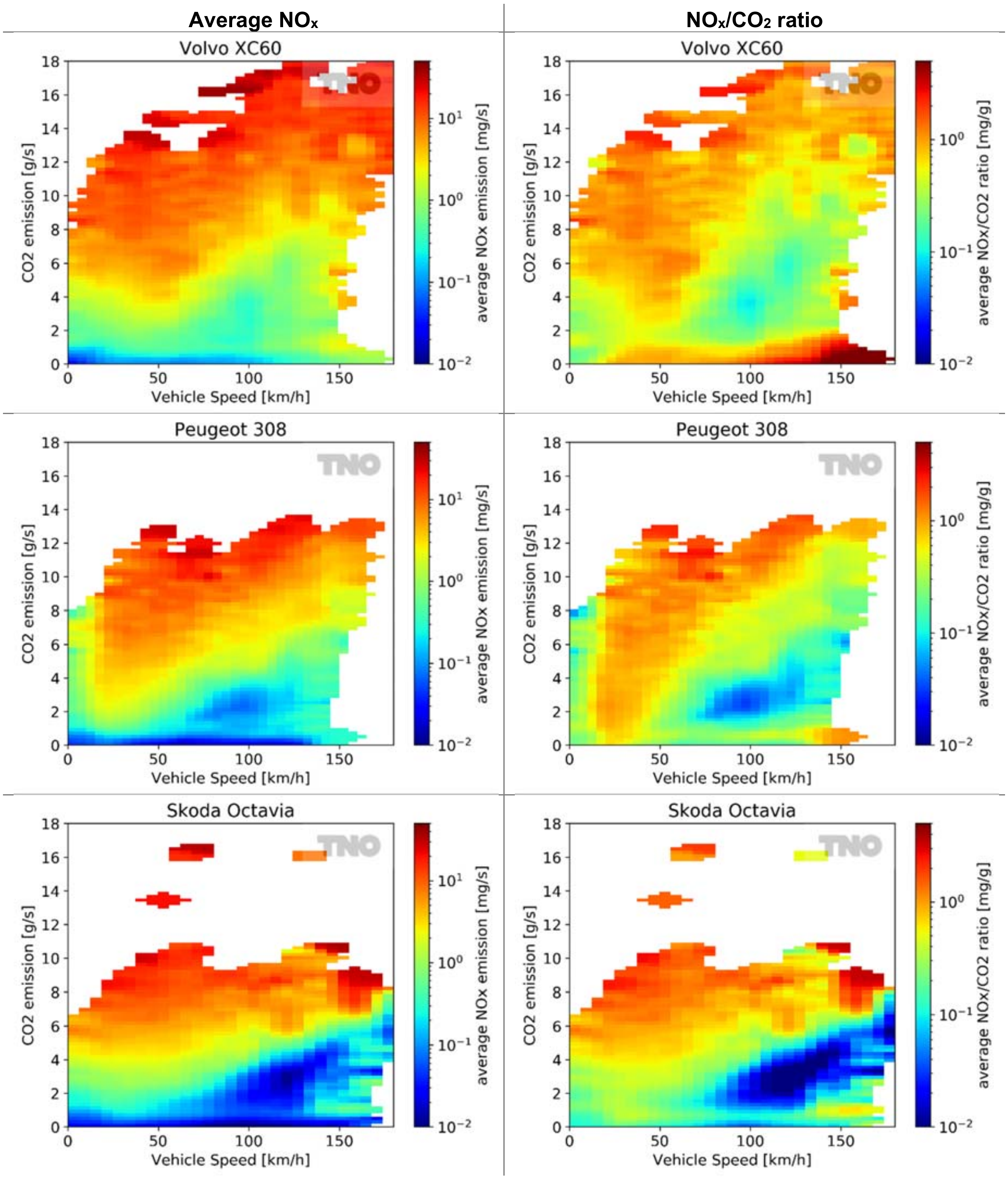
Dynamic driving plays a bigger role for the vehicles which perform worse than it did in the past (i.e. previous generations of diesel vehicles, in particular before 2014). Therefore, it is relevant to know actual driving behaviour in detail, as it is just as relevant as vehicle velocity for the emissions of these vehicles.

3.4 Emission maps give additional insight into NO_x emissions

Emission maps can be used to examine the dependencies of pollutant emissions. Here we use vehicle speed and CO_2 emissions as these have been shown to effectively show the NO_x emission behaviour of modern diesel vehicles. CO_2 emissions can be used as a proxy for the power demand of a vehicle as CO_2 emissions are directly related to fuel consumption. The variables vehicle speed and CO_2 emissions are also good descriptors of driving style: in general, high CO_2 emissions can be associated with high acceleration and high speeds, as well as other driving conditions such as pulling a trailer, driving when windy, or driving uphill. An extensive discussion on emission maps of this type can be found in [TNO 2020].

In Figure 3-8 we show the average NO_x per vehicle speed – CO_2 emission bin, as well as the average NO_x/CO_2 ratio. The latter is used to normalise NO_x levels with respect to CO_2 emissions.

The effect of this is especially obvious at low values of CO_2 emissions. All five vehicles demonstrate a local minimum around 100 km/h with CO_2 emissions in the vicinity of 2 – 4 g/s. In the cases of the Skoda Octavia, Mercedes B1 and Renault Master this minimum extends to higher speeds. The Renault Master, being a van, would be expected to have higher fuel consumption. This is reflected in the local minimum ranging from 2 – 8 g/s of CO_2.



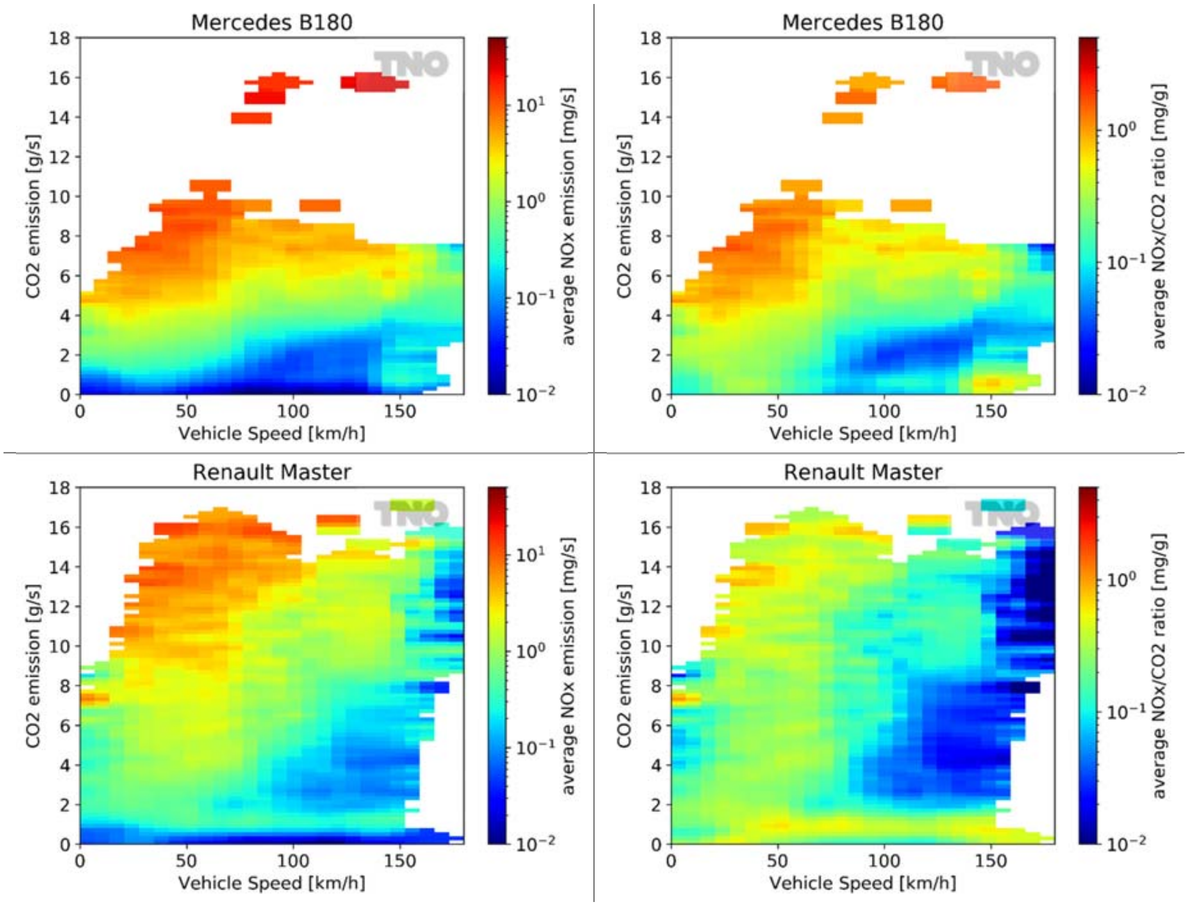


Figure 3-8: Two-dimensional emission map of average NO_x emissions (left) and average NO_x/CO_2 ratio (right), both shown dependent on CO_2 emissions and vehicle speed.

All vehicles have a “sweet spot” in the emissions around 100 km/h, where the NO_x/CO_2 ratio is low. This is a factor 10 lower than emissions at urban velocities. In the case of remote sensing data, the NO_x/CO_2 ratio uncovered in urban settings is extrapolated to all conditions. Clearly, that has limitations, as this ratio varies strongly with velocity, even though the engine power and CO_2 rate are similar.

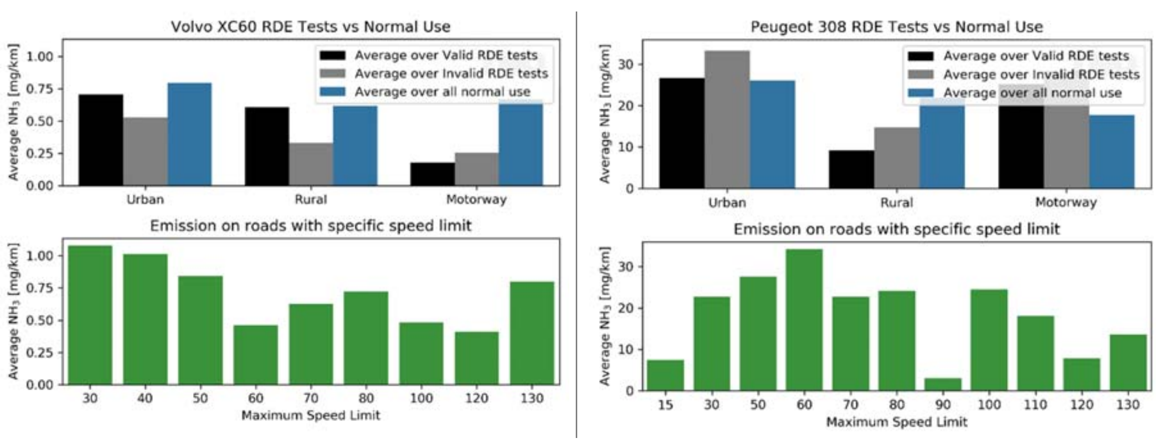
4 Legislation does not dictate NH_3 and N_2O limits

Neither NH_3 nor N_2O are accounted for within RDE legislation. However, these pollutants can both have large environmental impacts. During the test programme, NH_3 was both measured during the on-road monitoring programme as well as on the chassis dynamometer in the laboratory (mainly as validation of the on-road measurement equipment, see Section 0.2.3.3). The chassis dynamometer was used to measure N_2O in the laboratory, as reliable on-road measuring systems are not yet available for N_2O.

4.1 On-road monitoring shows large disparity in NH_3 emissions of different vehicles

Because NH_3 is now included in real-world monitoring, it can be analysed much the same way as NO_x emissions. In this section we discuss the average NH_3 emissions per RDE speed section and road-specific speed limit, a more detailed speed dependency, as well as NH_3 emission maps dependent on CO_2 emissions and speed.

The speed section/speed limit dependency of NH_3 emissions is shown in Figure 4-1. Although there are no clear trends across all vehicles, all except the Peugeot 308 do have higher NH_3 emissions at 30 km/h than at 50 km/h. At higher speed limits, the behaviour differs between vehicles. The Peugeot 308 does have much higher NH_3 emissions in general, with an average emission for normal use around 20 mg/km, while the other vehicles have average NH_3 emissions around 2 mg/km or less. This disparity in NH_3 emissions would suggest that low NH_3 emissions can be the norm, but that limits would be needed to avoid excessively high emissions.



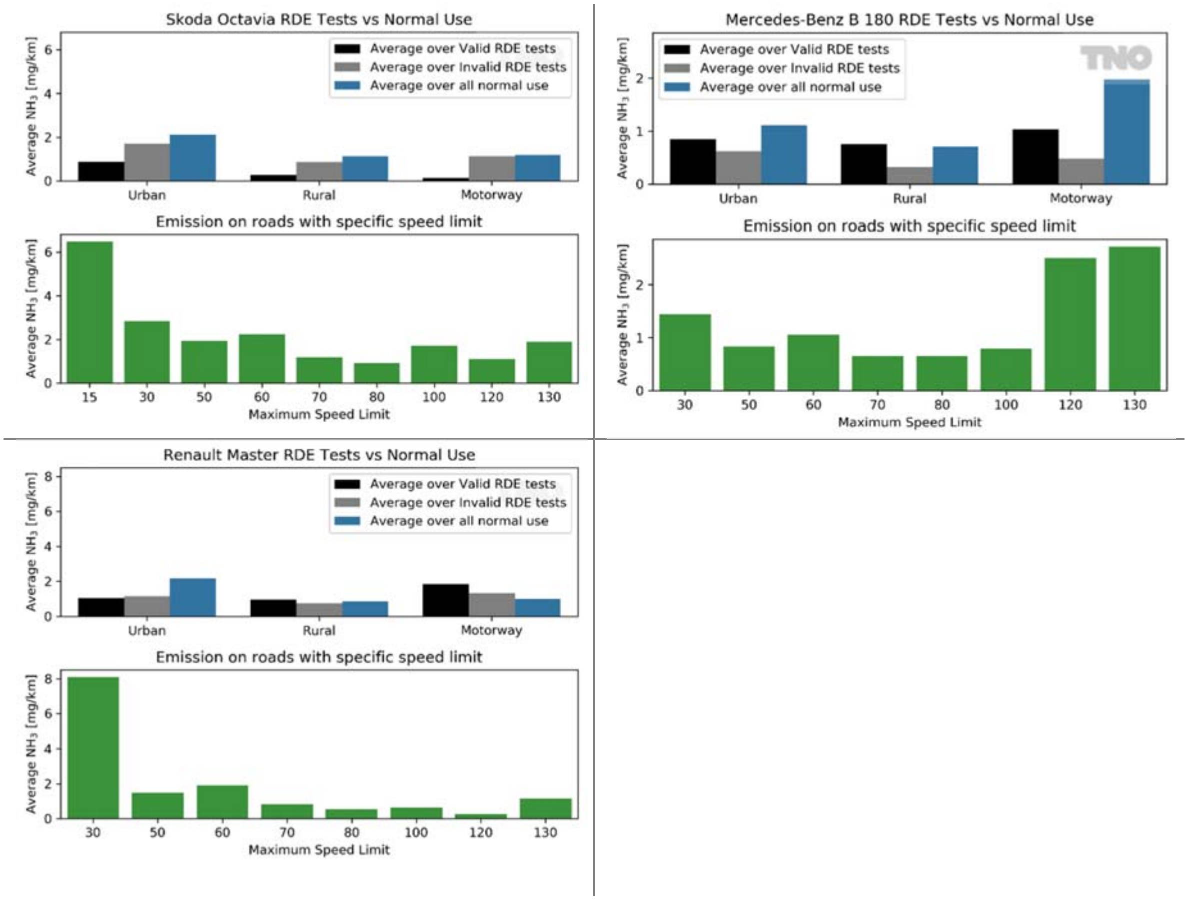


Figure 4-1: Average NH_3 emissions per RDE speed section for the 'RDE' trips (blue bars) and for all normal use/monitoring (orange bars), as compared to emissions on roads with specific speed limits (green bars). Note that speed limits are only shown if the respective vehicle has spent more than 15 min on roads with that limit.

The dependencies of NO_x emissions on driving dynamics for 6d-Temp vehicles was discussed in the previous chapter. However, NH_3 emissions have not been examined in such detail. It is hypothesised that these emissions are dependent on the engine management systems, as it is these systems that determine the dosage of ammonia injected. However, dosing strategies are not publicly available for further analysis. In Figure 4-2 and Figure 4-3 we show average NH_3 emissions dependent on driving dynamics. At low speeds, the average emissions of data including accelerations is generally higher than that without accelerating (Figure 4-2). Between 75 – 100 km/h the emissions for dynamic and constant driving are similar. Figure 4-3 shows that are differing behaviours for each of the five vehicles with regards to the boundaries of the areas of lower NH_3 emissions.

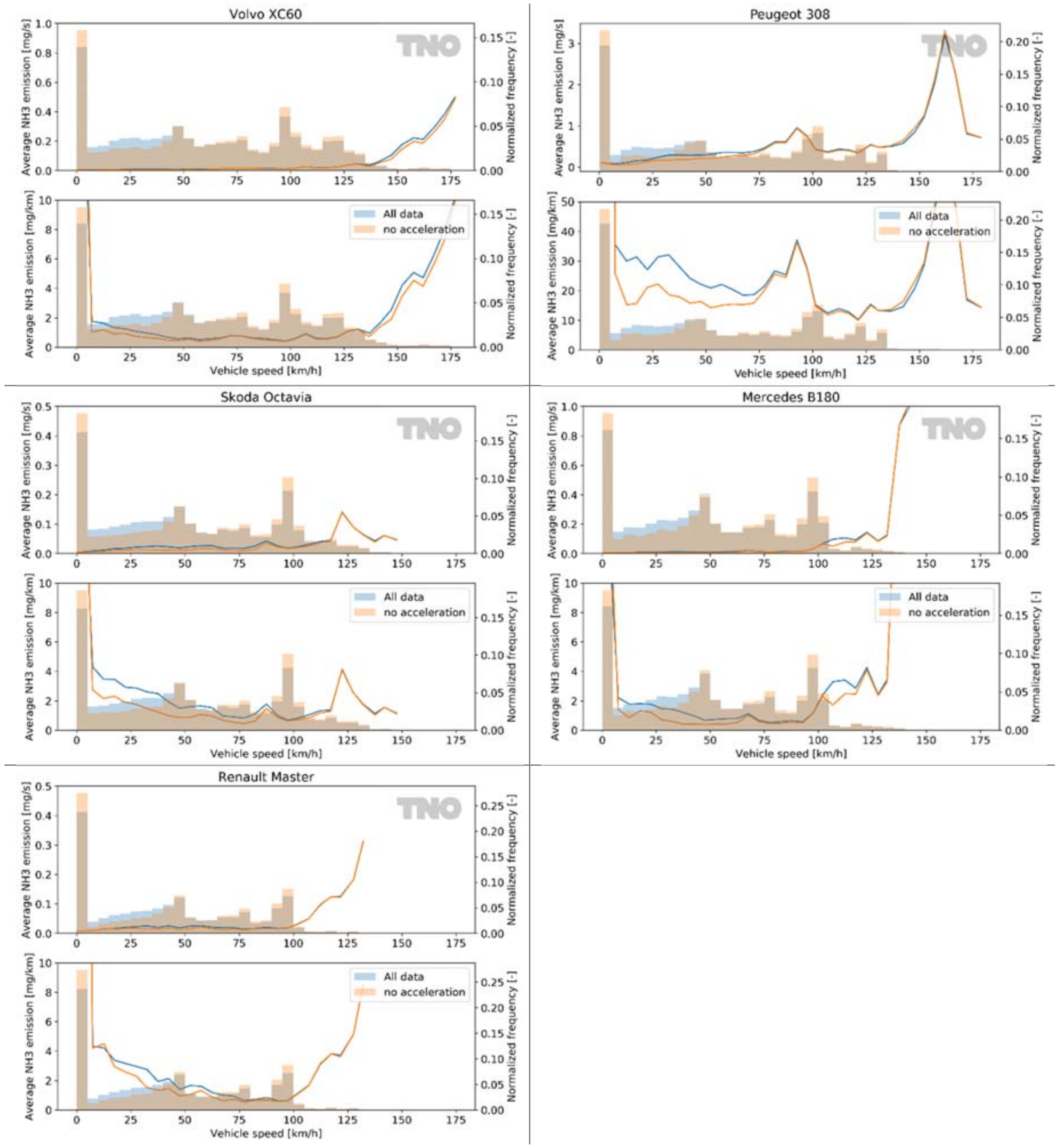


Figure 4-2: Average NH_3 (lines) and frequency distribution (bars) per speed bin for all data and data excluding acceleration (acceleration less than 0.5 m/s^2, equivalent to 1.8 km/h per second).

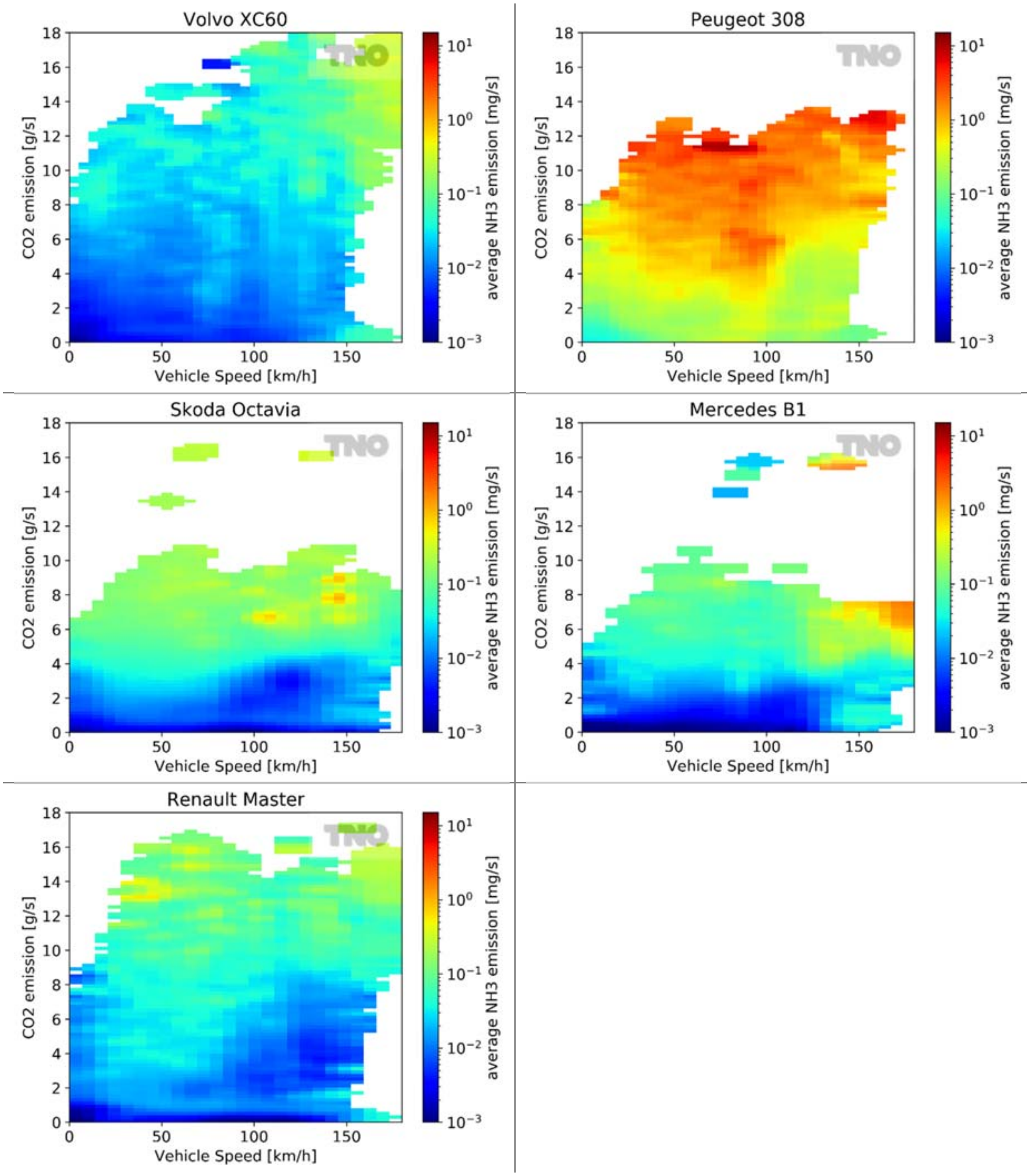


Figure 4-3: Two-dimensional emission map of average NH_3 emissions shown dependent on CO_2 emissions and vehicle speed.

4.2 Little is known about the N_2O emissions of 6d-Temp vehicles

N_2O is a greenhouse gas with a significant environmental impact; 1 g of N_2O is equivalent to 298 g of CO_2. During chassis dynamometer tests of the Peugeot 308 QCL (Quantum Cascade Laser) measurements were performed (see also Section 0.2.3.3), which included the measurement of N_2O emissions.

As shown in Table 4-1, the WLTC tests have an average N_2O emission of around 3.8 g/km CO_2-equivalent, while in the case of the 4*UDC test an average emission of 23.0 g/km CO_2-equivalent was measured. An approximation can be made as to the instantaneous extra CO_2 equivalents due to NO_x by linking the QCL-measured data to the SEMS-measured data. Figure 4-3 shows that the instantaneous extra CO_2 equivalents can easily be up to 5%, and incidentally be up to 20 and 25%. In other words, there are moments in which the N_2O emissions would lead to an effective increase of 20% in CO_2-equivalent emissions.

Table 4-1: Average N_2O emissions per chassis dynamometer test of a Peugeot 308 diesel 6d-Temp, as compared to CO_2 emissions.

Test	N_2O [mg/km]	CO_2 [g/km]	N_2O [g/km CO_2 equivalent]
WLTC Cold II	10.5	118.0	3.1
WLTC Cold III	11.7	119.8	3.5
WLTC Warm I	15.3	110.9	4.6
WLTC Warm DPF	13.3	155.4	4.0
4*UDC	77.3	128.1	23.0

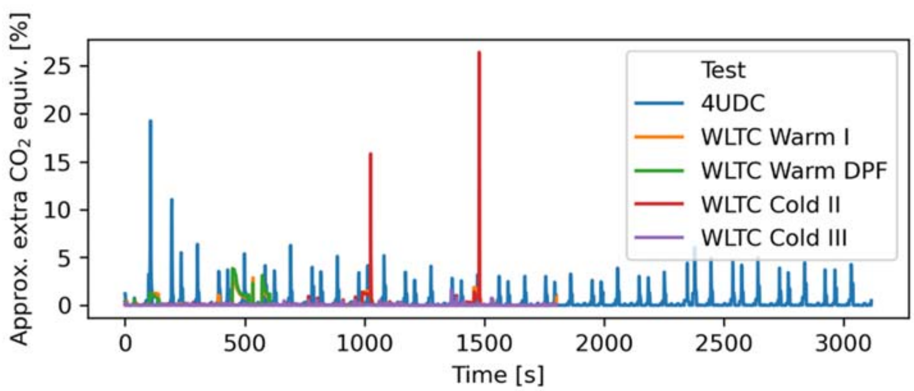


Figure 4-4: Approximate extra CO_2 equivalents of N_2O over time for each of the chassis dynamometer tests where N_2O was measured.

The above results are from limited measurements of one 6d-Temp vehicle. Further research would be needed to ascertain whether these results apply more widely.

5 Conclusions

In this research project the real-world NO_x, CO_2 and NH_3 emission performance of four Euro 6d-Temp diesel M1 (passenger vehicles) vehicles and one N1 class 3 Euro 6d-Temp (light commercial) vehicle were determined on the road in several test trips. The emissions were measured by means of TNO's Smart Emission Measurement System, which contains an automotive O_2/NO_x and NH_3 sensor. Combined with CAN bus data of the vehicle and a dedicated emission calculation method, the mass emission rates were determined.

The measurement results gathered within the performed test programme result in the following main conclusions:

- **Average NO_x emission levels are low, but large variations are observed**
  The total average real-world NOx emissions of all tested Euro 6d-Temp vehicles were 35 to 125 mg/km and well below the RDE NOx limit values of 168 or 262.5 mg/km. During short trips, hard accelerations, high velocities, and DPF regenerations (which occurred during normal use), emissions could be substantially higher.
- **RDE trips have low average NO_x emissions per trip compared to normal-use trips**
  For all vehicles a large proportion of the trips driven had higher average NO_x emissions than the valid RDE trips .Furthermore, large variations in emissions on different road types were not always reflected in RDE averages. For some vehicles, emissions due to extended idling were significant, while extended idling is not tested for within RDE.
- **'RDE' trips are not an accurate representation of how these vehicles can perform in normal on-road driving situations.**
  There are large differences in average NO_x emissions between the different trips driven as part of the emission monitoring programme. It is currently unclear what the reasons for these differences are. During 'RDE' trips, no excessive NO_x emission levels were measured dependent on different payloads and driving styles: different payloads in combination with economic/regular/sportive driving styles in 'RDE' tests resulted in NO_x emissions of 5 to 159 mg/km for all tested vehicles. Comparatively, the maximum of all normal-use trips per vehicle ranged from 250 to over 1000 mg/km.
- **Four out of five tested vehicles showed low NH_3 emission levels**
  The average NH_3 emission of four tested vehicles was in the range of 0.9 to 1.5 mg/km but the fifth vehicle had an average NH_3 emission of 21.7 mg/km. The measured NH_3 emissions clearly show that low NH_3 emissions are possible with SCR technologies because the technology is available and effective. Furthermore, the numbers indicate that NH_3 emission limit values (like in heavy-duty emission legislation) are needed to avoid excessive NH_3 emissions.

- **No excessive NO_x emission levels were measured as effect of different payloads and driving styles**
  Different payloads in combination with economic/regular/sportive driving styles in ‘RDE’ tests resulted in NO_x emissions of 5 to 159 mg/km for all tested vehicles. All these are below the RDE NOx limit values of 168 or 262.5 mg/km. Only in some ‘RDE’ tests with DPF regenerations, the RDE NO_x limit value was slightly exceeded.

- **N_2O measurements on chassis dynamometer signpost need for further investigation**
  During a 4*UDC test of a Peugeot 308, N_2O emissions of 77.3 mg/km were measured, which is 23.0 g/km CO_2-equivalent (+18%). It should be noted that only one 4*UDC result is available. On average for the WLTC tests, N_2O emissions were around 3.8 g/km CO_2-equivalent (+3%). The variation in these results, including the unexpectedly high emissions in the urban test, indicates that more research is needed with regards to N_2O.

- **SEMS test results in line with chassis dynamometer test results**
  The comparison of measurement results acquired with the Smart Emission Measurement System (SEMS) with those of the chassis dynamometer showed that in the three performed WLTC tests SEMS test results are very well in-line with those of the chassis dynamometer.

6 Recommendations

The five 6d-Temp vehicles performed reasonably well within moderate driving conditions, yet had higher emissions in normal-use situations such as extended idling, DPF regenerations, short trips, high acceleration, etc. In order to fully evaluate the real-world emissions of light-duty vehicles, current RDE emission testing should be supplemented with emission monitoring, or tests which also include ‘non-moderate’ normal-use driving conditions.

The vehicles measured during this programme were the first generation of vehicles to be tested under RDE legislation. Considering trends in vehicle technology development after the introduction of previous legislation, it is unlikely that the emission behaviour seen here will hold for future generations. Further testing of Euro 6d vehicles will be needed to see how vehicle technology responds to this legislation.

In this test programme one tested vehicle (a Peugeot 308) had substantial NH_3 emissions. In order to verify this NH_3 emission it is recommended to test a second sample of this vehicle type.
In addition, in one urban test cycle substantial N_2O emissions were measured. In order to verify this N_2O emission it is also recommended to test a second sample of this vehicle type in urban test cycles.

Additional investigations of N_2O emissions of modern vehicles in different test cycles are needed; first test results indicate that N_2O emissions are substantial.

The measured NO_x and NH_3 concentrations of the Peugeot 308 measured with the automotive sensors of SEMS were validated against chassis dynamometer analysers. Based on this validation, NO_x and NH_3 correction formulas were developed and SEMS test results were corrected. Verification of the correction formulas with a second vehicle with similar NO_x and NH_3 emissions on the chassis dynamometer is recommended.

In Euro 6 emission legislation of light duty vehicles NH_3 limit values are not defined. This test programme shows that NH_3 emission of Euro 6 light duty vehicles can be substantial. For future emission legislation it is recommended to add NH_3 limit values.

Euro 6d-Temp vehicles feature new and complex technology. It is unknown how these vehicles will deteriorate. Furthermore, within RDE legislation there is a low mileage limit for in-service conformity, and no allowance for various levels of maintenance. It is recommended that the knowledge gap surrounding the effects of durability on emission levels be addressed.

7 Closing remarks

7.1 General caveats regarding interpretation of the test results

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

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

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

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

8 Abbreviations

ASC	Ammonia Slip Catalyst
CF	Conformity Factor
cEGR	Cooled Exhaust Gas Recirculation
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
HP-EGR	High Pressure Exhaust Gas Recirculation
LNT	Lean NOx Trap
LP-EGR	Low Pressure Exhaust Gas Recirculation
NEDC	New European Driving Cycle
MIL	Malfunction Indication Light
OBD	On Board Diagnosis
PTI	Periodic Technical Inspection
SCR	Selective Catalytic Reduction
SCRF	Selective Catalytic Reduction + Particulate Filter
sDPF	Selective Catalytic Reduction + Particulate Filter
UDC	Urban Driving Cycle
WLTC	World harmonized Light duty Test Cycle

9 References

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[TNO 2016b] Kadijk et al., *NO_x emissions of Euro 5 diesel vans – test results in the lab and on the road*, TNO report 2016 R10356.

[TNO 2016c] Heijne et al., *NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch LD road vehicle emission testing programme 2016*, TNO report 2016 R11177.

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[TNO 2017b] Van Mensch, Ligterink, and Cuelenaere, *Assessment of risks for elevated NOx emissions of diesel vehicles outside the boundaries of RDE*, TNO report 2017 R10862.

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10 Signature

The Hague, 18 December 2020

TNO

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Projectleader

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Author

A The measurement programme in detail

1.1 Tested vehicles and test programme

This chapter presents the most important characteristics of the tested vehicles and the test programme as performed. Also, the emission limit values of the different emission classes are given. The measurement methods are described in more detail in the TNO methodology report [TNO 2016a].

1.1.1 Tested vehicles

In Table A-1 some primary data of the five tested diesel vehicles are specified and in Table A-2 the configurations of the emission control systems are specified.
All vehicles were rental cars.

Table A-1: Tested diesel vehicles.

No	Brand	Model	Euro class	Power [kW]	Registration Date	Odometer [km]	Empty Mass [kg]
1	Volvo	XC 60	6d-Temp	140	16-04-2018	17,598	1,766
2	Peugeot	308	6d-Temp	96	14-01-2019	15,297	1,155
3	Skoda	Octavia	6d-Temp	85	30-04-2019	20,473	1,285
4	Mercedes	B180	6d-Temp	85	29-08-2019	1,501	1,385
5	Renault	Master	6d-Temp	110	16-12-2019	7,263	2,044

Table A-2: Emission control systems of the tested Euro 6d-Temp vehicles.

No	Brand	Model	Engine	Exhaust		
1	Volvo	XC 60	HP - cEGR	LNT	DPF	SCR
2	Peugeot	308		DOC	LNT	SCR + DPF
3	Skoda	Octavia	No information received	No information received	No information received	No information received
4	Mercedes	B180	HP - EGR LP - cEGR	DOC	sDPF	SCR+ASC
5	Renault	Master	HP - cEGR	DOC	sDPF	SCR+ASC

~~1.1.2~~0.1.2 Emission limit values

In A-3 the emission limit values of chassis dynamometer tests of M1 & N1 Class 1 diesel vehicles of different emission classes are specified.
For Euro 6d-Temp and Euro 6d-final diesel vehicles the current emission limit values of on-road RDE tests (Real Driving Emissions) are specified in A-4.

Table A-3: Emission limit values of diesel M1 & N1 Class 1 vehicles (chassis dynamometer).

Emission class	THC	CO	NO_x	PM	HC+ NOx	PN	Durability limit	ISC limit
	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[#/km]	[km]	[km]
Euro 1	-	2,720	-	140	970	-	80,000	
Euro 2	-	1,000	-	80	700	-	80,000	-
Euro 3	-	640	500	50	560	-	80,000	-
Euro 4	-	500	250	25	300	-	100,000	tbr
Euro 5a	100	500	180	5.0	230	-	160,000	100,000
Euro 5b	100	500	180	4.5	230	6.0E+11	160,000	100,000
Euro 6	100	500	80	4.5	170	6.0E+11	160,000	100,000

Table A-4: Current status of emission limit values of diesel M1 & N1 Class 1 vehicles (On-road total RDE test and urban part) for Euro d-Temp and Euro d-final vehicles.

Euro Class	NO_x	NO_x	NO_x	PN
	[mg/km]	[mg/km]	[mg/km]	[#/km]
Vehicle category	M, N1 class I	N1 class 2	N1 class 3	
Euro 6d-Temp	168	220.5	262.5	9.0E+11
Euro 6d-final	114.4	150.1	178.8	9.0E+11

~~1.1.3~~0.1.3 *On-road test programme*

The on-road test programme consisted of two different parts:

- An emission test on defined routes.
- An emission monitoring phase: emissions were monitored during daily on-road use of the vehicle, with different drivers.

Emission test on defined routes

In A-5 details of the on-road emission test programme are specified. This test programme was executed in the vicinity of Rotterdam, The Hague and Amsterdam in The Netherlands. RDE tests were executed with different driving styles (economic, regular and sportive) and with different payloads. Most RDE tests did not meet the boundary conditions because they started with a warm engine and they are therefore marked as ‘RDE’ tests.
All vehicles except the Skoda Octavia were subject to this test program. The Skoda Octavia was subjected to a shortened test programme (2 days instead of 3 days).

Emission monitoring

Furthermore, emissions were measured in a random monitoring programme which consists of very short and very long trips with cold and warm starts. These trips were executed by different drivers.

Table A-5: On-road test trips of the emission test programme.

No.	Trip Name	Road Type(s)	Start condition	Test Day	Payload [%]	Driving style	Distance [km]	Average velocity* [km/h]
1	RDE_C	Urban / rural / motorway	Cold start	1	28	Economic	74.7	43
2	Motorway	Motorway	Warm start	1	28	Regular	89.5	79
3	RDE_H	Urban / rural / motorway	Warm start	1	28	Regular	74.7	43
4	Congest_H	Motorway, evening traffic	Warm start	1	28	Regular	84.3	56
5	Congest_C	Motorway, morning traffic	Cold start	2	95	Dynamic	85.3	83
6	City	Urban	Warm start	2	95	Regular	27.8	21
7	Rural	Rural	Warm start	2	95	Regular	64.5	50
8	RDE_H	Urban / rural / motorway	Warm start	2	55	Regular	74.7	43
9	City to City	Urban / rural / motorway	Warm start	2	95	Regular	21.2	36

*Due to traffic conditions the average velocity may vary.

~~1.1.4~~0.1.4 *Chassis dynamometer test cycles*

One vehicle (Peugeot 308) was also tested on the chassis dynamometer in WLTC tests and UDC test cycles. In Figure A-1 the vehicle speed profile of the WLTC is shown. In Figure A-2 the speed profile of the UDC test (16* ECE test cycle) is plotted.

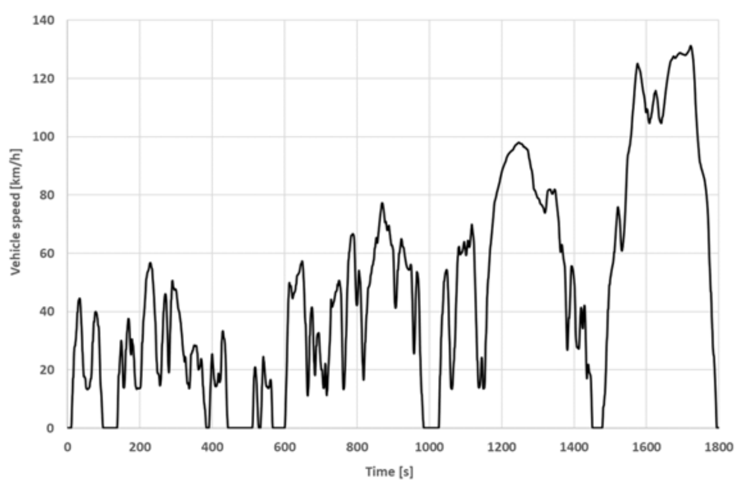


Figure A-1: The Worldwide harmonized Light-duty driving Test Cycle (WLTC_v5).

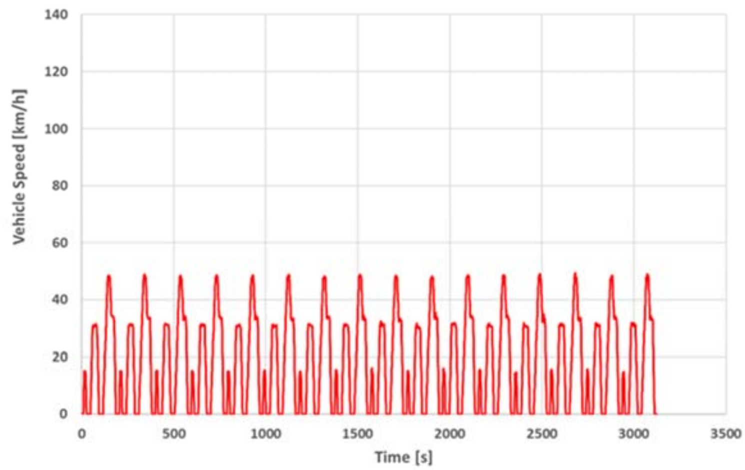


Figure A-2: 4* UDC driving test cycle.

~~1.1.5~~0.1.5 *Test equipment*

Emission measurements on the road were performed using our sensor-based Smart Emission Measurement System (SEMS). In Appendix C a schematic overview of SEMS and the post data processing steps is given.
The applied sensors (NO_x and O_2 measuring signals) as well as the Mass Air Flow sensors of the Skoda Octavia and Mercedes B180 were calibrated. All test results were corrected on the basis of these sensor calibrations.
In parallel with NO_x also NH_3 emissions were measured, these measuring results are used to apply cross sensitivity corrections of the measured NO_x signals.

To assess the accuracy of the SEMS equipment, SEMS measurements have been carried out on the Peugeot 308 on a chassis dynamometer, simultaneously recording the readings of the SEMS and those 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 A-3 and Figure A-4. 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 +6.6%). The accuracy of the SEMS equipment relies on the accuracy of the calibrated concentration measurements, the exhaust flow accuracy and the engine signals used.

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

The specifications of the applied chassis dynamometer are reported in Appendix B. The emissions of the Peugeot 308 were also measured with a Quantum Cascade Laser emission analyser which measures NO, NO_2, N_2O and NH_3 emissions.

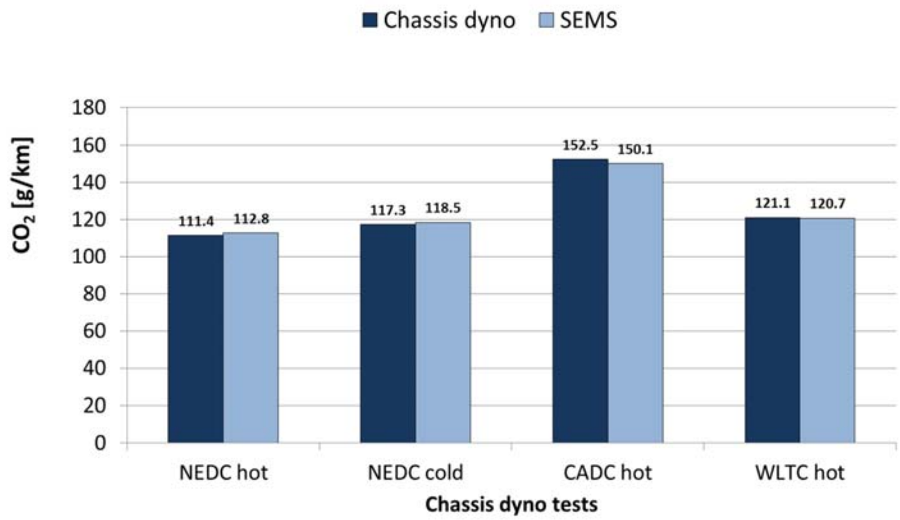


Figure A-3: CO_2 emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS.

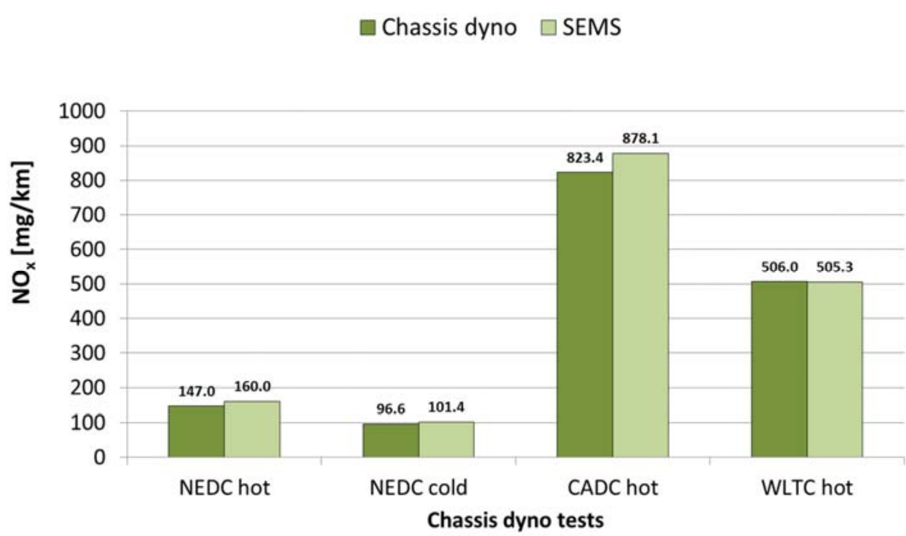


Figure A-4: NO_x emissions of a Euro 6 diesel passenger car on a chassis dynamometer test: comparison of simultaneously executed measurements with the CVS/bag method of the chassis dynamometer and SEMS.

~~1.1.6~~0.1.6 Particulate number emission tests

For some of the tested vehicles the particulate number emission at low idle speed was measured with a TSI 3795 particulate number counter (NPET).

1.2 Emission test results

1.2.1 Overview of the mileages and average emissions of the tested vehicles

Test results were collected in test programs that are subdivided into three sub test programmes, these are:

1. Monitoring test program: During daily on-road use of the vehicle with different drivers emission data were collected.
2. Emission test program: On defined routes in the western part of The Netherlands (in total appr. 1075 km) urban, rural and motorway emission data were collected.
3. Chassis dynamometer test program: Two vehicles were also tested on the chassis dynamometer but data of only one of the vehicles is reported. The chassis dynamometer test of the second vehicle was performed in another project.

In Table A-6 an overview of the mileages of the three sub test programs of the five tested vehicles is given. In the sections 1.2.2 to 1.2.6 detailed emission test results of the five tested vehicles are reported.

Table A-6: Overview of mileages of the different parts in test programs of the different vehicles.

No	**Brand**	**Model**	**Distances [km]**			
			Monitoring	Emission test program	Chassis dyno test program	Total
1	Volvo	XC 60	4065	1074	516	5654
2	Peugeot	308	6397	1095	628	8120
3	Skoda	Octavia	3560	707	-	4267
4	Mercedes	B180	2430	704	-	3134
5	Renault	Master	1259	1015	-	2274

In Table A-7 the average CO_2, NO_x and NH_3 emissions of the total test programme of the five tested Euro 6d-Temp vehicles are reported. The average real-world NO_x emissions were 35 to 125 mg/km and lower than the RDE NO_x limit values of 168 or 262.5 mg/km. The average NH_3 emission of four tested vehicles was 0.9 to 1.5 mg/km but the Peugeot 308 had an average NH_3 emission of 21.7 mg/km.

Table A-7: Overview of average CO_2, NO_x and NH_3 emission of the tested Euro 6d-Temp vehicles.

		Category	**Distance [km]**	**CO_2 [g/km]**	**NO_x [mg/km]**	**NH_3 [mg/km]**
Volvo	XC 60	M	5654	173	125	0,9
Peugeot	308	M	6397	131	54	21,7
Skoda	Octavia	M	4267	130	46	1,5
Mercedes	B180	M	3134	122	35	1,4
Renault	Master	N1 Cl. 3	2274	241	54	1,5

1.2.2 Volvo XC 60

Table A-8: Vehicle specifications of the Volvo XC 60 Euro 6d-Temp diesel

Trade Mark	[-]	Volvo
Type	[-]	Type: U Variant: UZA8 Uitvoering: UZA8UC??
Body	[-]	Passenger vehicle
Vehicle Class	[-]	M1
Fuel	[-]	diesel
Vehicle Registration Number	[-]	
Vehicle Identification Number	[-]	YV1UZA8UCJ1109080
Engine Code	[-]	D4204T14
Swept Volume	[cm^3]	1.969
Max. Power	[kW]	140
Euro Class	[-]	Euro 6d-Temp
Type Approval Authority	[-]	RDW Netherlands
Type Approval Number	[-]	e4*2007/46*1220*01
Emission class	[-]	715/2007*2017/1347AG
Vehicle Empty Mass	[kg]	1766
Odometer	[km]	17,598
Registration Date	[dd-mm-yyyy]	16-4-2018

The emission control of the Volvo XC 60 contains DOC + EGR + DPF + LNT +SCR.

~~1.2.2.1~~0.2.2.1 On-road test program

The on-road test programme of the Volvo XC 60 was performed from April 24th, 2019 to August 5th, 2019. In this period with a total distance of 5654 km SEMS data were logged and stored.

It is partitioned in three parts:

- A random on-road monitoring test programme of 4065 km which was executed on Dutch and German roads.
- A dedicated on-road emission test programme of 1074 km on defined (RDE) routes which was executed on Dutch roads between Amsterdam and Rotterdam.
- A chassis dynamometer test programme of 516 km which is part of another project.

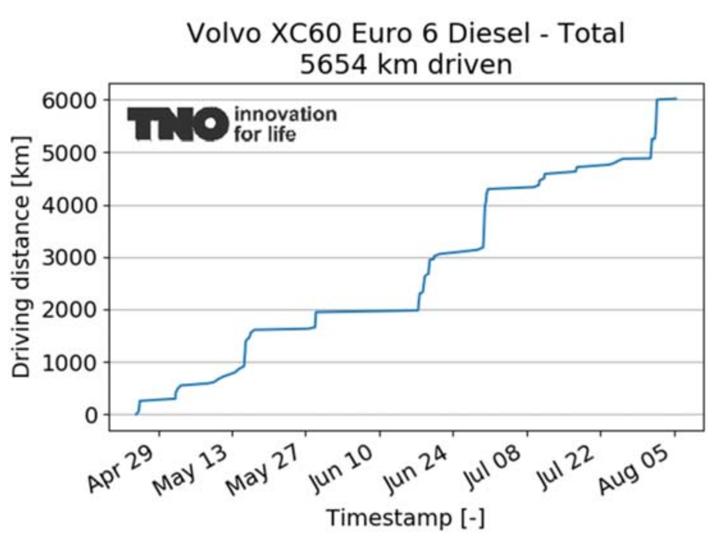


Figure A-5: Distance driven with respect to time of the test programme (in total 93,9 hours) of the Volvo XC 60.

As shown in Figure A-6, at a first glance, the NO_x emissions of the monitoring programme are higher than the NO_x emission of the emission test program. During the monitoring programme the vehicle was not driven with maximum payload. Within the speed range of 0 to 140 km/h the average NO_x emissions during the monitoring programme is 123.5% higher than during the emission test program.

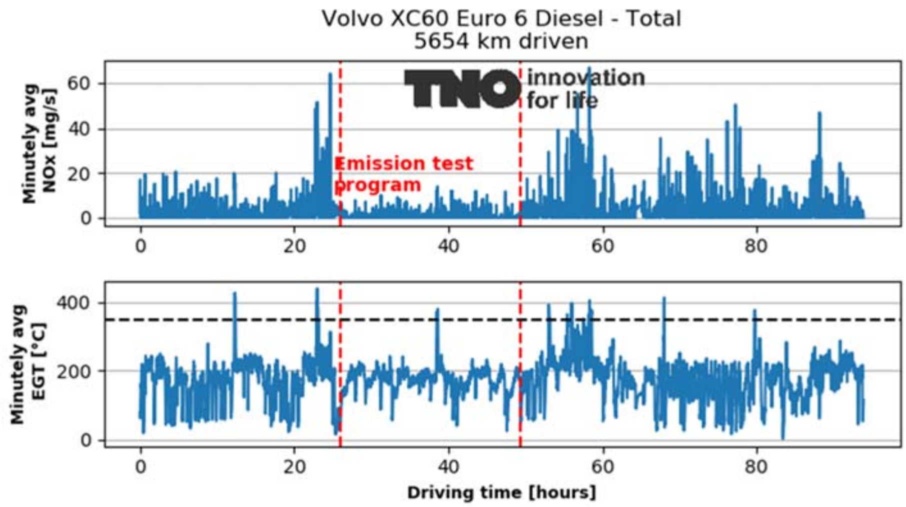


Figure A-6: NO_x emission and exhaust gas temperatures over the test programme (in total 93.9 hours) of the Volvo XC 60. The red dotted lines mark the period of the emission test program.

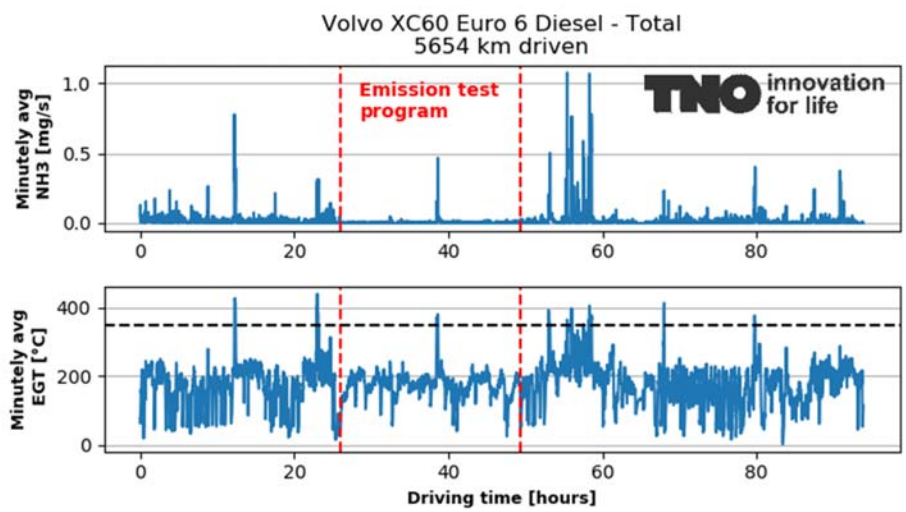


Figure A-7: NH_3 emission and exhaust gas temperatures over the test programme (in total 93.9 hours) of the Volvo XC 60. The red dotted lines mark the period of the emission test program.

In Table A-9 an overview of (average) test results of the total and partial test programs are given. The overall average fuel consumption was 6.52 litres per 100 km, the AdBlue consumption was not measured.

The average NO_x emission in the emission test programme with an average vehicle speed of 45.8 km/h is 71.7 mg/km and in the monitoring test programme with an average speed of 67,1 km/h the average NOx emission is 131.5 mg/km. In the monitoring test programme, the vehicle ran long distances on German motorways but also a lot of short trips (with cold start) were performed. In both test programs the NH_3 emission is up to 1 mg/km. The DPF was regenerated approximately once per 600 km and the average duration of the DPF regeneration was about 400 seconds.

Table A-9: Overall test results of the Volvo XC 60 Euro 6d-Temp diesel.

		Total*	Monitoring	Emission test program
Total Distance	[km]	5654.3	4065.0	1073.7
Total duration	[hh]	93.9	60.6	23.43
Average speed	[km/h]	60.2	67.1	45.8
Idle time	[%]	10.4	11.3	11.2
Start-stop time	[s]	38349	28025	4115
Start-stop time	[%]	11.4	12.9	4.9
Fuel cons. Grav.	[ltr / 100 km]	No result	No result	4.62
Fuel cons. SEMS	[ltr / 100 km]	6.52	6.45	6.75
AdBlue cons. Grav.	[ltr / 1000 km]	No result	No result	No result
CO_2 SEMS	[g/km]	172.9	171.0	179.0
NO_x	[mg/km]	124.8	131.5	71.6
NH_3	[mg/km]	0.9	1.0	0.4
No. of DPF regenerations	[-]	9	7	1
Total duration DPF regenerations	[s]	3437	3010	427
Av. DPF regeneration interval	[km]	628	581	1011
Av. DPF Regen. duration	[s]	382	430	427
Spec. DPF regen. duration	[s/1000 km]	608	740	398

*Incl. a chassis dynamometer test programme of 515.6 km of another project.

In Figure A-8 the average NO_x, CO_2 and NH_3 emissions of the Volvo XC 60 over the different speed bins of the total test programme of 5654 km and in Figure A-9 the 'RDE' average NOx results of the urban, rural and highway sections are shown. The NO_x emissions in the 'RDE' test are well below the limit value of 168 mg/km. At vehicle speeds higher than 130 km/h the NH_3 emission increases from 2 to 8 mg/km.

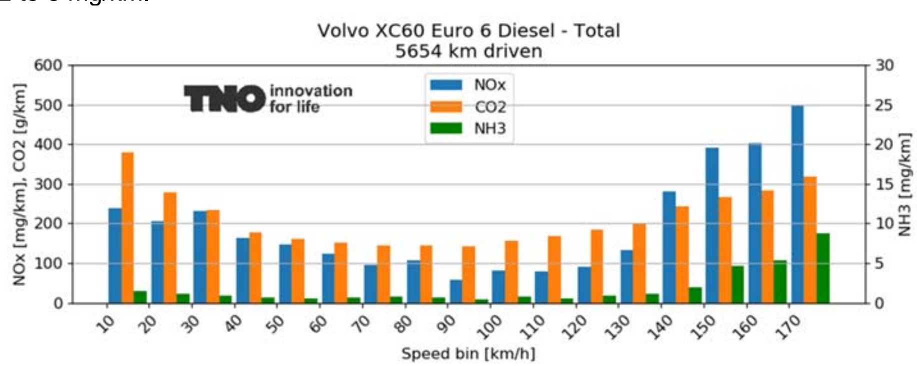


Figure A-8: Binned CO_2, NO_x and NH_3 emissions of the total test programme of the Volvo XC 60.

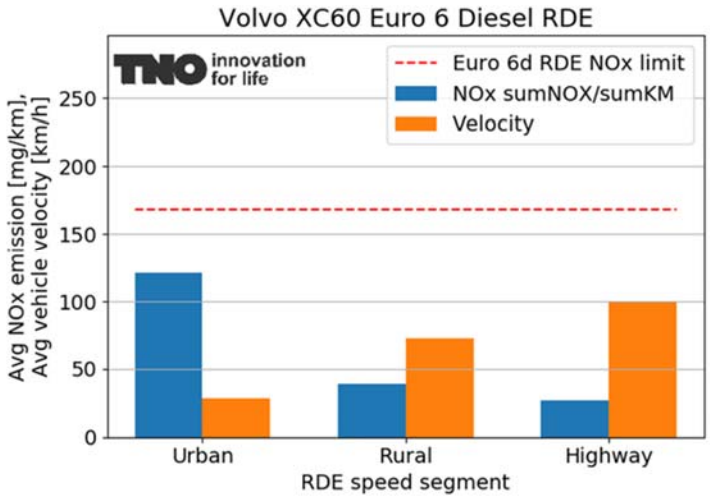


Figure A-9: Average velocities and average NOx emissions in the urban, rural and highway parts of the 'RDE' test of a Volvo XC 60.

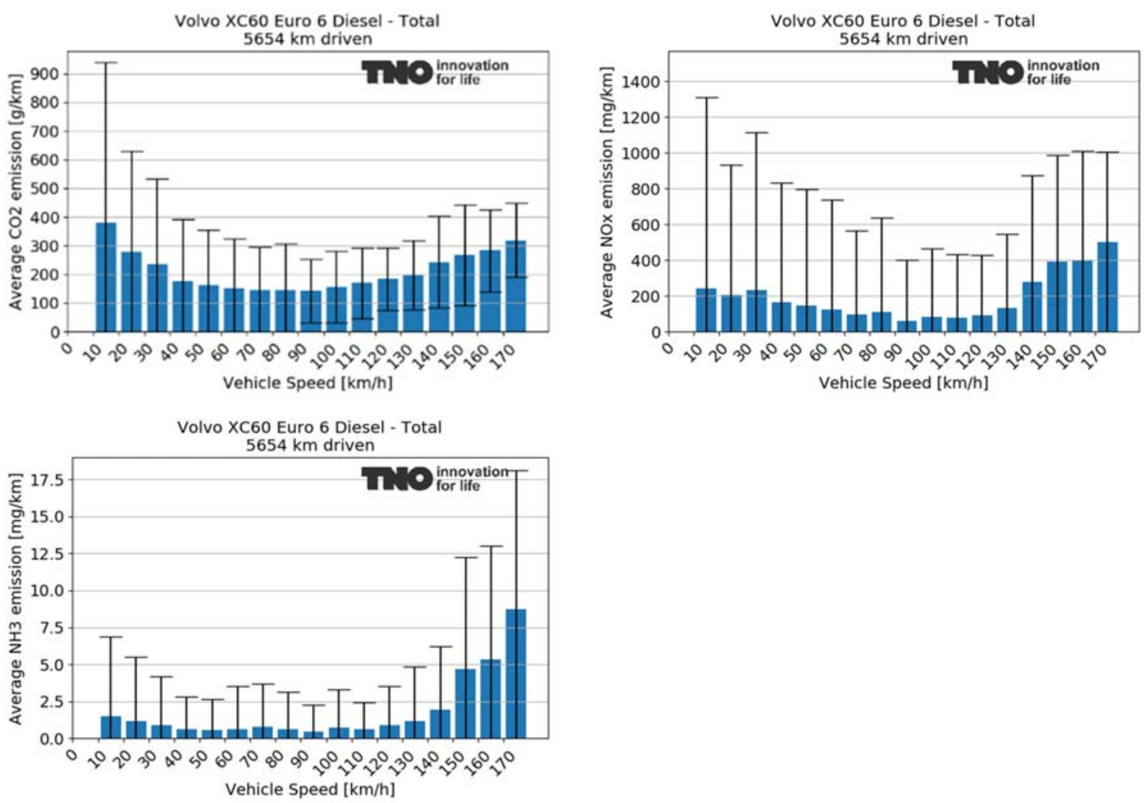


Figure A-10: Average CO_2, NO_x and NH_3 emissions dependent on vehicle speed bin during all driving for a Volvo XC 60.

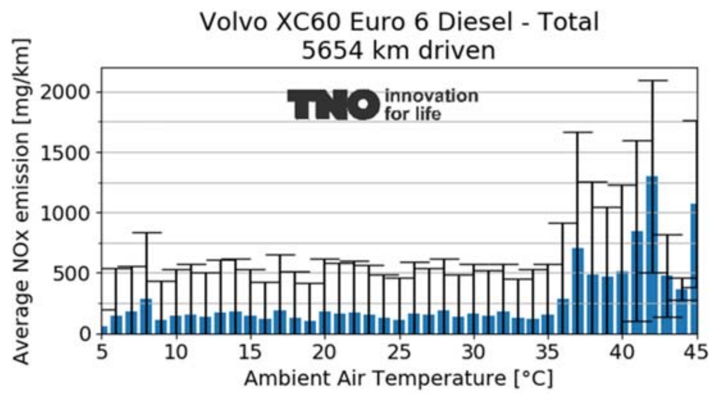


Figure A-11: Average NO_x emissions per ambient air temperature bin during all driving for a Volvo XC 60. Note that the ambient air temperature is logged by the vehicle, and therefore can be affected by the state of the vehicle itself. Furthermore, this does not address the respective driving situations at these temperatures (i.e. driving behaviour can be different in summer due to a range of factors, let alone the temperature).

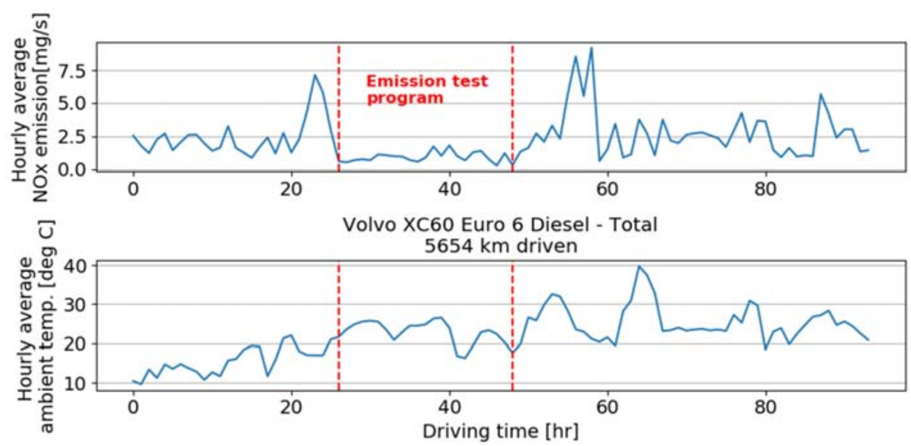


Figure A-12: NO_x emission and exhaust gas temperatures over the test programme (in total 93.9 hours) of the Volvo XC 60. The red dotted lines mark the period of the emission test program.

~~1.2.2.2~~0.2.2.2 *Emission test program*

The emission test programme consisted of a selected number of trips in the western part of The Netherlands. Urban, rural and motorway traffic is well covered and also cold and warm starts and congestion. Different 'RDE' tests with different loads and driving styles were executed. In the emission test programme of the Volvo XC 60 the average CO_2 emission was in the range of 149 to 272 g/km, the average NO_x emission was in the range of 25 to 125 mg/km and the average NH_3 emission was in the range of 0.2 to 2.1 mg/km.

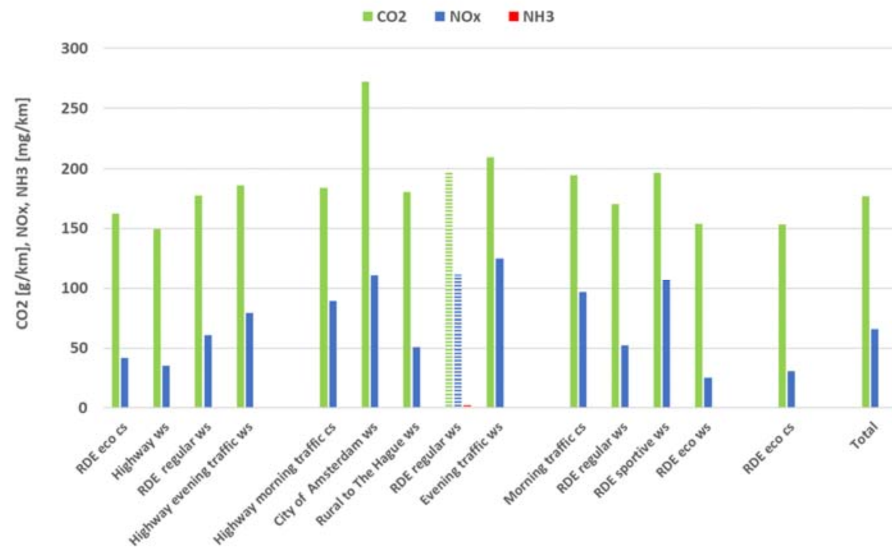


Figure A-13: Average CO_2, NO_x and NH_3 results of the emission test programme of the Volvo XC 60.

1.2.3 Peugeot 308

Table A-10: Vehicle specifications of the Peugeot 308 Euro 6d-Temp diesel

Trade Mark	[-]	Peugeot
Type	[-]	308
Body	[-]	Passenger vehicle
Vehicle Class	[-]	M1
Fuel	[-]	diesel
Vehicle Registration Number	[-]	
Vehicle Identification Number	[-]	VF3LBYHZPJS410781
Engine Code	[-]	YH01
Swept Volume	[cm^3]	1.499
Max. Power	[kW]	96
Euro Class	[-]	Euro 6d-temp
Type Approval Authority	[-]	France
Type Approval Number	[-]	e2*2007/46*0405*22
Emission class	[-]	715/2007*2017/1347*BG
Vehicle Empty Mass	[kg]	1155
Odometer	[km]	15,297
Registration Date	[dd-mm-yyyy]	14-1-2019

The emission control of the Peugeot 308 contains EGR + DOC + LNT+ SCR + SCRF.

~~1.2.3.1~~0.2.3.1 On-road emission test program

The emission test programme of the Peugeot 308 was performed from May 24th, 2019 to August 15th, 2019. In the test programme a total distance of 8120 km was run and SEMS data were logged (measuring frequency 1 Hz) and stored.

The test programme is partitioned in three parts;

- A random real-world on-road monitoring test programme of 6397 km which was executed on Dutch and German roads.
- An on-road dedicated emission test programme of 1095 km on defined (RDE) routes which was executed on Dutch roads between Amsterdam and Rotterdam.
- A chassis dynamometer test programme of 628 km.

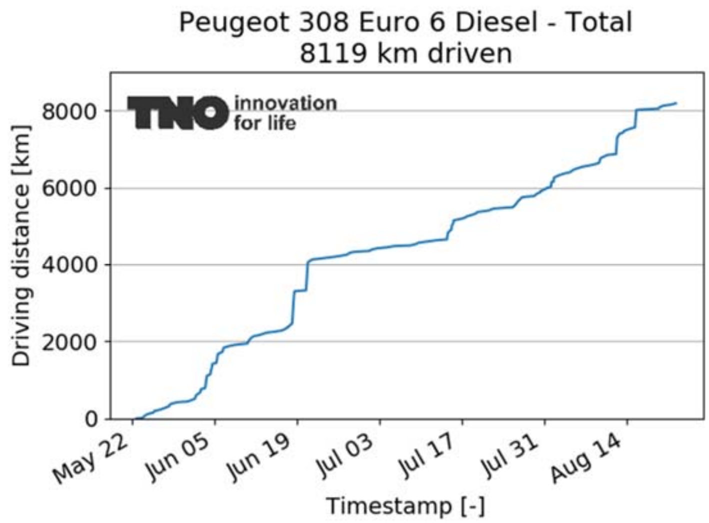


Figure A-14: Distance driven with respect to time of the test programme (in total 151.9 hours) of the Peugeot 308.

As shown in Figure A-15 at a first glance, the NO_x emissions of the monitoring programme is slightly higher than the NO_x emission of the emission test programme (56.9 versus 41.7 mg/km). During the monitoring programme the vehicle was driven with a low payload.

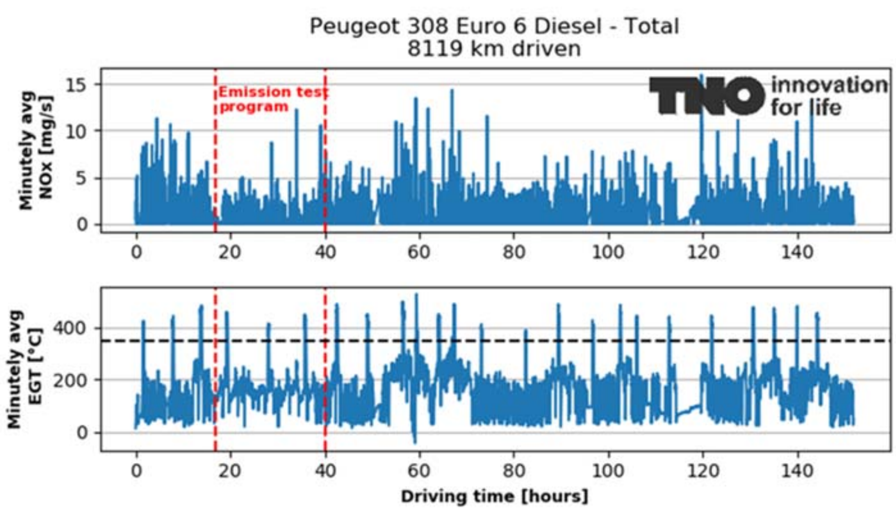


Figure A-15: NO_x emission and exhaust gas temperatures over the test programme (in total 151.9 hours) of the Peugeot 308. The red dotted lines mark the period of the emission test program.

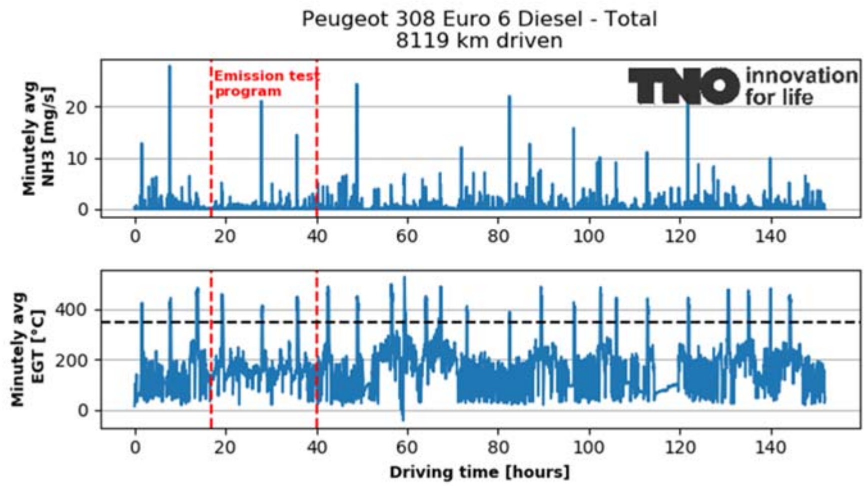


Figure A-16: NH_3 emission and exhaust gas temperatures over the test programme (in total 151.9 hours) of the Peugeot 308. The red dotted lines mark the period of the emission test program.

In Table A-11 an overview of (average) test results of the total and partial test programs is given. The overall average fuel consumption of the Peugeot 308 was 4.9 litres per 100 km and the overall average AdBlue consumption was 0.797 litre per 1,000 km. The average NOx emission in the emission test programme with an average vehicle speed of 46.4 km/h is 41.7 mg/km and in the monitoring test programme with an average speed of 53,4 km/h the average NOx emission is 56,9 mg/km. In the monitoring test programme the vehicle ran long distances on German motorways but also a lot of short trips (with cold start) were performed. The NH_3 emission in both programs is similar, 20.8 and 22.8 mg/km. In the WLTC tests of the chassis dynamometer test programme the NH_3 emission was 11.7 mg/km. The DPF was regenerated approximately once per 350 km and the average duration of the DPF regeneration was about 960 seconds.

Table A-11: Overall test results of the Peugeot 308 Euro 6d-Temp diesel

		Total	Monitoring	Emission test program	Chassis dyno.
Total Distance	[km]	8119.9	6396.9	1094.6	628.4
Total duration	[hh]	151.9	119.9	23.6	8.5
Average speed	[km/h]	53.5	53.4	46.4	74.4
Idle time	[%]	14.9	17.4	5.9	5.2
Start-stop time	[s]	21746	10944	9882	920
Start-stop time	[%]	4.0	2.5	11.6	3.0
Fuel cons. Grav.	[ltr / 100 km]	4.89	No result	No result	No result
Fuel cons. SEMS	[ltr / 100 km]	4.95	5.08	4.55	4.31
AdBlue cons. Grav.	[ltr / 1000 km]	0.797	No result	No result	No result
CO_2 SEMS	[g/km]	131.2	134.6	120.5	114.3
NO_x	[mg/km]	53.6	56.9	41.7	40.7
NH_3	[mg/km]	21.7	22.8	20.8	11.7
No. of DPF regen.	[-]	24	19	3	2
Total duration regen.	[s]	23045	18600	2984	1461

Av. regen. interval	[km]	338.3	336.7	364.9	314.2
Av. Regen. duration	[s]	960	979	995	730
Spec. regen. duration	[s/1000 km]	2838	2907	2726	2324

CO_2 emissions:
The measured CO_2 emission in the three partial emission test programs is 114.3 to 134.6 g/km. The lowest CO_2 emission of 114.3 g/km was measured on the chassis dynamometer and it is 15.1% lower than the CO_2 emission of 134.6 g/km of the monitoring program. Probably this is mainly caused by the execution of different road load adjustments and validation checks in the chassis dynamometer test programme in which the vehicle is motored by the chassis dynamometer.

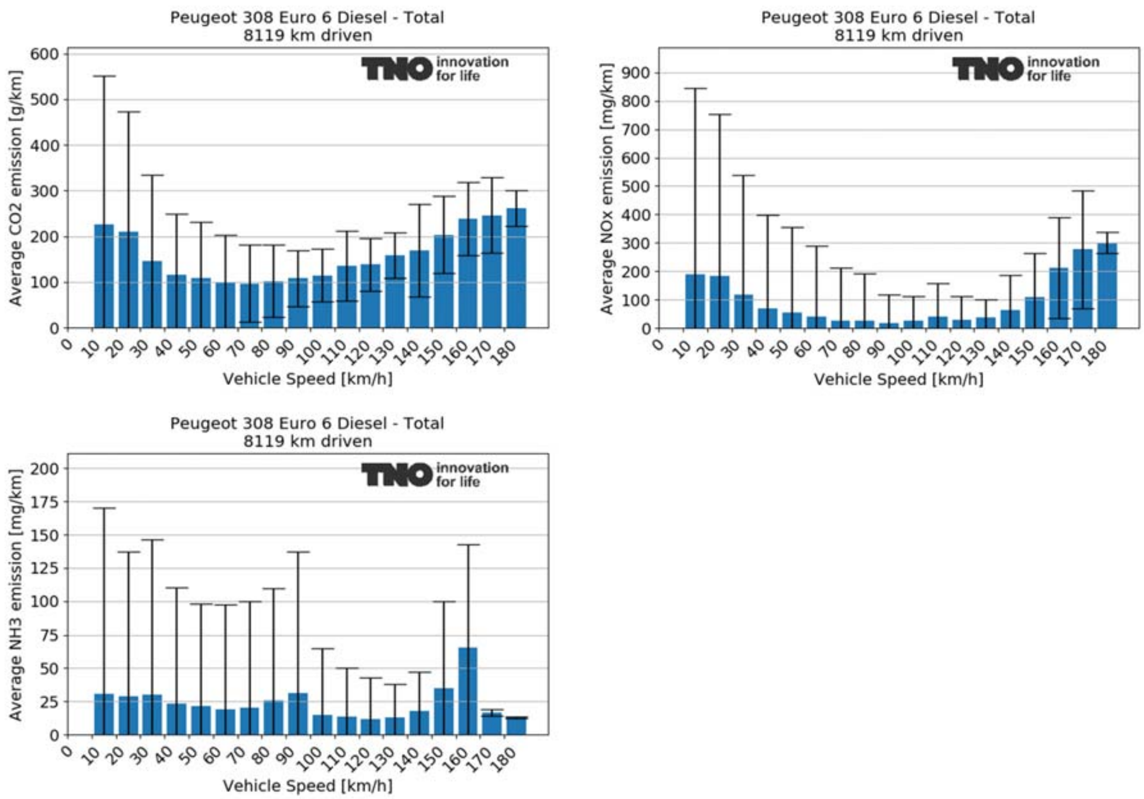


Figure A-17: Average CO_2, NO_x and NH_3 emissions dependent on vehicle speed bin during all driving for a Peugeot 308.

Fuel consumption:
Two independent methods were used to determine the fuel consumption.
At first the fuel tank fillings and odometer readings were registered. In this test programme over 7836 km 383.6 litres (12 fillings) of fuel were consumed which results in a fuel consumption of 4.89 ltr / 100 km. Secondly every second the fuel consumption was measured/determined by the SEMS (via carbon-balance method), this measured fuel consumption is 4.87 ltr / 100 km.

NO_x emissions:
The measured NO_x emission in the three partial emission test programs is 40.7 to 56.9 mg/km.

The lowest NO_x emission of 40.7 mg/km was measured on the chassis dynamometer and is 28.5% lower than the NOx emission of 56.9 mg/km of the monitoring program.

In Figure A-18 the average NO_x, CO_2 and NH_3 emissions of the Peugeot 308 over the different speed bins of the total test programme of 8119 km are shown. In Figure A-19 the 'RDE' NO_x results of the urban, rural and highway sections are shown. The NOx emissions in the 'RDE' test are well below the limit value of 168 mg/km.

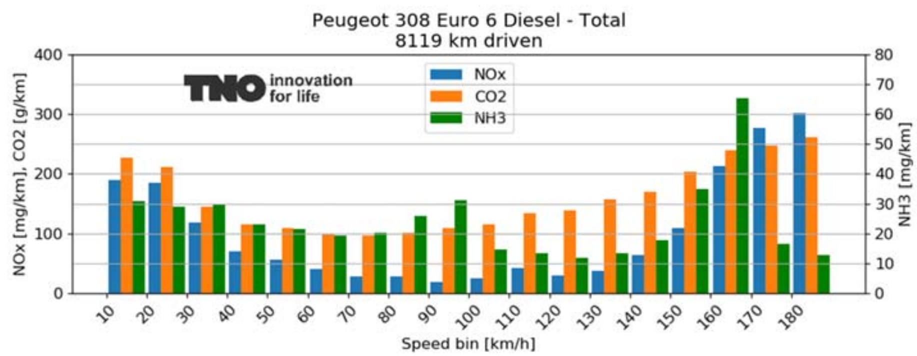


Figure A-18: Binned CO_2, NO_x and NH_3 emissions of the total test programme of the Peugeot 308.

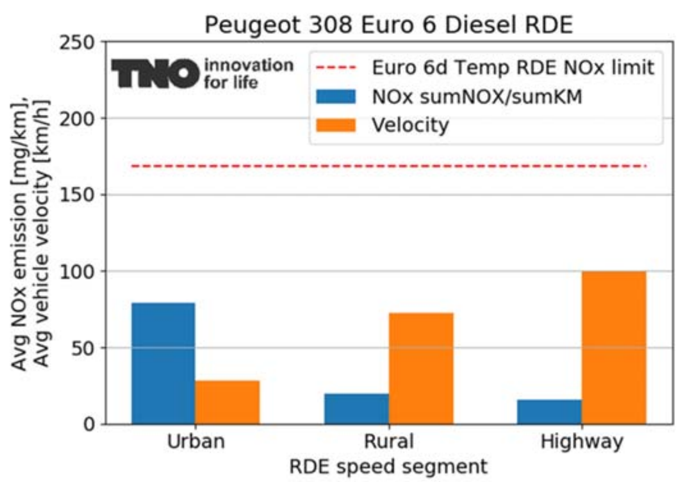


Figure A-19: Average velocities and average NOx emissions in the urban, rural and highway parts of the 'RDE' test of a Peugeot 308.

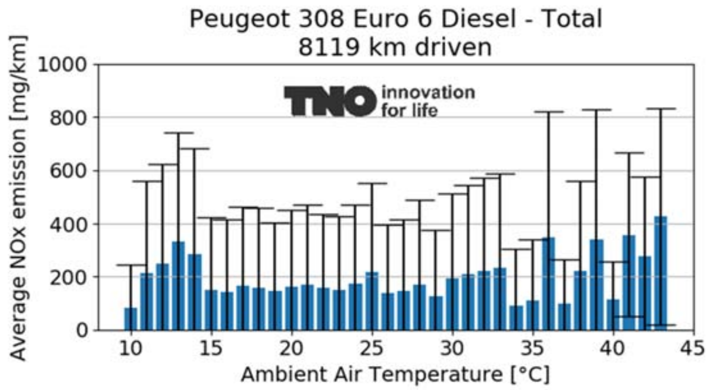


Figure A-20: Average NO_x emissions per ambient air temperature bin during all driving for a Peugeot 308. Note that the ambient air temperature is logged by the vehicle, and therefore can be affected by the state of the vehicle itself. Furthermore, this does not address the respective driving situations at these temperatures (i.e. driving behaviour can be different in summer due to a range of factors, let alone the temperature).

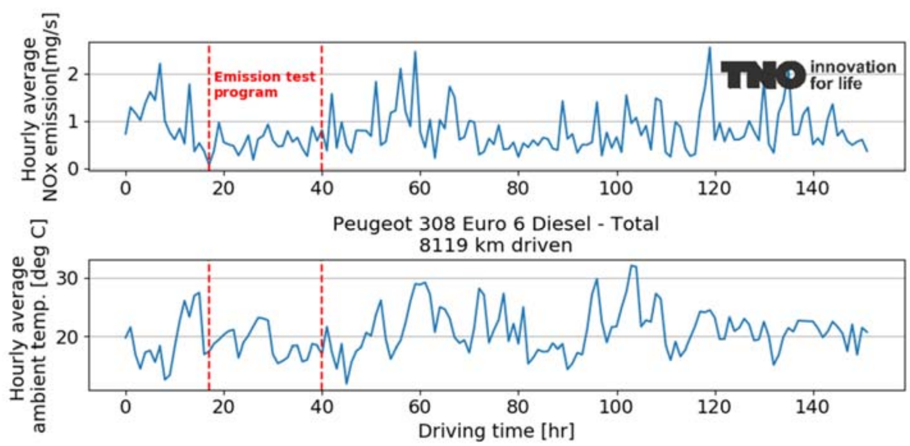


Figure A-21: NO_x emission and exhaust gas temperatures over the test programme (in total 151.9 hours) of the Peugeot 308. The red dotted lines mark the period of the emission test program.

AdBlue consumption:
At the start of the test programme the AdBlue tank was completely filled. After 8093 km again the AdBlue tank was filled and 6.45 litres was added. This results in an average AdBlue consumption of 0.797 litre per 1,000 km.

NH_3 emissions:
The NH_3 emission seems not related to vehicle speed and ranges from 12 to 65 mg/km (average 22.8 mg/km), see Figure A-18. At lower speeds (10 to 40 km/h) the NH_3 emission is around 30 mg/km. At higher speeds (140 to 180 km/h) the NH_3 emission varies independent from the vehicle speed from 12 to 65 mg/km.
Figure A-22 shows that the highest peaks in NH_3 emissions occur during regeneration of the DPF. This is possibly caused by urea deposits in the exhaust system which sublimate at the higher exhaust gas temperature during regeneration.

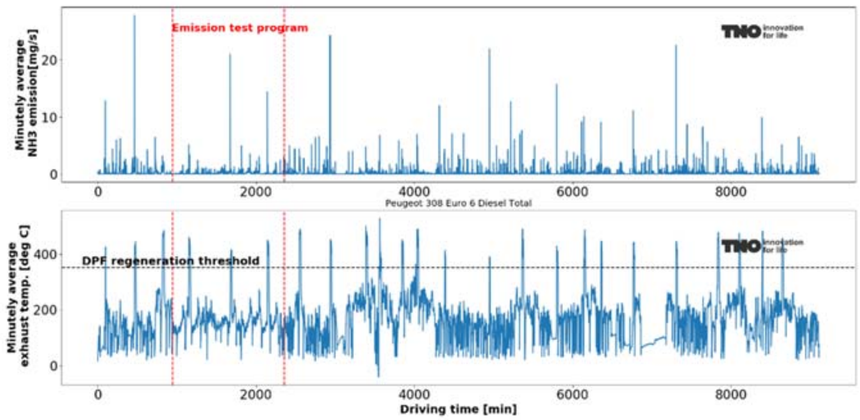


Figure A-22: Minutely average NH_3 emissions and exhaust gas temperature of the Peugeot 308 over all measurement data.

DPF regenerations:

In Figure A-22 the minutely averages of the NH_3 emissions and the exhaust gas temperature are shown. The peaks in the exhaust gas temperature are indicated as DPF regeneration when the exhaust gas temperature is above 350 °C and the time interval between the start of two regenerations is more than 30 minutes. The DPF regeneration interval in the three separate parts is between 314.2 to 364.9 km and the average duration of a DPF regeneration is 730 to 995 s. The total duration of all DPF regenerations is 6.4 hours and this is 4.2% of the total run time of 151.9 hours.

~~1.2.3.2~~0.2.3.2 *Emission test program*

The emission test programme consists of a selected number of trips in the western part of The Netherlands. Urban, rural and motorway traffic is well covered and also cold and warm starts and congestion. Different 'RDE' tests with different loads and driving styles were executed. In the emission test programme of the Peugeot 308 the CO_2 emission was in the range of 97 to 159 g/km, the NO_x emission was in the range of 10 to 121 mg/km and the NH_3 emission was in the range of 6 to 52 mg/km.

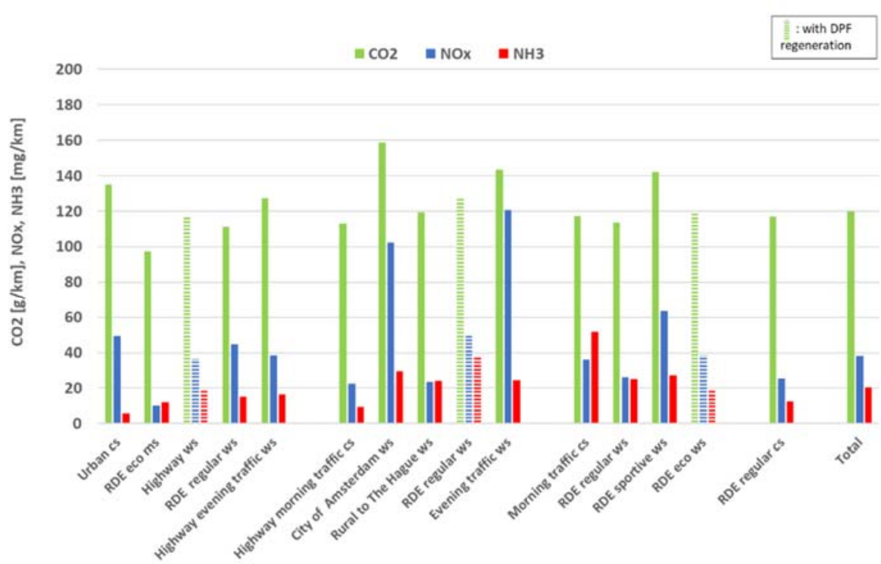


Figure A-23: Test results of the emission test programme of the Peugeot 308.

~~1.2.3.3~~0.2.3.3 *Results of chassis dynamometer test program*

From August 12th to 15th, 2019 Urban Driving Cycles (UDC tests) and Word Harmonised Test Cycles (WLTC) were executed on the chassis dynamometer of Horiba Europe GmbH in Oberursel. Soaking, preconditioning and all emission tests were executed at ambient temperatures of 23 to 25 ºC. A QCL analyser for NO, NO_2, N_2O and NH_3 measurements was installed. In Appendix B the specifications of the chassis dynamometer and test equipment are reported.
The emissions of all tests were simultaneously measured with a TNO Smart Emission Measurement System (SEMS). In the post processing the measured NO_x and NH_3 concentrations were corrected according to the most recent correction formulas.

Table A-12: Chassis dynamometer test results of the Peugeot 308 Euro 6d-Temp diesel

Date	Test	Road load	Start	HC	CO	CO2	NOx	NO	NMHC	CH4	HC + NOx	Particle		Fuel cons.	DPF regen.
			cold/warm									Grav.	counts		
				[mg/km]	[mg/km]	[g/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[mg/km]	[1/km]	[l/100km]	
13-8-2019	WLTC	1	cold	5.1	60.0	118.4	41.5	28.1	2.3	3.3	46.6	0.43	1.1E+11	4.48	No
14-8-2019	WLTC	1	cold	5.5	81.5	118.0	46.1	32.1	0.1	3.2	51.6	0.39	8.5E+10	4.46	No
15-8-2019	WLTC	1	cold	6.4	85.5	119.8	45.3	29.7	3.5	3.5	51.8	0.42	9.4E+10	4.55	No
12-8-2019	WLTC	1	warm	6.8	20.7	110.9	96.8	64.9	5.9	0.9	103.5	0.45	8.1E+10	4.20	No
13-8-2019	WLTC	2	warm	32.2	631.2	155.4	132.1	92.2	12.7	22.5	164.3	2.54	4.2E+11	5.92	Yes
12-8-2019	4* UDC	1	warm	21.7	130.0	128.1	128.8	89.1	16.8	5.4	150.4	0.35	2.0E+11	4.85	No

In order to investigate the repeatability of the measurements three WLTC tests with road load setting 1 with cold start were executed. In Table A-13 average results are reported. The CO_2 emission was in the range of 118.0 to 119.8 g/km (SEMS 118.9 to 125,6 g/km, deviations +0.8 to +4.9%) and the NO_x emission was 41.5 to 46.1 mg/km (SEMS 42.8 to 48.6 mg/km, deviations -5.5 to +5.5%), see Figure A-24 and Figure A-25.
The NH_3 emissions with QCL technology were 23.4 and 25.8 mg/km (SEMS 23.3 to 26.0 mg/km, deviations 1 to +11%), see Figure A-26. The N_2O emission was 10.5 and 11.7 mg/km, i.e., 3 g/km $CO_{2\text{-eq}}$.

Table A-13: Chassis dynamometer MEXA and QCL test results of a Peugeot 308 Euro 6d-Temp diesel.

Test	Start	Road load	DPF regen.	CO_2	NO_x	NH_3	NO	NOx	N_2O
				[g/km]	[mg/km]				
				MEXA	MEXA	QCL	QCL	QCL	QCL
WLTC	cold	1	No	118.4	41.5	-	-	-	-
WLTC	cold	1	No	118.0	46.1	25.8	42.0	66.1	10.5
WLTC	cold	1	No	119.8	45.3	23.4	34.2	53.7	11.7
WLTC	warm	1	No	110.9	96.8	61.9	38.2	59.4	15.3
WLTC	warm	2	Yes	155.4	132.1	49.9	84.5	133.1	13.3
4*UDC	warm	1	No	128.1	128.8	8.2	119.8	185.0	77.3

The NO_x emission of the WLTC test with a warm start (road load 1) was 96.8 mg/km and surprisingly higher than the WLTC test with a cold start; The NH_3 emission with both measurement technologies was 61.9 and 64.6 mg/km which is more than 2 times higher than WLTC tests with cold start. The N_2O emission was 15.3 mg/km, i.e., 5 g/km $CO_{2\text{-eq}}$.

In addition a WLTC test with an increased road load setting and warm start was executed, in this test the DPF was regenerated; The emissions were: CO_2 155.4 g/km, NOx 132.1 mg/km, NH_3 49.9 mg/km and N_2O 13.3 mg/km, i.e., 4 g/km $CO_{2\text{-eq}}$.

Finally a 4*UDC test with warm engine start was executed. These emissions were: CO_2 128.1 g/km, NOx 128.8 mg/km , NH_3 8.2 mg/km and N_2O 77.3 mg/km, i.e., 23 g/km $CO_{2\text{-eq}}$.

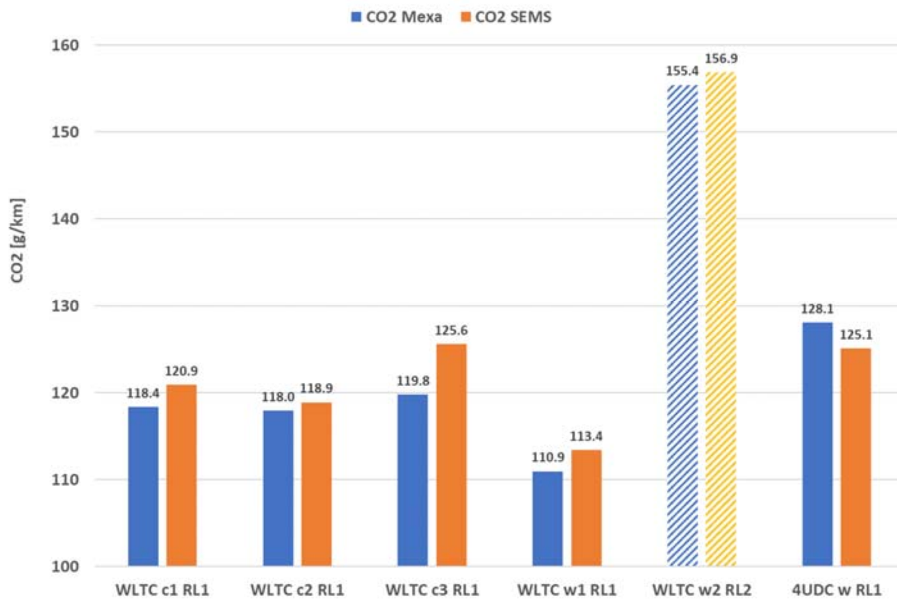


Figure A-24: WLTC and UDC CO_2 test results of a Peugeot Euro 6d-Temp diesel measured with CVS and SEMS. In the WLTC w2 RL2 test the DPF was regenerated.

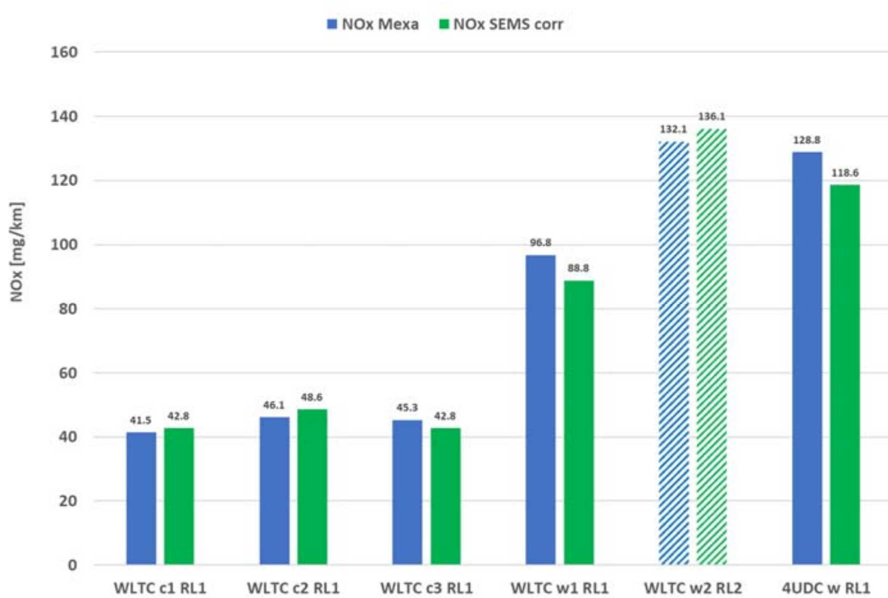


Figure A-25: WLTC and UDC NO_x test results of a Peugeot Euro 6d-Temp diesel measured with CVS and SEMS. In the WLTC w2 RL2 test the DPF was regenerated.

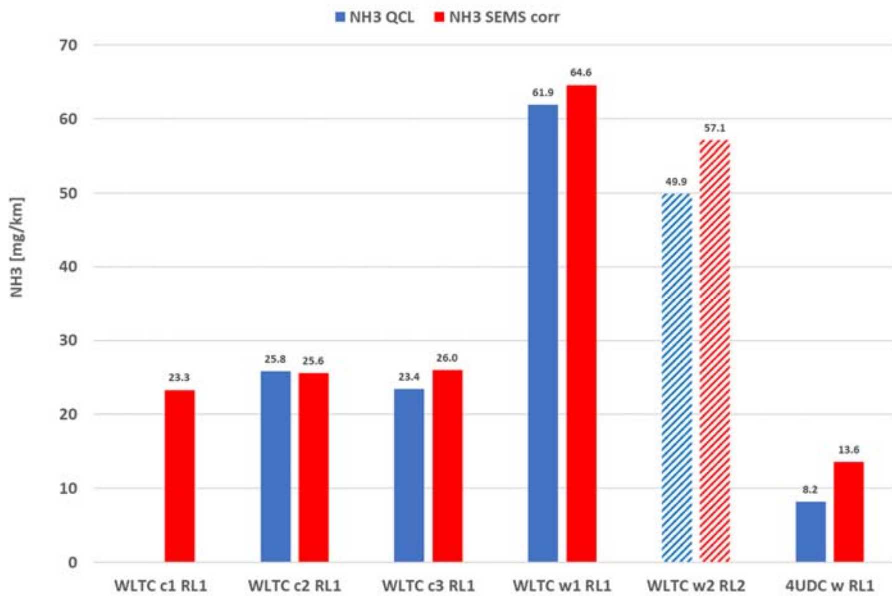


Figure A-26: WLTC and UDC NH_3 test results of a Peugeot Euro 6d-Temp diesel measured with QCL analyser and SEMS. In the WLTC w2 RL2 test the DPF was regenerated.

From this comparison of the chassis dynamometer and SEMS results in the three WLTC tests it can be concluded that both measuring technologies (NH_3 sensor and QCL analyser) measure similar and repeatable emissions.

~~1.2.3.4~~0.2.3.4 *DPF regenerations and emission monitoring*

Monitoring of emissions yields insights in emission behaviour over longer periods and of specific conditions, see Figure A-15. In this section DPF regenerations are studied in more detail. In Figure A-27 emission data of four different motorway trips (2 journeys, back and forth) are shown. In the second trip the DPF was regenerated during 21 minutes at vehicle speeds of 115 to 130 km/h (exhaust gas temperature was more than 450 ºC); The additional NO_x contribution caused by the DPF regeneration was substantial (appr. 4 g).

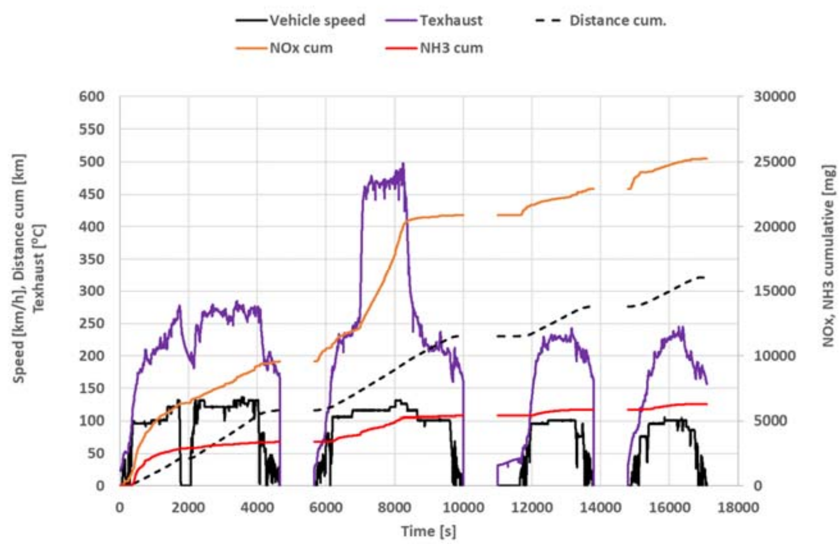


Figure A-27: Four motorway trips (total distance 321.7 km). In the second trip the duration of the DPF regeneration at vehicle speeds of 115 to 130 km/h was 21 minutes.

In Figure A-28 emission data of a long-haul trip from Switzerland to The Netherlands with a total distance of 814 km are shown. During this trip the DPF was regenerated two times. Both regenerations took 20 minutes and the distance interval was 333 km. The additional NO_x emission caused by the DPF regenerations is substantial and similar to the test of Figure A-27. For this specific long haul trip the relative DPF regeneration time was 10%. The relative DPF regeneration time of the total test programme was 4.2%.

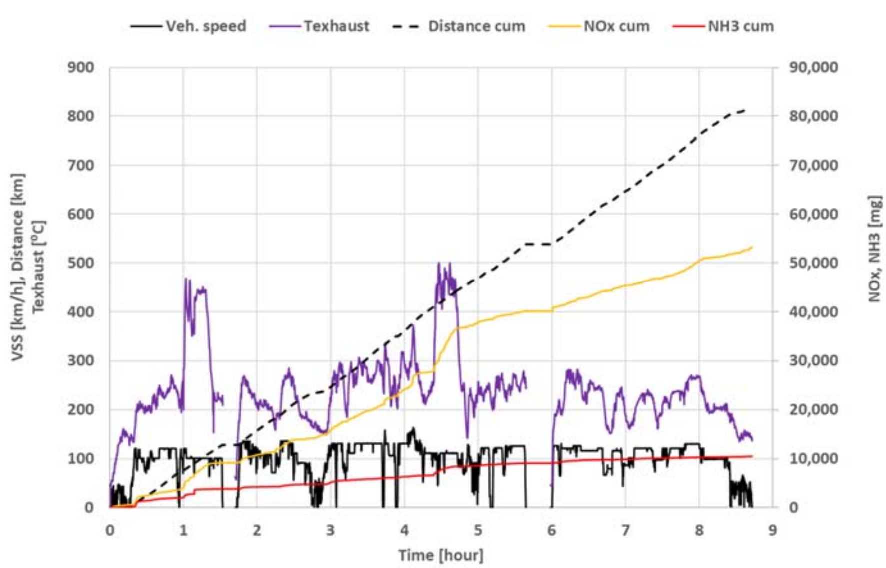


Figure A-28: Example of a long haul trip from Switzerland to The Netherlands (815 km, average vehicle speed 99.4 km/h). The average emissions were CO_2 133 g/km, NO_x 65 mg/k0m and NH_3 13 mg/km. The DPF was regenerated two times during 20 minutes, the interval was 333 km).

1.2.3.5 Particle number emissions at low idle speed

The particle number emission of the warm engine of the Peugeot 308 at low idle speed was less than 1,000 #/cm³.

1.2.4 Skoda Octavia

Table A-14: Vehicle specifications of the Skoda Octavia Euro 6d-Temp diesel

Trade Mark	[-]	Skoda
Type	[-]	Octavia
Body	[-]	Passenger vehicle
Vehicle Class	[-]	M1
Fuel	[-]	diesel
Vehicle Registration Number	[-]	
Vehicle Identification Number	[-]	TMBJG9NE4K0140578
Engine Code	[-]	R4 1.6l TDI
Swept Volume	[cm^3]	1.598
Max. Power	[kW]	85
Euro Class	[-]	Euro 6d-Temp
Type Approval Authority	[-]	
Type Approval Number	[-]	e8*2007/46*0318*05
Vehicle Empty Mass	[kg]	1285
Odometer	[km]	20,473
Registration Date	[dd-mm-yyyy]	30-4-2019

The emission control of the Skoda Octavia contains DOC + EGR + DPF + SCR.

~~1.2.4.1~~0.2.4.1 On-road emission test program

The on-road test programme of the Skoda Octavia was performed from September 23rd, 2019 to November 4th, 2019. In this period SEMS data were logged over 4267 km and stored. It is partitioned in two parts;

- A random real-world on-road monitoring test programme of 3560 km which was executed on Dutch roads.
- An on-road dedicated emission test programme of 707 km on defined (RDE) routes which was executed on Dutch roads between Amsterdam and Rotterdam.

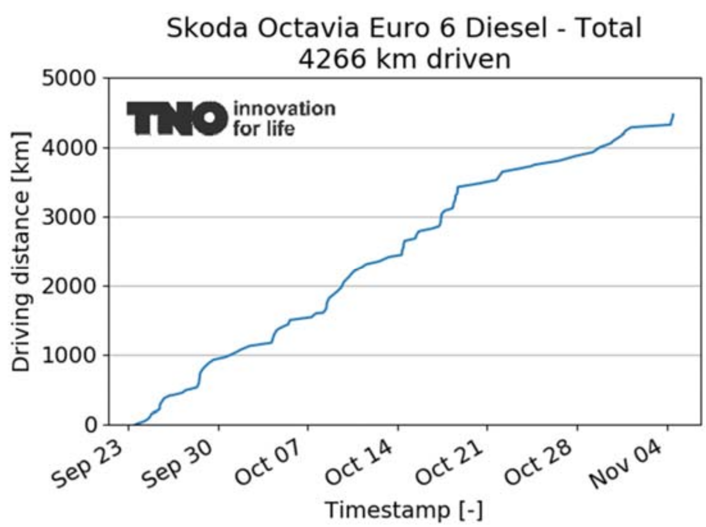


Figure A-29: Distance driven with respect to time of the test programme (in total 82.6 hours) of the Skoda Octavia.

As shown in Figure A-30, at a first glance, the NO_x emissions of the monitoring programme seems lower than the NO_x emission of the emission test program. During the monitoring programme the vehicle was not driven with maximum payload.

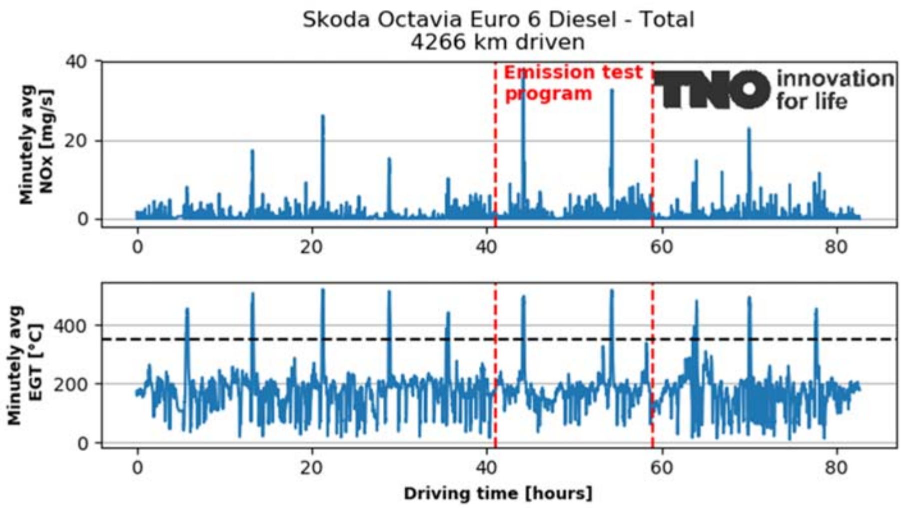


Figure A-30: NO_x emission and exhaust gas temperatures over the test programme (in total 82.6 hours) of the Skoda Octavia. The red dotted lines mark the period of the emission test programme and the black dotted line marks the DPG regeneration threshold temperature.

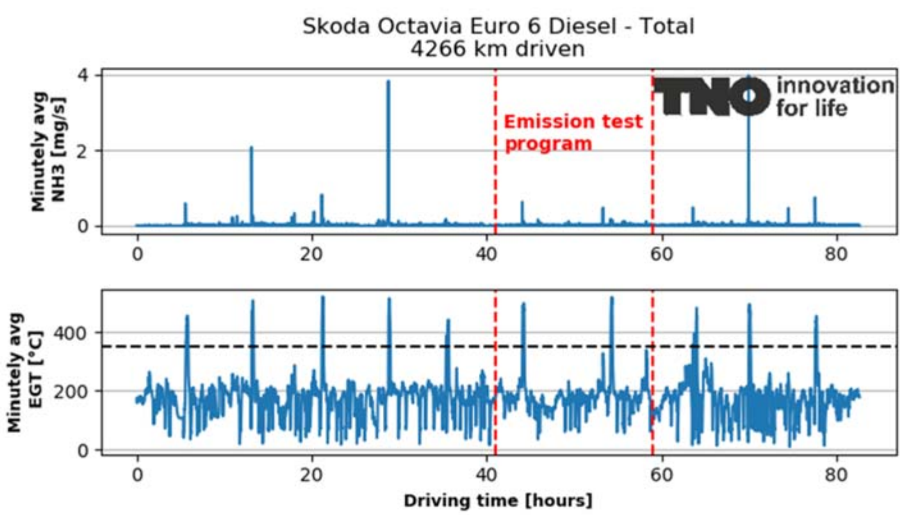


Figure A-31: NH_3 emission and exhaust gas temperatures over the test programme (in total 82.6 hours) of the Skoda Octavia. The red dotted lines mark the period of the emission test programme and the black dotted line marks the DPG regeneration threshold temperature.

In Table A-15 an overview of (average) test results of the total and partial test programs is given.

The overall average AdBlue consumption was 0.538 litre per 1,000 km.
The average NO_x emission in the emission test programme with an average vehicle speed of 41.7 km/h is 59.9 mg/km and in the monitoring test programme with an average speed of 54.2 km/h the average NO_x emission is 42.9 mg/km.
In both test programs the average NH_3 emission is up to 1.5 mg/km.
The DPF was regenerated once per 427 km and the average duration of the DPF regeneration was 824 seconds.

Table A-15: Overall test results of the Skoda Octavia Euro 6d-Temp diesel.

		Total	Monitoring	Emission test program
Total Distance	[km]	4267	3560	707
Total duration	[hh]	82.6	65.7	16.9
Average speed	[km/h]	51.6	54.2	41.7
Idle time	[%]	11.1	9.5	17.1
Start-stop time	[s]	16606	11237	5369
Start-stop time	[%]	5.6	4.7	8.8
Fuel cons. Grav.	[ltr / 100 km]	5.49	No result	No result
Fuel cons. SEMS	[ltr / 100 km]	4.89	4.79	5.41
AdBlue cons. Grav.	[ltr / 1000 km]	0.538	No result	No result
CO_2 SEMS	[g/km]	129.5	126.9	143.4
NO_x	[mg/km]	45.6	42.9	59.9
NH_3	[mg/km]	1.5	1.5	1.1
No. of DPF regen.	[-]	10	9	1
Total duration regen.	[s]	8239	7352	887
Av. regen. interval	[km]	427	396	-
Av. Regen. duration	[s]	824	817	887
Spec. regen. duration	[s / 1000 km]	1931	2065	1255

In Figure A-32 the average NO_x, CO_2 and NH_3 emissions of the Skoda Octavia over the different speed bins of the total test programme of 4266 km and in Figure A-33 the 'RDE' NOx results of the urban, rural and highway sections are shown. The average NOx emissions in the test(s) on the RDE route are well below the limit value of 168 mg/km. In the vehicle speed bins the average NO_x emission is 20 to 170 mg/km and the average NH_3 emission is 1 to 3.5 mg/km.

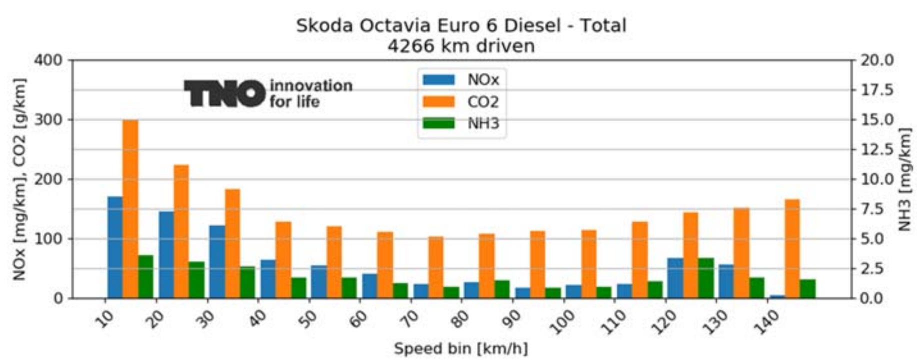


Figure A-32: Binned CO_2, NO_x and NH_3 emissions of the total test programme of the Skoda Octavia.

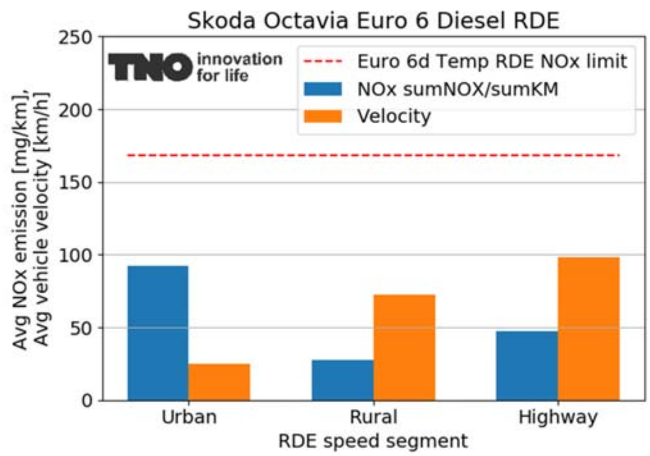


Figure A-33: Average velocities and average NOx emissions in the urban, rural and highway parts of the 'RDE' test of a Skoda Octavia.

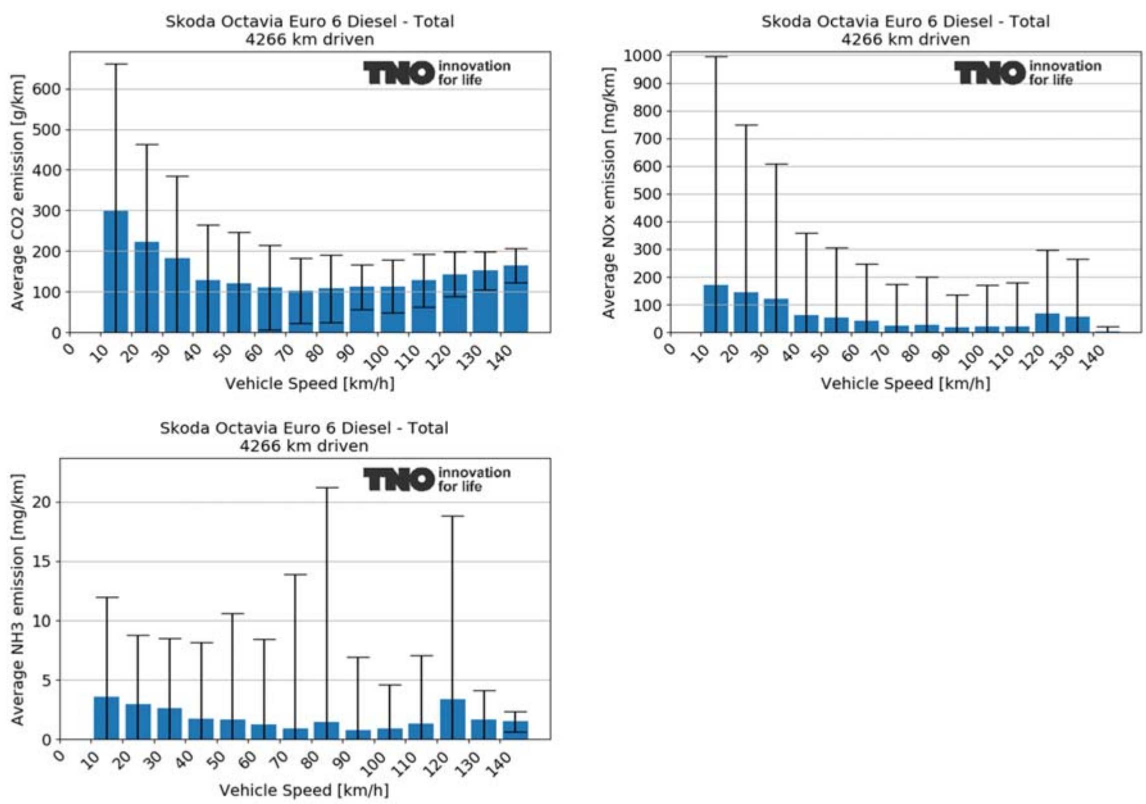


Figure A-34: Average CO_2, NO_x and NH_3 emissions dependent on vehicle speed bin during all driving for a Skoda Octavia.

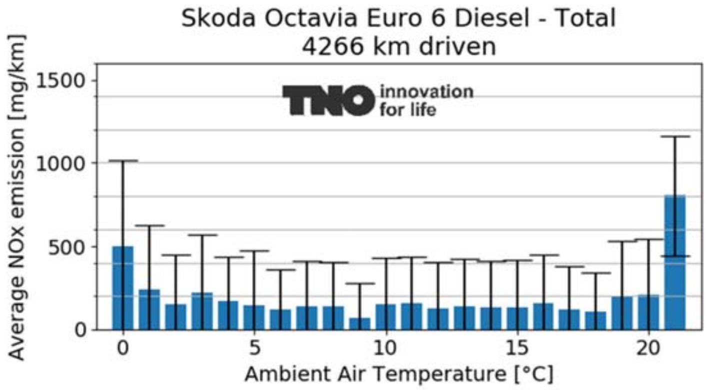


Figure A-35: Average NO_x emissions per ambient air temperature bin during all driving for a Skoda Octavia. Note that the ambient air temperature is logged by the vehicle, and therefore can be affected by the state of the vehicle itself. Furthermore, this does not address the respective driving situations at these temperatures (i.e. driving behaviour can be different in summer due to a range of factors, let alone the temperature).

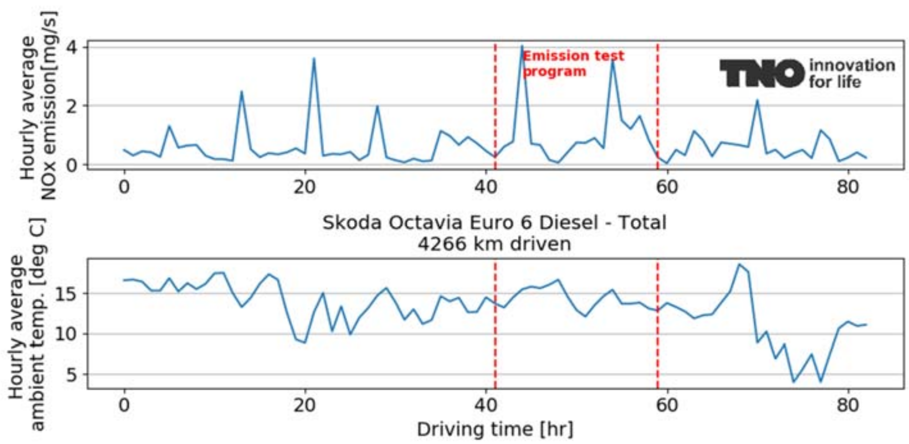


Figure A-36: NO_x emission and exhaust gas temperatures over the test program of the Skoda Octavia. The red dotted lines mark the period of the emission test program.

~~1.2.4.2~~0.2.4.2 *Emission test program*

In the emission test programme of the Skoda Octavia the composition of the emission tests deviated from the other vehicles because more ‘RDE’ tests were driven with a high payload. The average CO_2 emission was in the range of 118 to 182 g/km, the average NO_x emission was in the range of 12 to 209 mg/km and the average NH_3 emission was in the range of 0.5 to 2.1 mg/km. The NO_x emission in one ‘RDE’ test was 209 mg/km and exceeded the RDE limit value of 168 mg/km because the DPF was regenerated. In the other tests the average NO_x emission was below 168 mg/km.

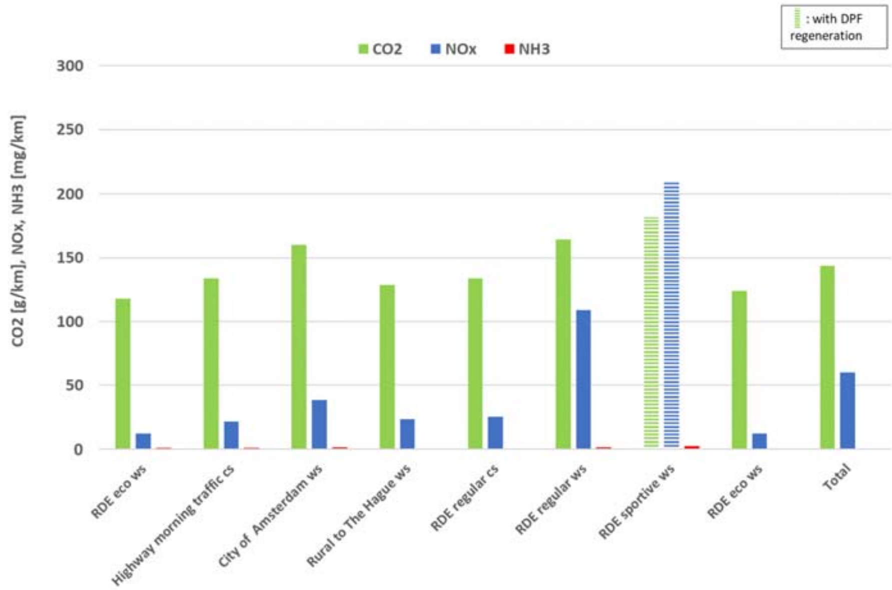
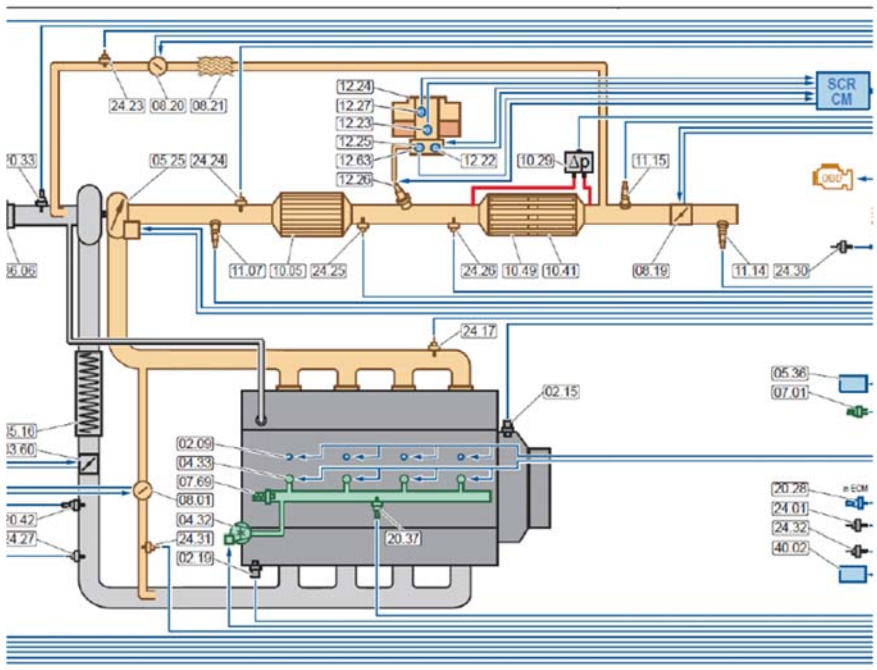


Figure A-37: Average CO_2, NO_x, NH_3 test results of the emission test programme of the Skoda Octavia

~~1.2.5~~0.2.5 *Mercedes B180*

Table A-16: Vehicle specifications of the Mercedes B180 Euro 6d-Temp diesel

Trade Mark	[-]	Mercedes-Benz
Type	[-]	B180
Body	[-]	Passenger vehicle
Vehicle Class	[-]	M1
Fuel	[-]	diesel
Vehicle Registration Number	[-]	
Vehicle Identification Number	[-]	WDD2470031J007844
Engine Code	[-]	
Swept Volume	[cm^3]	1.461
Max. Power	[kW]	85
Euro Class	[-]	Euro 6d-Temp
Type Approval Authority	[-]	Germany
Type Approval Number	[-]	e1*2007/46*1909*00
Vehicle Empty Mass	[kg]	1385
Odometer	[km]	1,501
Registration Date	[dd-mm-yyyy]	29-8-2019



: Functional Schematic of Emission Control System

Figure A-38: Functional schematic of the Mercedes B180's emission control system (source: Mercedes-Benz Cars Nederland B.V).

Table A-17: Details of the emission control of the Mercedes B180.

Reference number	Component type	Component designation	Function / Task	Mounting Point
10.05	Component	Diesel oxidation catalyst (DOC)	The first catalytic converter in the exhaust system. Description see 3.3.8	Exhaust system, downstream turbine
10.41	Component	Catalyst SCR	The third catalytic converter in the exhaust system. Includes an ASC coating to control Ammonia slip. Description see 0	Exhaust system, downstream sDPF
10.49	Component	Particulate filter incl. Catalyst SCR (sDPF)	The second catalytic converter and particulate filter. Description see 3.3.9	Exhaust system, downstream DOC

~~1.2.5.1~~0.2.5.1 *On-road emission test program*

The on-road test programme of the Mercedes B180 was performed from October 8th, 2019 to November 11th, 2019. In this period SEMS data were logged over 3134 km and stored.

It is partitioned in two parts;

- A random real-world on-road monitoring test programme of 2430 km which was executed on Dutch roads.
- An on-road dedicated emission test programme of 704 km on defined (RDE) routes which was executed on Dutch roads between Amsterdam and Rotterdam.

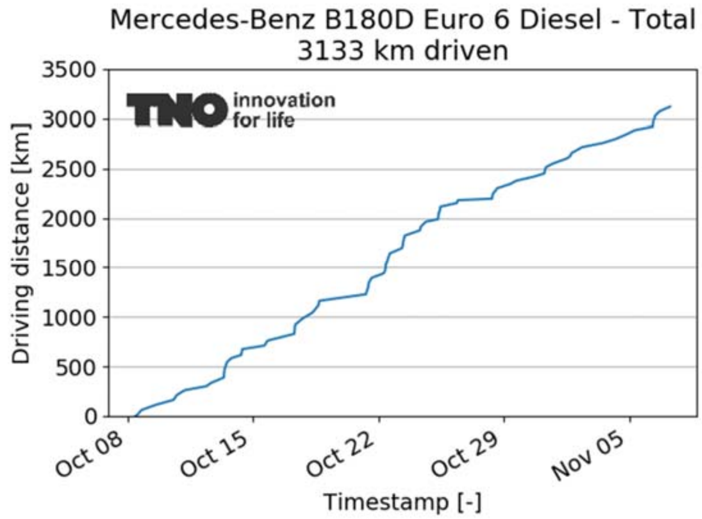


Figure A-39: Distance driven with respect to time of the test programme (in total 64.0 hours) of the Mercedes B180.

As shown in Figure A-40, at a first glance, the NO_x emissions of the monitoring programme are similar to the NO_x emission of the emission test program. During the monitoring programme the vehicle was not driven with maximum payload.

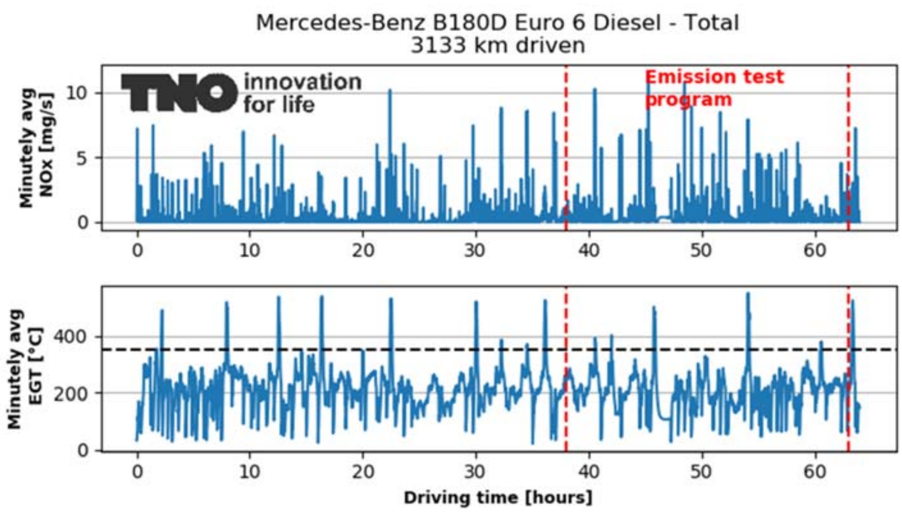


Figure A-40: NO_x emission and exhaust gas temperatures over the test programme (in total 64.0 hours) of the Mercedes B180. The red dotted lines mark the period of the emission test program. The black dotted line marks the DPF regeneration threshold temperature.

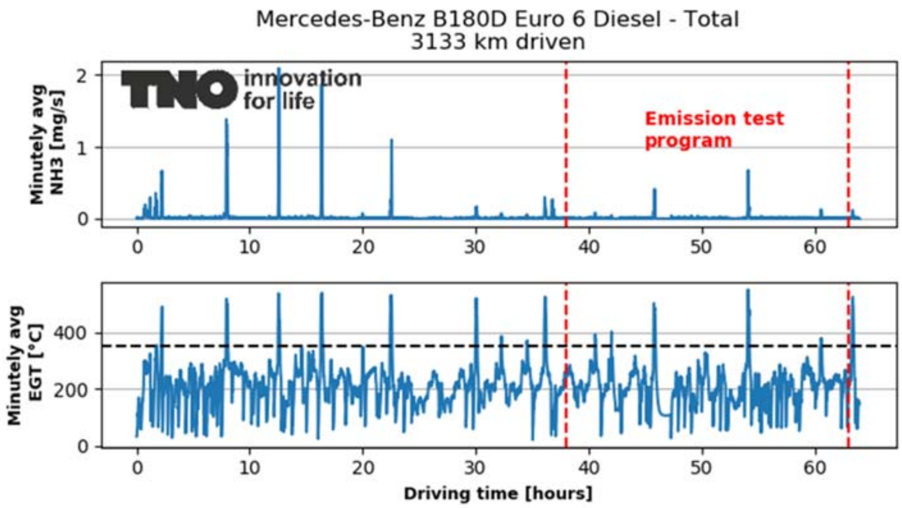


Figure A-41: NH_3 emission and exhaust gas temperatures over the test programme (in total 64.0 hours) of the Mercedes B180. The red dotted lines mark the period of the emission test program. The black dotted line marks the DPF regeneration threshold temperature.

In Table A-18 an overview of (average) test results of the total and partial test programs is given. The overall average AdBlue consumption was 0.690 litre per 1,000 km. The average NO_x emission in the emission test programme with an average vehicle speed of 46.2 km/h is 26.9 mg/km and in the monitoring test programme with an average speed of 49.9 km/h the average NO_x emission is 37.8 mg/km. In both test programs the NH_3 emission is up to 1.6 mg/km.
On average the DPF was regenerated every 209 km and the average duration of the DPF regeneration was 536 seconds.

Table A-18: Overall test results of the Mercedes B180 Euro 6d-Temp diesel

		Total	Monitoring	Emission test program
Total Distance	[km]	3134	2430	704
Total duration	[hh]	64.0	48.8	15.2
Average speed	[km/h]	49.0	49.9	46.2
Idle time	[%]	10.9	10.9	10.8
Start-stop time	[s]	15743	10229	5514
Start-stop time	[%]	6.8	5.8	10.0
Fuel cons. Grav.	[ltr / 100 km]	5.23	No result	No result
Fuel cons. SEMS	[ltr / 100 km]	4.60	4.58	4.63
AdBlue cons. Grav.	[ltr / 1000 km]	0.690	No result	No result
CO_2 SEMS	[g/km]	121.8	121.5	122.6
NO_x	[mg/km]	35.4	37.8	26.9
NH_3	[mg/km]	1.4	1.6	0.6
No. of DPF regen.	[-]	15	12	3
Total duration regen.	[s]	8033	6727	1306
Av. regen. interval	[km]	209	203	235
Av. regen. duration	[s]	536	561	435
Spec. regen. duration	[s/1000 km]	2563	2768	1855

In Figure A-42 the average NO_x, CO_2 and NH_3 emissions of the Mercedes B180 over the different speed bins of the total test programme of 3123 km and in Figure A-43 the 'RDE' NO_x results of the urban, rural and highway sections are shown. The NO_x emissions in the 'RDE' tests are well below the limit value of 168 mg/km. In the vehicle speed bins the average NO_x emission is 20 to 120 mg/km and the average NH_3 emission up to 120 km/h is 1 to 4 mg/km. Between 125 and 145 km/h the average NH_3 emission is 10 to 25 mg/km.

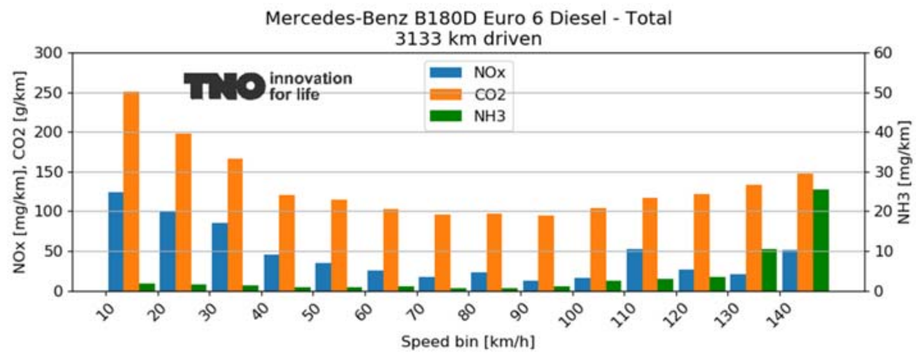


Figure A-42: Binned CO_2, NO_x and NH_3 emissions of the total test programme of the Mercedes B180.

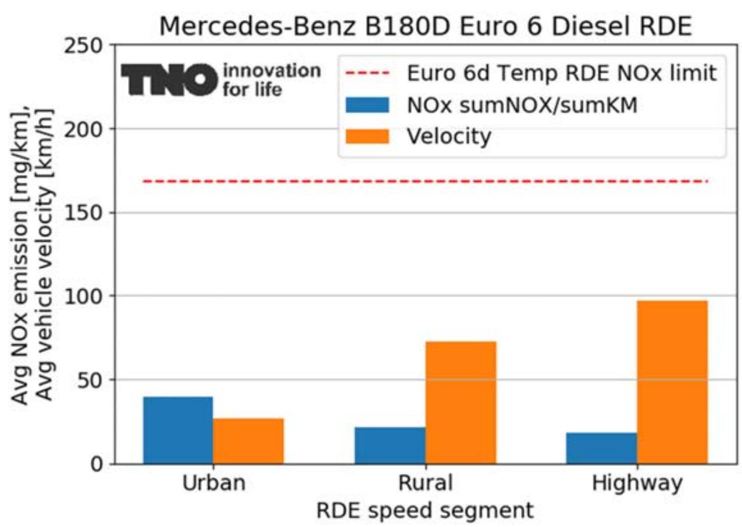


Figure A-43: Average velocities and average NOx emissions in the urban, rural and highway parts of the 'RDE' tests of a Mercedes B180.

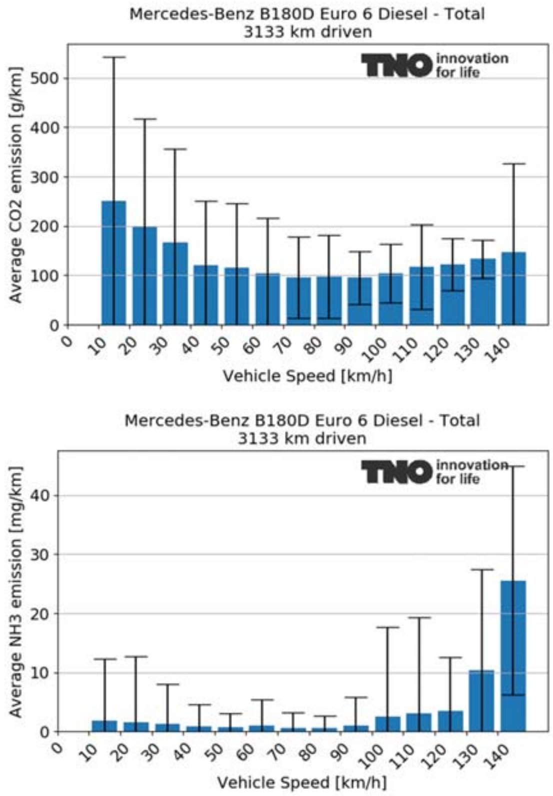


Figure A-44: Average CO_2, NO_x and NH_3 emissions dependent on vehicle speed bin during all driving for a Mercedes B180

~~1.2.5.2~~0.2.5.2 *Results of emission test program*

In the emission test programme of the Mercedes B180 the average CO_2 emission was in the range of 109 to 182 g/km, the average NO_x emission was in the range of 12 to 56 mg/km and the average NH_3 emission was in the range of 0.3 to 1.6 mg/km. The NO_x emission in the emission test programme was well below the RDE limit value of 168 mg/km.

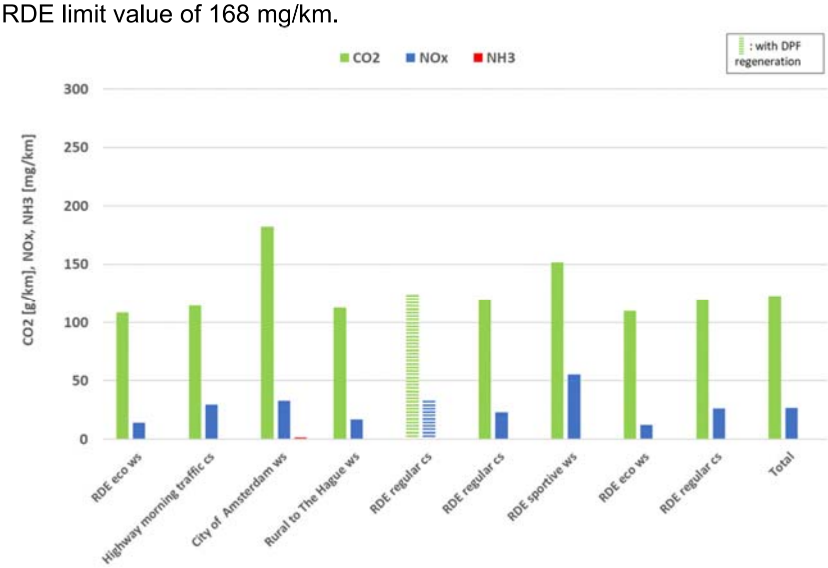


Figure A-45: Average CO_2, NO_x, NH_3 results of the emission test programme of the Mercedes B180.

More details of the emission characteristics of the Mercedes B180 are reported in Appendix F.

1.2.6 *Renault Master*

Table A-19: Vehicle specifications of the Renault Master Euro 6d-Temp diesel .

Trade Mark	[-]	Renault
Type	[-]	Master
Body	[-]	Light Commercial Vehicle
Vehicle Class	[-]	N1 Class 3
Fuel	[-]	diesel
Vehicle Registration Number	[-]	
Vehicle Identification Number	[-]	VF1MA000664336573
Engine Code	[-]	M9T/R9M
Swept Volume	[cm^3]	2.299
Max. Power	[kW]	110
Euro Class	[-]	Euro 6d-Temp
Type Approval Authority	[-]	255
Type Approval Number	[-]	e2*200746*0016*37
Emission class	[-]	715/2007*2018/1832CI
Vehicle Empty Mass	[kg]	2044
Odometer	[km]	7,263
Registration Date	[dd-mm-yyyy]	16-12-2019

The emission control of the Renault Master contains HP-EGR, LP-EGR, DOC + SCRF, SCR and ASC.

~~1.2.6.1~~0.2.6.1 *On-road emission test program*

The on-road test programme of the Renault Master was performed from March 5th, 2020 to March 25th, 2020. In this period SEMS data were logged over 2274 km and stored.

It is partitioned in two parts;

- A random real-world on-road monitoring test programme of 1259 km which was executed on Dutch roads.
- An on-road dedicated emission test programme of 1015 km on defined (RDE) routes which was executed on Dutch roads between Amsterdam and Rotterdam.

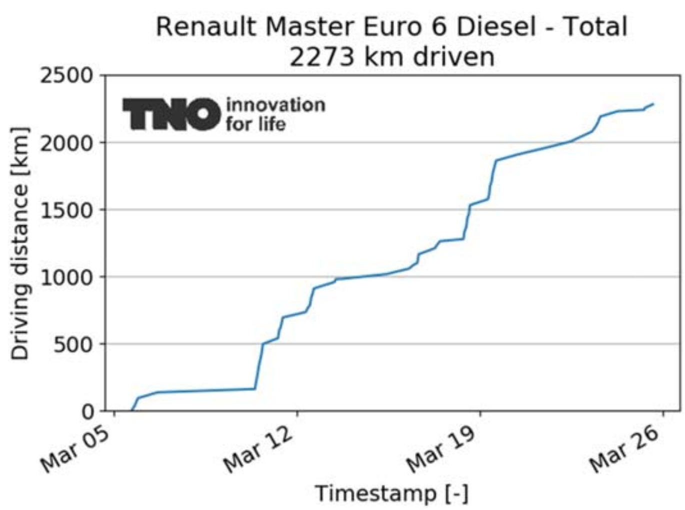


Figure A-46: Distance driven with respect to time of the test programme (in total 53.5 hours) of the Renault Master.

As shown in Figure A-47, at a first glance, the NO_x emission of the monitoring programme seems higher than the NO_x emission of the emission test program. During the monitoring programme the vehicle was not driven with maximum payload.

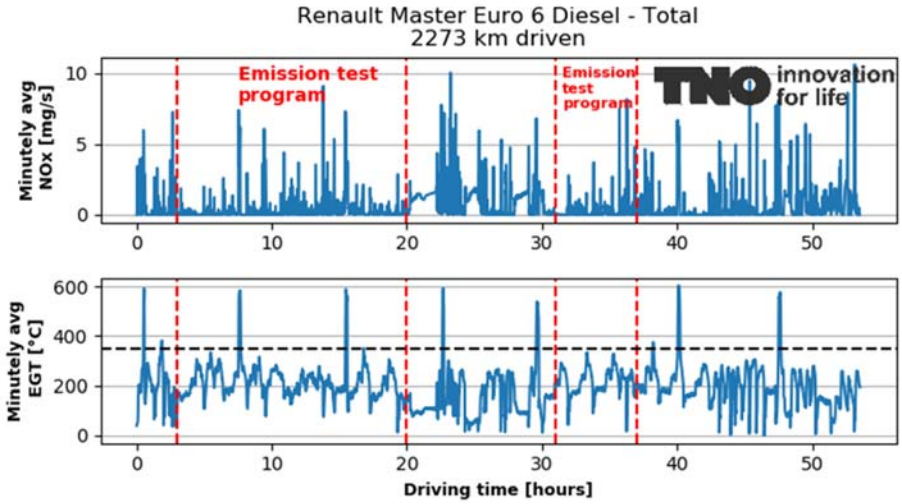


Figure A-47: NO_x emission and exhaust gas temperatures over the test programme (in total 53.5 hours) of the Renault Master. The red dotted lines mark the period of the emission test program. The black dotted line marks the DPF regeneration threshold temperature.

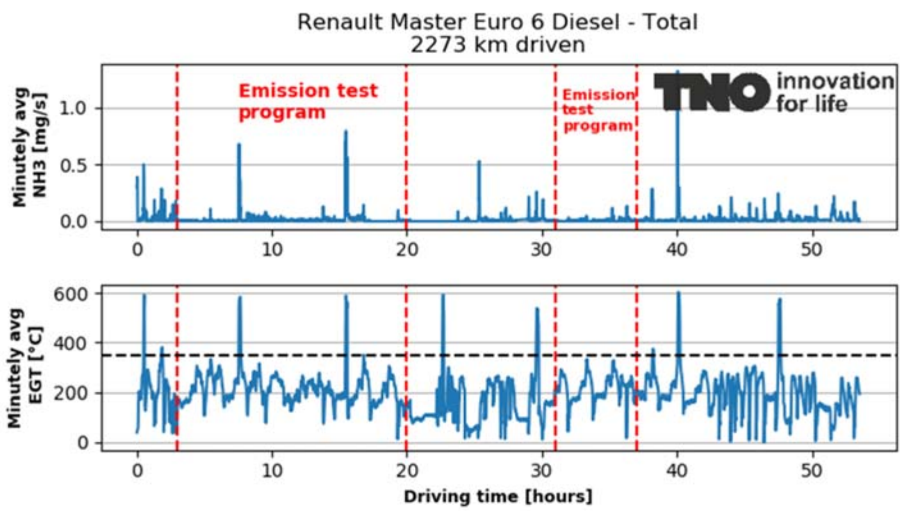


Figure A-48: NH_3 emission and exhaust gas temperatures over the test programme (in total 53.5 hours) of the Renault Master. The red dotted lines mark the period of the emission test program. The black dotted line marks the DPF regeneration threshold temperature.

In Table A-20 an overview of (average) test results of the total and partial test programs is given. The overall average AdBlue consumption was 0.97 litre per 1,000 km. The average NO_x emission in the emission test programme with an average vehicle speed of 51 km/h is 26.5 mg/km.

In the monitoring test programme with an average speed of 37.4 km/h the average NO_x emission is 75.9 mg/km. In both test programs the average NH_3 emission is up to 1.9 mg/km. On average the DPF was regenerated every 284 km and the average duration of the DPF regeneration was 586 seconds.

Table A-20: Overall test results of the Renault Master Euro 6d-Temp diesel.

		Total	Monitoring	Emission test program
Total Distance	[km]	2273.5	1258.9	1014.6
Total duration	[hh]	53.54	33.65	19.89
Average speed	[km/h]	42.5	37.4	51
Idle time	[%]	19.8	26.6	8.4
Start-stop time	[s]	5976	2697	3279
Start-stop time	[%]	3.1	2.2	4.6
Fuel cons. Grav.	[ltr / 100 km]	9.42	No result	No result
Fuel cons. SEMS	[ltr / 100 km]	9.08	9.45	8.63
AdBlue cons. Grav.	[ltr / 1000 km]	0.97	No result	No result
CO_2 SEMS	[g/km]	240.7	250.3	228.8
NO_x	[mg/km]	53.9	75.9	26.5
NH_3	[mg/km]	1.5	1.9	1.1
No. of DPF regen.	[-]	8	5	3
Total duration regen.	[s]	4687	3132	1555
Av. regen. interval	[km]	284.2	251.8	338.2
Av. Regen. duration	[s]	586	626	518
Spec. regen. duration	[s/1000 km]	2062	2488	1532

In Figure A-49 the average NO_x, CO_2 and NH_3 emissions of the Renault Master over the different speed bins of the total test programme of 2273 km and in Figure A-50 the 'RDE' NO_x results of the urban, rural and highway sections are shown. The average NOx emissions in the 'RDE' tests are well below the limit value of 262.5 mg/km. In the vehicle speed bins the average NO_x emission is 20 to 125 mg/km and the average NH_3 emission is 1 to 8 mg/km.

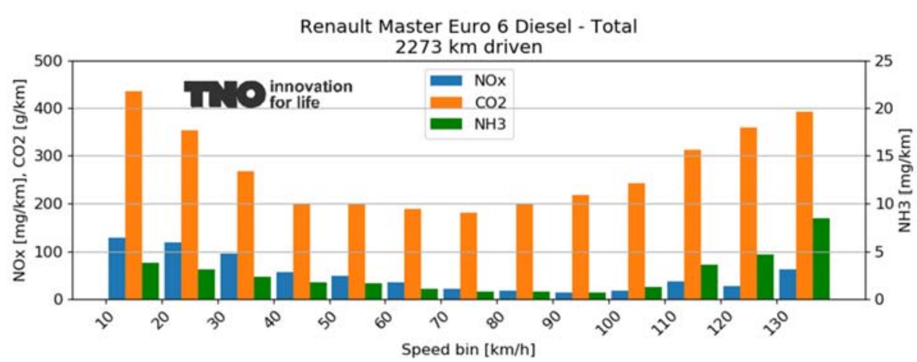


Figure A-49: Binned CO_2, NO_x and NH_3 emissions of the total test programme of the Renault Master.

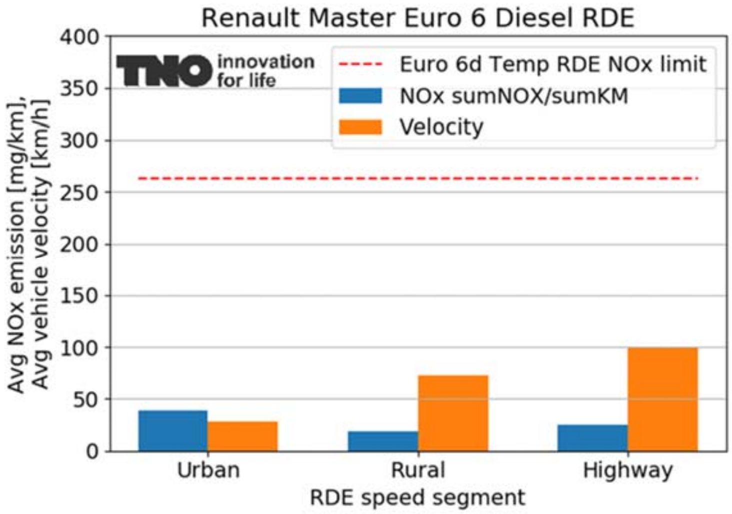


Figure A-50: Average velocities and average NOx emissions in the urban, rural and highway parts of the 'RDE' tests of a Renault Master.

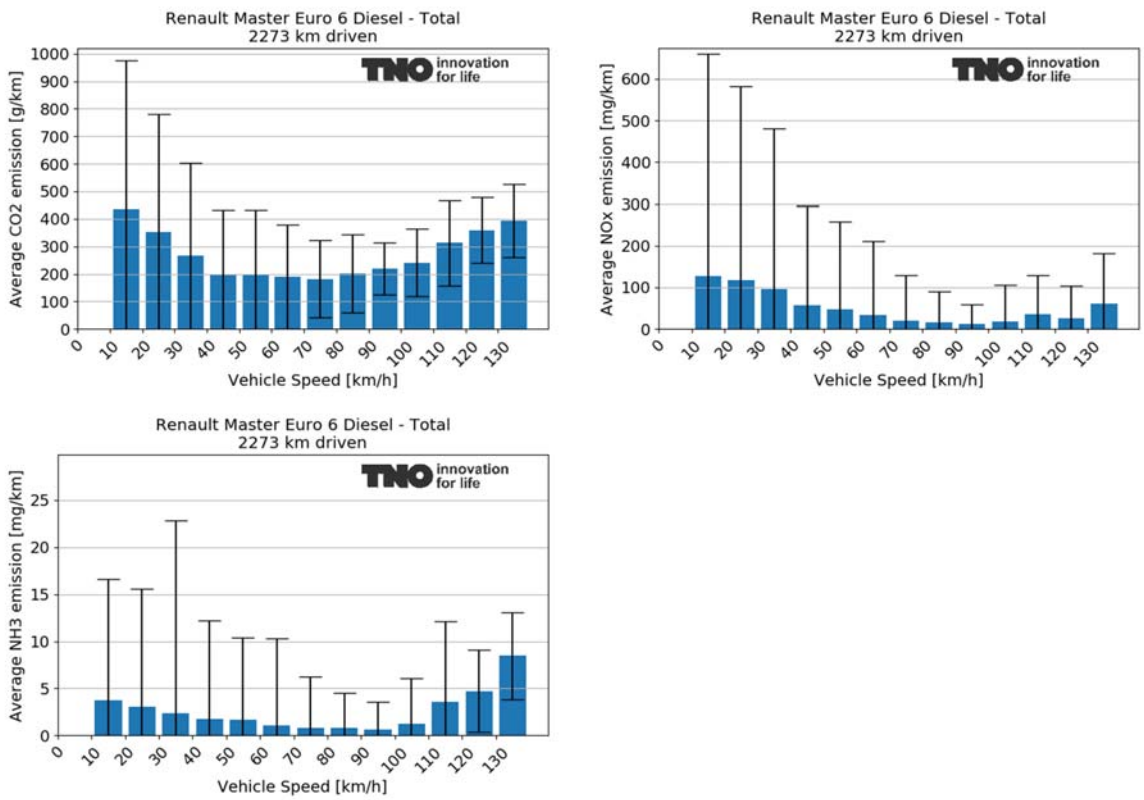


Figure A-51: Average CO_2, NO_x and NH_3 emissions dependent on vehicle speed bin during all driving for a Renault Master

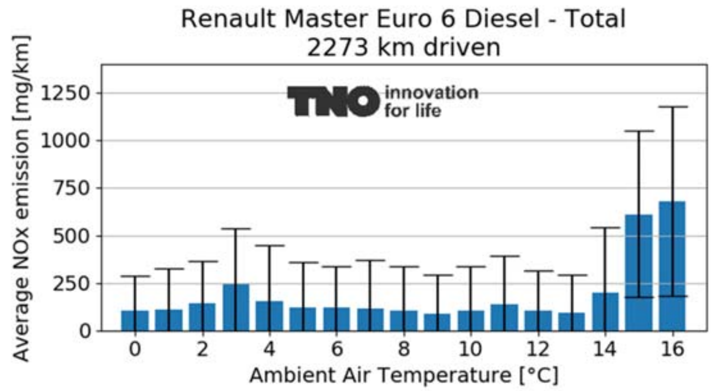


Figure A-52: Average NO_x emissions per ambient air temperature bin during all driving for a Renault Master. Note that the ambient air temperature is logged by the vehicle, and therefore can be affected by the state of the vehicle itself. Furthermore, this does not address the respective driving situations at these temperatures (i.e. driving behaviour can be different in summer due to a range of factors, let alone the temperature).

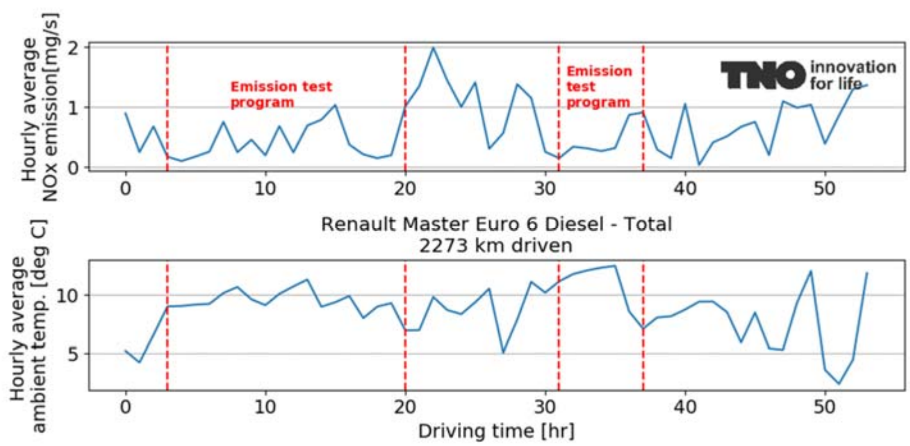


Figure A-53: NO_x emission and exhaust gas temperatures over the test program of the Renault Master. The red dotted lines mark the period of the emission test program.

~~1.2.6.2~~0.2.6.2 Results of emission test program

In the emission test programme of the Renault Master the average CO_2 emission was in the range of 194 to 272 g/km, the average NO_x emission was in the range of 5 to 72 mg/km and the average NH_3 emission was in the range of 0.4 to 1.2 mg/km. The NO_x emission in the emission test programme was well below the limit value of 262.5 mg/km.

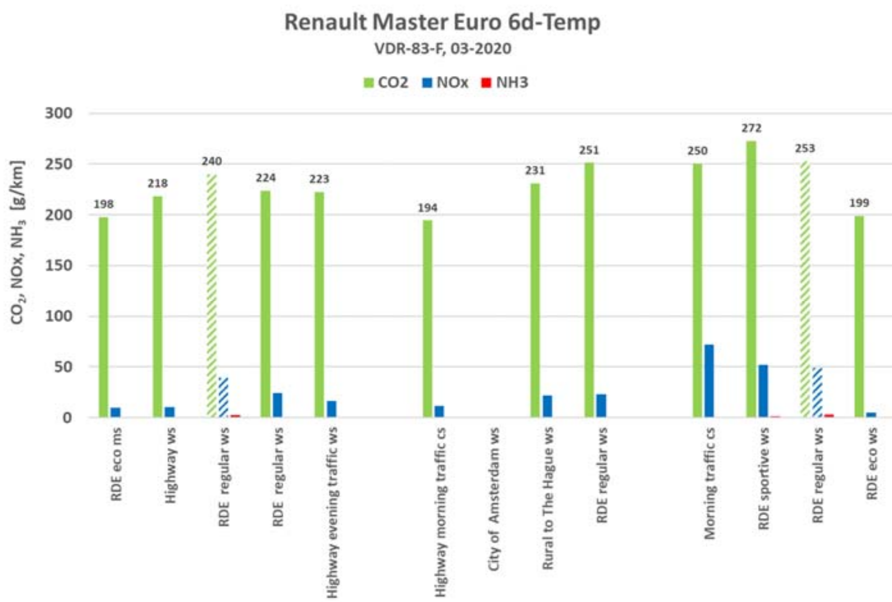


Figure A-54: Average CO_2, NO_x, NH_3 results of the emission test programme of the Renault Master.

~~1.2.6.3~~0.2.6.3 *Low speed trips at low ambient temperatures and cold start*

In order to assess the emission behaviour in urban trips three different trips with the Renault Master were executed with cold starts at ambient temperatures in the range of 0 to 7 ºC. In these trips the start-stop system was not activated. The tests with the lowest average speed is assumed most challenging because the temperature of the aftertreatment system tends to be low.

In Table A-21 and Figure A-55 to A-57 the test results of the three urban trips are reported. The NO_x emission in these urban tests is 37 to 287 mg/km and just above or well below the RDE NO_x limit value of 262.5 mg/km. During longer periods of engine idling, see Figure A-56, the NO_x concentrations are in the first 500 seconds very low (< 10 ppm) and increase to a NOx concentration around 170 ppm. The cumulative NO_x mass flows (NO_x mf) show significant NO_x contributions after the cold start and in longer idling periods.

Table A-21: Parameters of three different urban trips with cold start and emission test results.

Trip	Duration	Length	Average speed	Ambient temperature	CO_2	NO_x	NH_3
	[min]	[km]	[km/h]	[ºC]	[g/km]	[mg/km]	[mg/km]
1	51	24.3	27.9	0 - 3	256	37	2.0
2	105	24.9	14.4	1 - 7	352	287	7.9
3	66	13.0	11.5	0 - 3	367	198	5.4

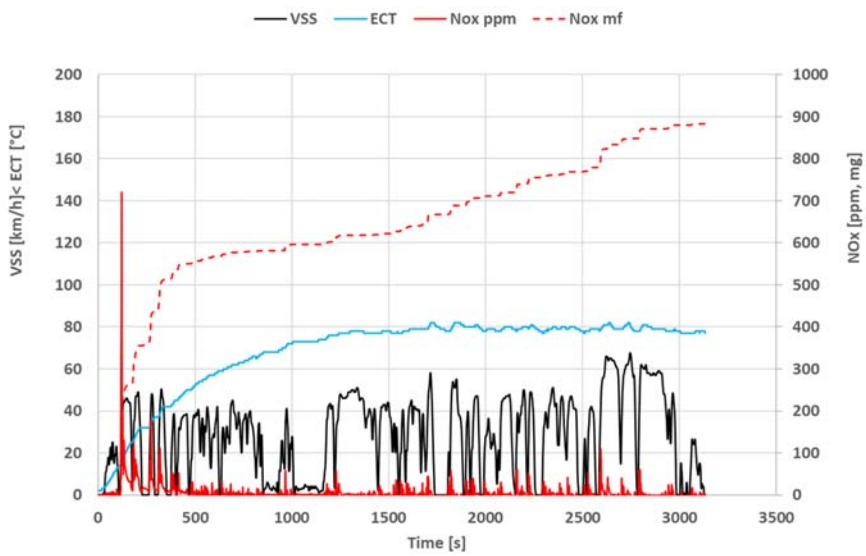


Figure A-55: Urban trip of 51 minutes with cold start of a Euro 6d-Temp Renault Master with ambient temperatures of 0 – 3 ºC. Average speed is 27.9 km/h, CO_2 256 g/km, NO_x 37 mg/km.

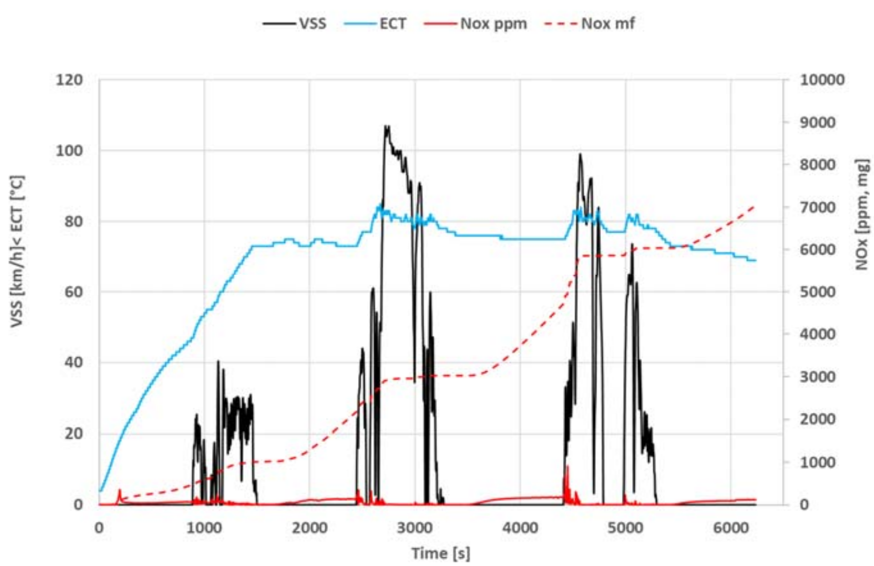


Figure A-56: Trip of 105 minutes with cold start and idling periods of a Euro 6d-Temp Renault Master with ambient temperatures of 1 – 7 ºC. Average speed is 14.4 km/h, CO_2 352 g/km, NO_x 287 mg/km.

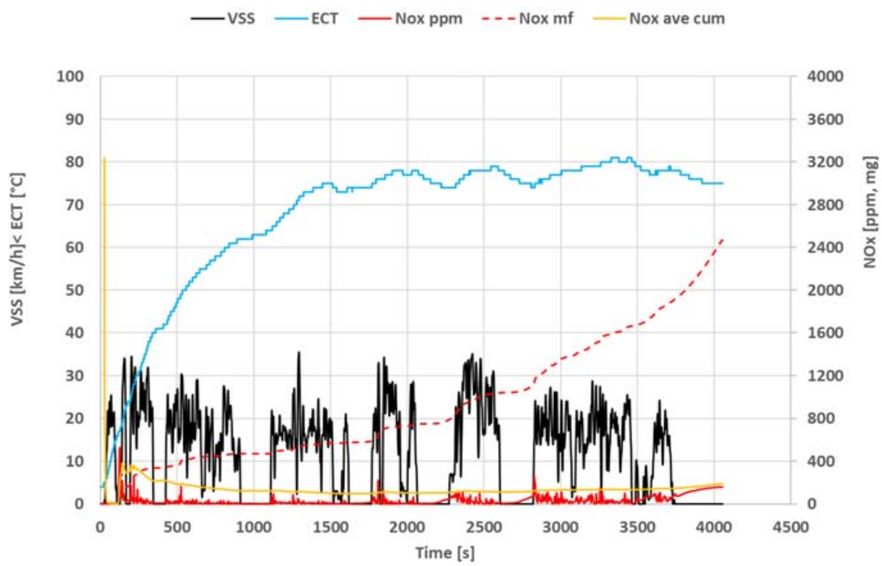


Figure A-57: Delivery trip of 66 minutes with cold start of a Euro 6d-Temp Renault Master with ambient temperatures of 0 – 3 ºC. Average speed is 11.5 km/h, CO_2 367 g/km, NO_x 198 mg/km.

1.2.6.4 *Particle number emissions at low idle speed*

The particle number emission of the warm engine of the Renault Master at low idle speed was 40,000 #/cm^3.

1.3 Analysis of test results

1.3.1 *Comparison of results of 'RDE' tests, emission test programme and monitoring data for the tested vehicles*

In this section test results of the five tested Euro 6d-Temp vehicles are summarised.

In Figure A-58 up to Figure A-60 the average emissions of the next tests are shown:
- 'RDE' test, economic driving style
- 'RDE' test, sportive driving style
- Emission test program
- Monitoring test program.

The bars with yellow patterns represent an 'RDE' test with a DPF regeneration.

CO_2 emissions:

Figure A-58 shows the CO_2 test results of the four tests of five vehicles. For all vehicles the CO_2 emission of the economic is the lowest and the sportive 'RDE' test has the highest CO_2 emission (with a typical difference of 28 to 46%). In the sportive 'RDE' test of the Skoda Octavia the DPF was regenerated. All average CO_2 emissions of the emission test programme and the monitoring test programme are in between the 'RDE' test results.

NO_x emissions:
Figure A-60 shows the NO_x test results of the four tests of five vehicles. For three vehicles the NO_x emission of the economic ‘RDE’ test is the lowest and the sportive ‘RDE’ test has the highest NO_x emission. All average NOx emissions are below the RDE limit values of 168 versus 262.5 mg/km (M1 and N1 class 3) except the sportive ‘RDE’ test of the Skoda Octavia in which a DPF regeneration took place.

NH_3 emissions:
Figure A-60 shows the NH_3 test results of the four tests of five vehicles.
The average NH_3 emission of four vehicles was 1.0 to 1.9 mg/km but the fourth vehicle (a Peugeot 308) had an average NH3 emission of 22.8 mg/km in the monitoring test program. In Figure A-61 the average binned emissions of the Peugeot 308 are plotted and they are over the whole speed range 12 to 65 mg/km. The configuration of the exhaust aftertreatment system of the Peugeot contains the next catalysts DOC + LNT + SCR + SCRF but an ammonia slip catalyst is probably not implemented and this may declare the relative high NH_3 emission.

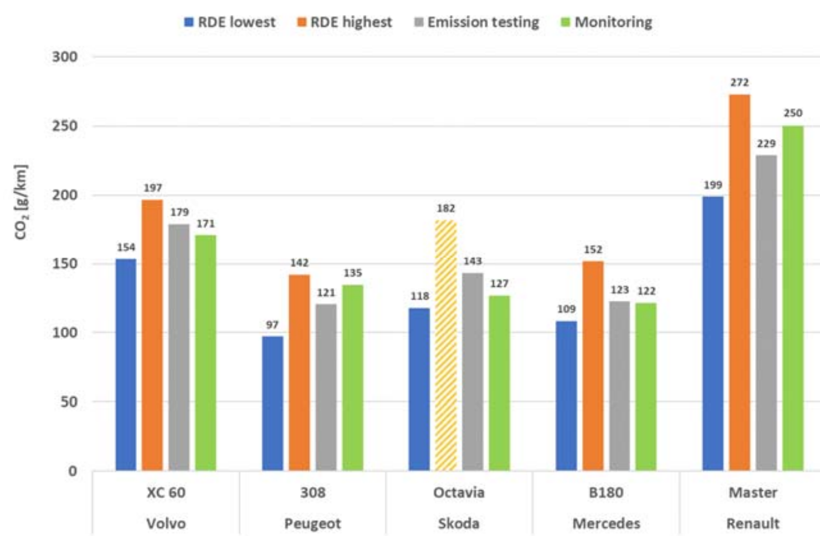


Figure A-58: CO_2 test results of ‘RDE’ tests, the emission test programme and the monitoring programme of the five tested Euro 6d-Temp diesel vehicles.

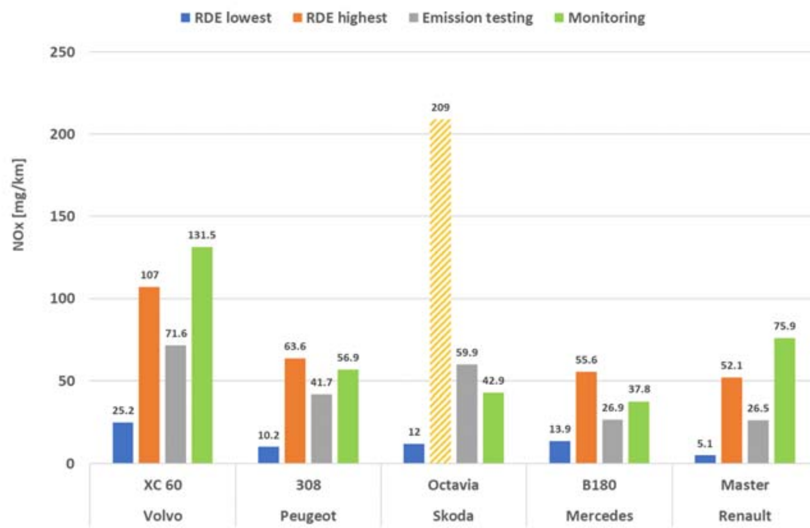


Figure A-59: NO_x test results of ‘RDE’ tests, the emission test programme and the monitoring programme of the five tested Euro 6d-Temp diesel vehicles.

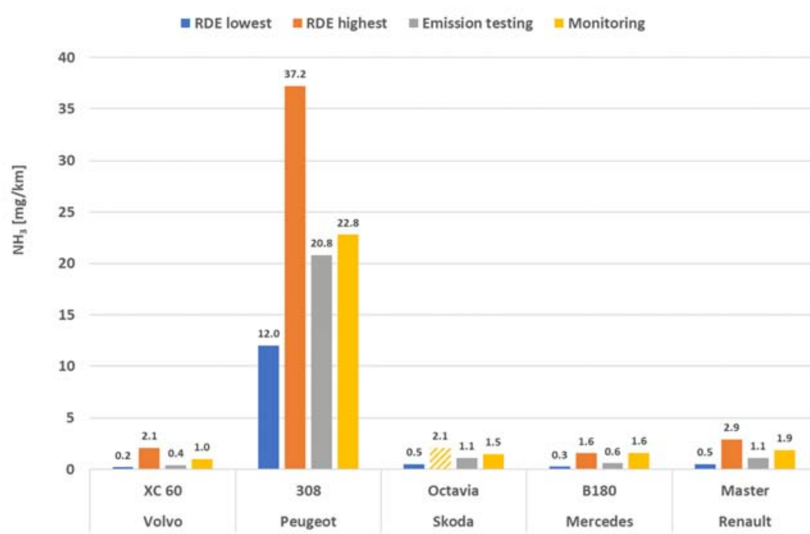


Figure A-60: NH_3 test results of ‘RDE’ tests, the emission test programme and the monitoring programme of the five tested Euro 6d-Temp diesel vehicles.

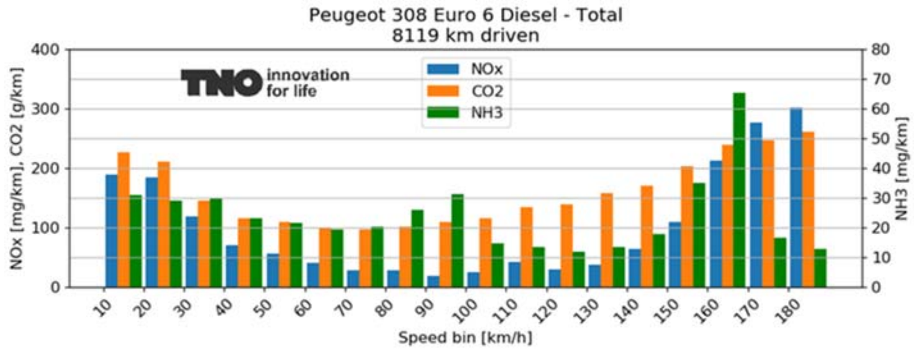


Figure A-61: Binned average emissions of the Peugeot 308 Euro 6d-Temp

~~1.4~~0.4 DPF regenerations

Further monitoring of vehicle data and emissions generate more insights in DPF regenerations per vehicle type. In Table A-22 the DPF regeneration parameters of the five tested vehicle are reported. The average DPF regeneration intervals of the five vehicles are 208 to 628 km and the average DPF regeneration durations are 382 to 960 seconds. Specific durations of DPF regenerations of four vehicles are in the range of 1931 to 2907 seconds per 1000 km and the Volvo XC 60 had a specific DPF regeneration duration of 608 seconds per 1000 km. These data indicate that vehicle manufacturers can apply different emission control strategies with different DPF regeneration frequencies.

Table A-22: DPF regeneration parameters of the five tested Euro 6d-Temp vehicles.

Vehicle	Av. DPF regen. interval	Av. DPF regen. duration	Spec. regen. duration
	[km]	[s]	[s/1000 km]
Volvo XC 60	628	382	608
Peugeot 308	338	960	2907
Skoda Octavia	427	824	1931
Mercedes B 180	209	536	2563
Renault Master	285	586	2062

B Specification of the chassis dynamometer and test equipment

Horiba Europe GMBH carries out emission tests in its laboratory according to ISO 17025 standards and is certified for this. The following measuring equipment has been installed in the test room:

Chassis Test Cell

Air conditioning
Weiss Umwelttechnik
cooling performance 150 kW
air circulation 30.000 m³/h
fresh air 2.000 m³/h
CVS-dilution air 1.200 m³/h
waist air 2.000 – 4.000 m³/h

Chassis Dynamometer
VULCAN II EMS-CD48L 4WD
max. speed 200 km/h
max. capacity/power 2 x 155 kW
wheel base 1800 – 3400 mm
max. axle load 2.500 kg
Fan LTG VQF 500/1250

Exhaust Measurement Equipment
MEXA ONE D1-EGR
Exhaust gas analyser,
Undiluted (direct) for:

O_2, CO, CO_2, NO_x/NO, THC and CH_4,
separate EGR-Analyser

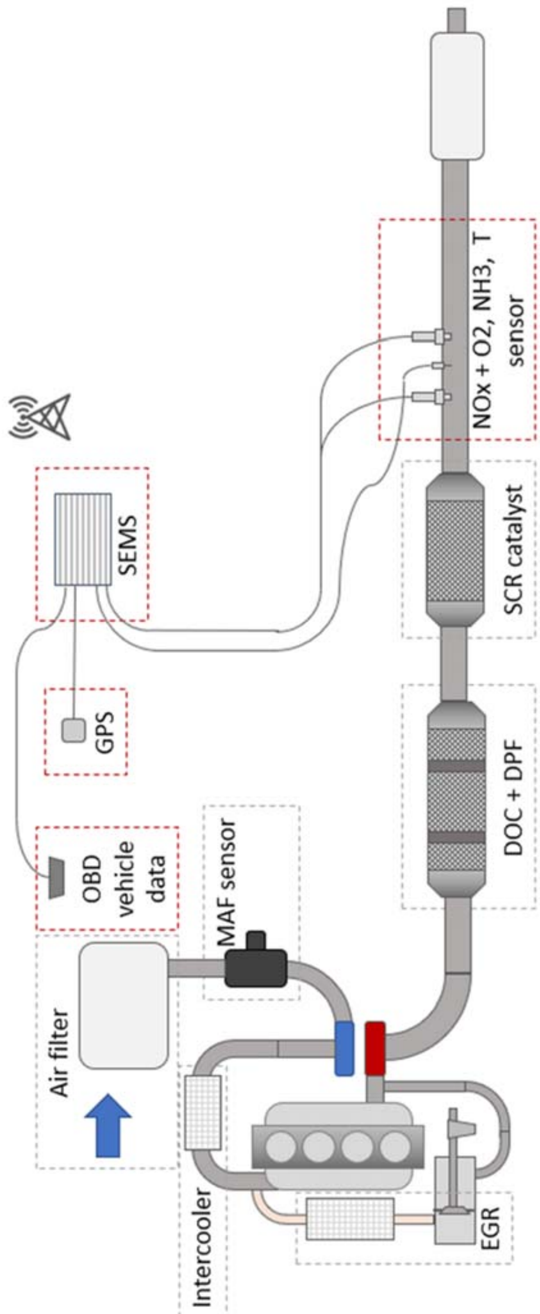
MEXA ONE 2-OV
Exhaust gas analyser,
dilute bag & continuous measurement
for: O_2, CO, CO_2, NO_x/NO, THC, CH4.

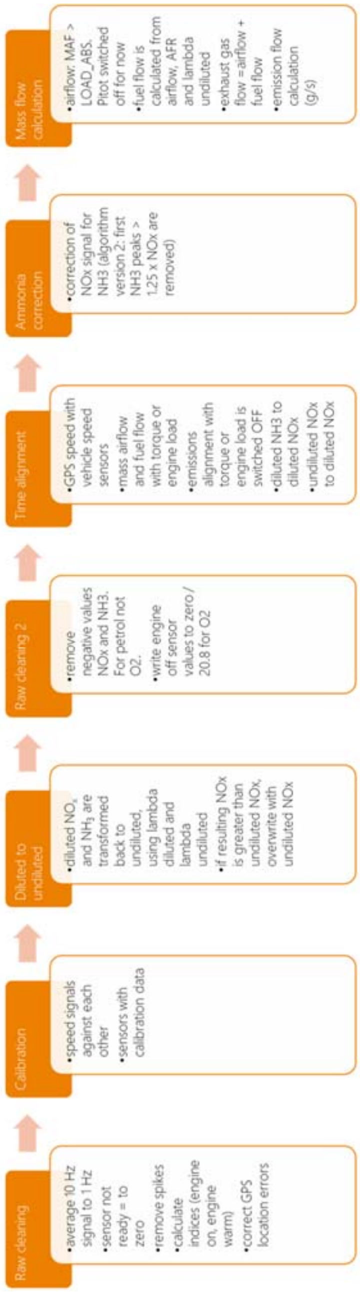
Heated Bag Cabinet
with 3 x 4 emission bags for ambient air-, gasoline– and diesel measuring.

MEXA 2100 SPCS
Measures solid particle number concentration in raw engine exhaust gas in real time, within a specified particle size range (UN/ECE Regulation 83).

- **Horiba MEXA ONE D1-EGR**, Exhaust Gas Analysing System for direct measurement
  (1-line) with following analysers: O_2, CO, CO_2, NO_x/NO, THC, CH4 and separate EGR-Analyser.
- **Horiba MEXA ONE 2-OV**, Exhaust Gas Analysing System for dilute bag & continuous measurement with following analysers: O_2, CO, CO_2, NO_x/NO, THC, CH4.
- **Horiba MEXA 2100 SPCS**, Solid Particle Counting System.
- **Horiba MEXA ONE CVS**, Constant Volume Sampler System, 6 m³/min to 18 m³/h.
- **Horiba DLS 7000**, Particulate Measuring System with Dilution Tunnel DLT 18.
- Different temperature and pressure regulators (according to the test application), max. 16 temperature inputs (Type K) and 8 voltage- and current analogue inputs.
- **Horiba VETS One**, Host Computer and evaluation of measuring data with DIVA.
- **Horiba PWS-ONE**, Particle measurement and conditioning chamber with micro balance and robot.
- **Horiba MEXA-ONE-QL-NX**, Quantum Cascade Laser Infrared Spectroscopy (QCL-IR spectrocopy).

C Schematic of the Smart Emission Measurement System (SEMS)




Raw cleaning
•average 10 Hz signal to 1 Hz
•sensor not ready = to zero
•remove spikes
•calculate indices (engine on, engine warm)
•correct GPS location errors
Calibration
•speed signals against each other
•sensors with calibration data
Diluted to undiluted
•diluted NOx and NH3 are transformed back to undiluted, using lambda diluted and lambda undiluted
•if resulting NOx is greater than undiluted NOx, overwrite with undiluted NOx
Raw cleaning 2
•remove negative values NOx and NH3. For petrol not O2.
•write engine off sensor values to zero / 20.8 for O2
Time alignment
•GPS speed with vehicle speed sensors
•mass airflow and fuel flow with torque or engine load
•emissions alignment with torque or engine load is switched OFF
•diluted NH3 to diluted NOx
•undiluted NOx to diluted NOx
Ammonia correction
•correction of NOx signal for NH3 (algorithm version 2: first NH3 peaks > 1.25 x NOx are removed)
Mass flow calculation
•airflow: MAF > LOAD_ABS. Pitot switched off for now
•fuel flow is calculated from airflow, AFR and lambda undiluted
•exhaust gas flow = airflow + fuel flow
•emission flow calculation (g/s)