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TNO report

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Emissions of twelve petrol vehicles with high mileages

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Samenvatting

Inleiding
In opdracht van het Ministerie van Infrastructuur en Waterstaat heeft TNO de uitlaatemissies van twaalf oudere benzinevoertuigen, met driewegkatalysator en bouwjaar na 1998, gemeten. Eén Euro 2, drie Euro 3, zeven Euro 4 en één Euro 5 personenauto met kilometerstanden tussen 155.000 en 254.000 km zijn getest op een rollenbank volgens een praktijkgerichte (CADC) ritcyclus, met representatieve rijweerstanden. De testen zijn uitgevoerd tussen de herfst van 2017 en de zomer van 2018.

Emissies van benzinevoertuigen zijn eveneens in het verleden gemeten, toen deze voertuigen slechts een paar jaar oud waren en bij beperkte kilometerstanden. Op basis van deze gegevens zijn toen emissiefactoren opgesteld voor de verschillende praktijksituaties op de weg. De vraag is of deze voertuigen, bij toenemende leeftijd en kilometerstanden nog dezelfde emissieniveaus laten zien.

Benzinevoertuigen leveren meer dan 70% van al het stadsverkeer en zij hebben een gemiddelde levensduur van meer dan 200.000 km. Deze voertuigen moesten, voor typegoedkeuring, voldoen aan een NEDC emissietest die zorgde voor goede emissieprestaties van deze nieuwe voertuigen. Echter, deze moderne voertuigen hoeven bij een kilometerstand groter dan 100.000 km niet te voldoen aan een duurzaamheidseis. Bovendien geldt er voor uitlaatgasnabehandelingssystemen boven een kilometerstand van 160.000 km geen duurzaamheidseis.
Met het nu uitgevoerde emissie-onderzoek wordt de volledige levensduur van de voertuigen bestreken.

Testresultaten
De resultaten van testen op de rollenbank laten een grote spreiding zien in het emissiegedrag van de twaalf voertuigen. Gemiddelde NO_x-emissies per voertuig variëren tussen 17 en 1234 mg/km. De gemeten PM-emissies variëren eveneens maar zijn, op die van één voertuig na, laag. Dit twaalfde voertuig heeft een gemeten PM-emissie van 9.1 mg/km. Dit kan echter gerelateerd zijn aan de vervanging van een uitlaatpijp tijdens het testprogramma hetgeen nodig was om lekkages te voorkomen. Een nieuwe uitlaatpijp kan, gedurende een paar honderd kilometer, grote deeltjes uitstoten welke de PM emissies kunnen beïnvloeden.
Alle voertuigen voldoen goed op het gebied van THC (koolwaterstoffen) emissies, die varieert van 8 tot 138 mg/km.

Onderstaande tabel vat de resultaten samen van de rollenbanktesten voor alle twaalf voertuigen.

	Euro Class	CO		THC		NO_x		PM	
		[mg/km]	CF	[mg/km]	CF	[mg/km]	CF	[mg/km]	CF
Citroën Xsara	3	719	0.3	8	0.0	39	0.3	0.1	0.0
Toyota Aygo	5	4135	4.1	25	0.3	17	0.3	1.1	0.2
Ford Focus	3	2476	1.1	97	0.5	254	1.7	2.3	0.5
VW Polo	4	2500	2.5	53	0.5	96	1.2	1.5	0.3
Opel Corsa1	4	724	0.7	23	0.2	375	4.7	3.9	0.8
Fiat Punto 1	4	5133	5.1	138	1.4	1234	15.4	3.7	0.7
Fiat Punto 2*	4	2317	2.3	25	0.3	30	0.4	3.5	0.7
Opel Corsa 2*	4	6187	6.2	86	0.9	275	3.4	3.6	0.7
Renault Megane Scenic*	4	1028	1.0	16	0.2	17	0.2	2.8	0.6
BMW 325i*	4	2021	2.0	130	1.3	1059	13.2	4.4	0.9
Kia Picanto*	3	6545	2.8	29	0.1	18	0.1	9.1	1.8
Volkswagen Golf*	2	1098	0.5	88	-	172	-	3.5	0.7

De conformiteitsfactoren (CF) van de twaalf voertuigen vergelijken de gemeten waarden in de CADC praktijktest (stad-buitenweg-snelweg), met de koude start, met de limietwaarden volgens NEDC typegoedkeuring. Euro 3 en Euro 4 PM conformiteitsfactoren zijn gebaseerd op een limietwaarde van 5 mg/km, hoewel er geen wettelijke eis is voor deze voertuigen, zelfs als ze nieuw zijn. De PM-emissies van de laatste zes voertuigen zijn bepaald met een verlengde CADC (stad-buitenweg-snelweg-stad) ritcyclus.

Het probleem van de hoge emissies in de praktijktesten kan nog niet op een andere, simpele wijze worden vastgesteld. In aanvullende, eenvoudige emissietesten met zes van de twaalf voertuigen waarbij is, gemeten bij stationair toerental of een constante snelheid van 50 km/uur, is voor de NO_x-emissies geen correlatie gevonden met de resultaten uit de CADC test. Er is in deze eenvoudige testen wel een verband waargenomen tussen de hoge NO_x-emissie uit de CADC test en de lucht-brandstof verhouding en overmatige zuurstofconcentratie in het uitlaatgas, die de basis kan zijn voor een simpele test.

Negen voertuigen hebben ook een reguliere APK test ondergaan. De drie voertuigen met verhoogde NO_x-emissie en de twee voertuigen met zeer hoge NO_x-emissie passeerden allen de test zonder foutmelding. De uitstoot NO_x maakt geen deel uit van de APK test, en het probleem zou alleen indirect vastgesteld kunnen worden met de huidige APK test.

TNO heeft eerder het SEMS emissiemeetsysteem ontwikkeld en gevalideerd. Dit systeem wordt gebruikt voor het monitoren van NO_x-emissies op de weg bij diesel personen-, bestel-, en vrachtwagens. In zijn huidige uitvoering kan SEMS, met daarbij een goede nauwkeurigheid, worden gebruikt voor de detectie van hoge NO_x-emissies tijdens brandstofarme, zuurstofrijke, werking van de motor van benzinevoertuigen. Bij brandstofrijke werking van de motor zijn er echter nog wat beperkingen die wel op verschillende manieren kunnen worden opgelost. Deze zijn in onderzoek.

Conclusies
Met de introductie van de driewegkatalysator, in 1992, zijn benzinevoertuigen veel schoner geworden dan oudere benzine- en dieselvoertuigen. Euro 3 benzinevoertuigen, die moeten voldoen aan een strengere test, verminderen vergeleken met voertuigen zonder een driewegkatalysator, NO_x-emissies met een factor 20. Binnen het nu uitgevoerde testprogramma met praktijktesten op de rollenbank, vertonen twee van de twaalf geteste voertuigen met een kilometerstand van ongeveer 200.000 km, een defect emissiecontrolesysteem. De NO_x-emissies van deze voertuigen zijn een factor 10, of meer, hoger. Bij een aantal andere voertuigen uit deze groep zijn de NO_x-emissies enigszins verhoogd.

De waargenomen hoge emissies in de praktijktest laten weinig correlatie zien met de NO_x-emissies bij stationair toerental of bij constante snelheid. Vandaar dat met dergelijke testen deze emissieproblemen niet kunnen worden vastgesteld. Ook APK testen en goed onderhoud geven geen emissieproblemen aan bij deze voertuigen.

De hoge emissies hangen niet samen met een bepaald automerk of voertuigmodel, noch met een emissieklasse Euro 2 tot Euro 5, leeftijd of specifieke hoge kilometerstanden. Omdat de emissieproblemen ook bij een Euro 5 voertuig voorkomen, wordt verwacht dat het probleem de luchtkwaliteit kan verslechteren tot 2030. Dit omdat Euro 5 voertuigen waarschijnlijk tot 2030 aanwezig zullen zijn op de Nederlandse wegen.

Nieuwe efficiënte meettechnieken, om grotere aantallen auto’s te kunnen meten, zijn nodig voor die situaties waarbij een klein aandeel voertuigen significant bijdragen aan de totale emissies. De ontwikkelingen van dergelijke meettechnieken zijn in gang gezet, en de resultaten zijn goed.

Aanbevelingen
Uit het huidige testprogramma is de voorlopige conclusie dat 1-op-6 voertuigen een defect emissiecontrolesysteem heeft, leidend tot een tienvoudige - of grotere - toename van de NO_x-emissie voor dat voertuig. Slechts gebaseerd op twee defecte voertuigen, kan het probleem in de praktijk blijken niet te bestaan of zelfs twee keer zo groot zijn. Om meer zekerheid te krijgen moeten een redelijk aantal, negen of meer, voertuigen worden ontdekt met een vergelijkbare toename in NO_x-emissie. Het aandeel defecte voertuigen en de toename in emissies bepalen gezamenlijk de grootte van het probleem in de totale voertuigvloot. Op basis van de huidige informatie moeten er daarvoor 60 auto’s getest worden.

Door meer voertuigen te identificeren met een defect emissiecontrolesysteem en hoge NO_x-emissie, wordt verder onderzoek mogelijk. De opties om a) defecten eenvoudiger en directer te kunnen detecteren, b) de oorzaken van de problemen vast te kunnen stellen, en c) de defecten te kunnen repareren, moeten daarin worden meegenomen.

Gebaseerd op het huidige testprogramma vereist een acceptabel vertrouwen dat tenminste zestig voertuigen worden getest. Maar gegeven de huidige onzekerheid en de impact dat een klein aantal voertuigen heeft op de totale emissie, zal het testen van een groter aantal dan zestig voertuigen de onzekerheid verder doen verkleinen. Bij minder dan zestig voertuigen, en een verwacht aantal van tenminste 9 defecte voertuigen, blijft de onzekerheid in de resultaten groot.

Een dergelijk groot testprogramma vereist een hoge efficiëntie qua testen, mogelijk gecombineerd met enige pre-screening. De SEMS meettechnologie, en verdere verbeteringen daarvan, kan mogelijk een goede manier opleveren om te komen tot een efficiënte werkwijze.

Er zijn bij twee voertuigen indicaties dat drift in de lambda sensor (die de werking van de driewegkatalysator regelt) de belangrijkste oorzaak is van de zeer hoge NO_x-emissies. Echter, ook andere oorzaken, of combinaties daarvan zijn mogelijk. Dit geeft al richting aan mogelijke oplossingen om een lambda sensor na de duurzaamheidslimiet van 160,000 km te laten vervangen, mogelijk in combinatie met een controle test.

Dit kan mogelijkheden opleveren om passende maatregelen te nemen om dit probleem goed te herkennen en op te lossen.

Summary

Introduction
On behalf of the Ministry of Infrastructure and Water Management, TNO measured the tailpipe emissions of twelve older petrol vehicles, model year after 1998, with three-way catalysts. One Euro 2, three Euro 3, seven Euro 4 vehicles and one Euro 5 passenger vehicle, with odometer readings between 155.000 and 254.000 km have been tested on the chassis dynamometer according to a real-world (CADC) driving cycle, with representative road loads. The tests were performed between autumn 2017 and summer 2018.

Emissions of petrol passenger cars have been measured in the past when these vehicles were a few years old and had limited odometer readings. On the basis of this data, emission factors have been determined for the different practical situations on the road. With increasing age and odometer readings, the question is whether these vehicles still have the same emission levels.

Petrol vehicles constitute more than 70% of all urban traffic and they have an average lifespan over 200,000 km. These vehicles had to satisfy and type-approval the NEDC emission test, which did ensure proper emission performance of new vehicles. However, these modern vehicles with a mileage above 100,000 km do not have to meet these durability requirements, Moreover, emission control technology has no durability requirements above 160,000 km. This investigation extends the emission testing to the full lifespan of the vehicles, beyond these limits.

Test results
The results of the chassis dynamometer tests show a large spread in the emission behaviour of these twelve vehicles. Measured average NO_x emissions vary between 17 and 1234 mg/km. Particulates emissions of these vehicles vary as well, but these emission levels are low, except for one vehicle. The twelfth vehicle has a measured PM emission of 9.1 mg/km. This may be related to the replacement of the exhaust pipe during the test program, to prevent exhaust gas leakage. A new exhaust pipe may emit large particulates for a few hundred kilometres, which may affect the PM emissions. All vehicles perform well on THC (total hydrocarbons) emission, ranging from 8 to 138 mg/km.

The table below summarizes the chassis dynamometer test results of all twelve vehicles.

	Euro Class	CO		THC		NO_x		PM	
		[mg/km]	CF	[mg/km]	CF	[mg/km]	CF	[mg/km]	CF
Citroën Xsara	3	719	0.3	8	0.0	39	0.3	0.1	0.0
Toyota Aygo	5	4135	4.1	25	0.3	17	0.3	1.1	0.2
Ford Focus	3	2476	1.1	97	0.5	254	1.7	2.3	0.5
VW Polo	4	2500	2.5	53	0.5	96	1.2	1.5	0.3
Opel Corsa1	4	724	0.7	23	0.2	375	4.7	3.9	0.8
Fiat Punto 1	4	5133	5.1	138	1.4	1234	15.4	3.7	0.7
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Kia Picanto*	3	6545	2.8	29	0.1	18	0.1	9.1	1.8
Volkswagen Golf*	2	1098	0.5	88	-	172	-	3.5	0.7

The Conformity Factors (CF) of the twelve tested vehicles, on the CADC with cold start, is the comparison with the NEDC type approval limit values. Note: Euro 3 and Euro 4 PM conformity factors are based on a limit value of 5 mg/km, although there is no legal requirement for these vehicles. The PM emissions of the last six vehicles* are determined with the extended CADC (urban-rural-motorway-urban) driving cycle, with a cold start.

The problems in real-world use could not be detected in a simpler manner. In additional, simple tests with six of the twelve vehicles, at stationary operation or constant 50 km/h velocity, the NO_x emissions show no correlation with the results of the CADC test. There is, however, a correlation of the air-fuel ratio, and the excess oxygen, in these tests, and the high NO_x emission in the real-world tests.

Nine vehicles were also subjected to a regular Periodic Technical Inspection (PTI) emission test (in Dutch named ‘APK’). The three vehicles with elevated NO_x emissions and the two vehicles with high NO_x emissions all passed this test. NO_x is not included in the PTI test.

TNO formerly developed and validated the SEMS emission measuring system. This system is used for monitoring NOx emissions on road for diesel passenger cars, vans, and trucks. In the test programme two vehicles were equipped with SEMS, to investigate the feasibility of SEMS for measuring NOx emissions of petrol cars. In the current state SEMS can also be used to detect high NOx emissions in lean engine operation for petrol vehicles, with good accuracy. For rich operations there are some limitations, which can be resolved in different ways, which are under investigation.

Conclusions
With the introduction of the three-way catalyst in 1992, petrol cars have become much cleaner than the older petrol- and diesel cars. Euro-3 petrol vehicles, which have to satisfy a more stringent test, reduce the NO_x emissions by a factor 20, compared to vehicles without a three-way catalyst. In this study, with real-world tests on the chassis dynamometer, 2 out of 12 vehicles with around 200,000 kilometers on the odometer, have defective emission control technology. The NO_x emissions are tenfold or more higher. In a number of other cases, of the 12 vehicles, NO_x emissions are somewhat elevated.

The high emissions over a real-world test show little correlation with NO_x emissions in the simple tests like stationary operation, or at constant speed. Hence, with such tests the problem cannot be established. Moreover, also PTI tests and proper maintenance do not indicate the emission problems with these vehicles.

The high emissions are not correlated with a particular brand or model, nor with the emission class, Euro-2 to Euro-5, age, and specific high mileages. Since the problems also occur in a Euro-5 vehicle, it is expected that this problem may affect the air-quality until 2030, since Euro-5 vehicles are likely to be present on Dutch road until then.

New efficient measurement techniques are required for situations where a small fraction of vehicles contribute significantly to the total emissions.

Recommendations
From the current test program the preliminary conclusion is that one out of six vehicles has a defective emission control, leading to a tenfold or more increase of the NO_x emission for that vehicle. Based on only two defective vehicles, the actual problem can be non-existent or even double the size. For any confidence, at least sixty vehicles must be tested, with the expectation to uncover nine vehicles with such increases in NO_x emissions. Together, the fraction of defective vehicles and the increase in emissions determine the magnitude of the problem in the total fleet.

With the uncovering of more vehicles with a defective emission control, and high NO_x emissions, further investigation is possible. The options to detect a) defects more simply and directly, b) the causes of the problems, and c) the solutions to fix the defects, should be taking into account. This will provide the options to take appropriate measures to resolve this problem.

Based on the current study, acceptable confidence requires at least sixty vehicles tested. But given the current uncertainty, and the impact a few vehicles have on the total emission, testing more vehicles will reduce the risk. With less than sixty vehicles the uncertainty in the findings remains large. Such a large test program requires high efficiency in testing, possibly combined with some pre-test screening. The SEMS measurement technology, and improvements thereof, may provide a good way to attain this efficiency.

There are indications, from the two vehicles, that drift in the lambda sensor, controlling the operation of the three-way catalyst, is the main culprit of very high NO_x emissions. However, other possible causes, and combinations thereof, are also possible.

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1 Introduction

This report presents detailed results of emission tests carried out by TNO in the period autumn 2017- summer 2018. The tests focussed on emissions of in-use, older, petrol vehicles with three-way catalyst and high mileages. The emission tests were carried out as part of a project for the Dutch Ministry of Infrastructure and Water Management. This vehicle group has a significant impact on the total emissions after 2020, mainly due to the fact that it concerns more than six million vehicles in the Netherlands.

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 measurements with a first set of six vehicles were published in an earlier stage (TNO report 2018-STL-RAP-0100315010, June 2018). However, it was decided to test an additional set of six vehicles. The current report presents the measurement results of the first and second set of vehicles together.

1.1 Context

Euro emission standards
To minimize air pollutant emissions of light-duty vehicles, in 1992 the European Commission introduced the Euro emission standards. In the course of time, these standards have become more stringent. Currently produced light duty vehicles of categories M and N must comply with the Euro 6b standard. The Euro 6c, 6d-Temp, and 6d standards, that further limit the emissions, will become mandatory in the period of 2018 - 2020. The standards apply to vehicles with spark ignition engines and to vehicles with compression ignition engines and cover the following gaseous and particulate emissions:

- CO (carbon monoxide);
- THC (total hydrocarbons);
- NO_x (nitrogen oxides);
- PM (particulate mass),
- PN (particulate number, for petrol 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. The real driving emissions of nitrogen oxides, or NO_x, from diesel vehicles are currently the most important issue with regard to pollutant emissions, as many cities fail to satisfy the NO_2 air-quality standards mainly through the poor real-world performance of diesel cars.[1] As NO_x represents the sum of NO and NO_2 emitted, and much of the

[1] http://www.platformparticipatie.nl/projecten/alle-projecten/projectenlijst/aanpassing-nationaal-samenwerkingsprogramma-luchtkwaliteit-2018/index.aspx

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 exceeds European limits at numerous urban road-side locations[2].
For petrol vehicles, tested by TNO annually till 2008 and more intermittently after that time, limited deviations between the type-approval tests and the real-world tests were observed. The NEDC type-approval test, with the low test velocity, short distance, and the cold start, formed stringent requirements for petrol vehicle technology which ensured in real-world circumstances the emissions were typically lower than the emission limits in the type-approval test. Moreover, from monitoring programs, such as remote sensing studies carried out across Europe, there was little concern on the real-world performance of petrol vehicles. However, given the size of the fleet and, for example, the impact on the total emissions after 2020, there are risks that minor deviations in the estimates will have considerable consequences for the total real-world emissions.

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 the lab. In recent years, however, the emphasis has shifted towards gathering emission data under conditions that are more representative for real-world driving, by using various non-standard, i.e., real-world, driving cycles in the lab and by increasingly testing cars on the road with mobile emission measurement equipment.

Emission factors

Table 1-1: Emission factors for Euro-2 to Euro-5 petrol vehicles for the Dutch air-quality assessments.

road type	g/km	Euro-2	Euro-3	Euro-4	Euro-5
urban	NOx	0.4684	0.1480	0.0539	0.0431
	HC	0.5132	0.4374	0.4197	0.3357
	PM	0.0046	0.0023	0.0023	0.0019
	CO	10.6833	6.6475	5.6150	4.4920
	Elemental Carbon	0.0012	0.0004	0.0004	0.0003
	real-world CO2	284.7	254.6	235.9	213.2
rural	NOx	0.2130	0.0594	0.0248	0.0199
	HC	0.2334	0.2153	0.2118	0.1694
	PM	0.0023	0.0012	0.0012	0.0009
	CO	4.3987	3.2906	2.8732	2.2985
	Elemental Carbon	0.0006	0.0002	0.0002	0.0001
	real-world CO2	143.3	152.6	149.2	134.9
motorway	NOx	0.1984	0.0360	0.0147	0.0117
	HC	0.0654	0.0216	0.0189	0.0151
	PM	0.0050	0.0025	0.0025	0.0025
	CO	3.4073	1.8849	1.6523	1.3218
	Elemental Carbon	0.0013	0.0004	0.0004	0.0004
	real-world CO2	203.0	203.6	194.8	176.1

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

The emission factors, or average emissions, for pollutant tailpipe emissions of this group of vehicles are typically below the type-approval limit. The current, 2018, emission factors are given in
Table 1-1. The urban emissions are substantially higher than rural and motorway emissions. This is the result of the cold start contribution. In the total emissions, the start of the cold engine typically dominates the emissions. In the first 300 metres of driving the same emissions are produced as in the next twenty or more kilometres. For urban driving it is estimated that for every 7 kilometres of driving one cold start occurs.[3]

TNO is one of the few institutes in Europe that perform 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 and air quality 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.

Lack of data of older petrol vehicles
With the focus in recent years on diesel vehicles and NO_x emissions, the test programmes for petrol vehicles were limited. With Euro-5 a few incidental and specialized test programmes for petrol vehicles were executed. The last test programme in 2016, was intended to determine PM and EC emissions of the emerging GDI (Gasoline Direct Injection) technology vehicles.

A lack of emission data of older petrol vehicles was identified: Petrol passenger cars have been measured in the past when these vehicles were only a few years old and had limited odometer readings. On the basis of this data, emission factors have been determined for the different practical situations on the road. With increasing age and mileages, the question is whether these vehicles still have the same emission levels.

Because petrol cars are their entire lifespan on the Dutch roads (they are hardly exported), and because, as they get older, they become a growing share of the total amount of vehicles within cities, they are relevant for urban air quality. It is also the largest group of cars: they constitute more than 70% of all urban traffic. Modern petrol cars reach on average 100,000 kilometres after 7 years. A vehicle from 1990 and before had an average lifespan of 18 years or less and 150,000 kilometres. Vehicles from 2005 and earlier reach the 150,000 at 10 years, and likely drive more than 200,000 kilometres in total.[4]

[3] See report: CBS Methods for calculating emissions of transport in the Netherlands, 2017.
[4] TNO report R11872 Nederlandse wagenparksamenstelling 2016,

Therefore it was decided to perform an exploratory emission measurement program with twelve petrol passenger cars with high mileages. Also the fact that the Dutch petrol fleet has an increasing age, underlines the importance of this study.

1.2 Aim and approach

The aim of the project was to assess the real-world emission performance of petrol passenger cars with three way catalyst and higher mileages and to provide input for generating emission factors for this vehicle category. This was done by performing emission measurements on the chassis dynamometer under real-world conditions. In particular, particulate emissions, such as particulate mass and particulate numbers, can only be measured with confidence in the laboratory. There are no indications the laboratory tests will not be representative for the real-world emissions, for these vehicles. However, SEMS measurement equipment was installed to make this comparison with on-road emissions.

This study involves chassis dynamometer measurements on a total of twelve Euro 2, Euro 3, Euro 4 and Euro 5 passenger vehicles. This number of vehicles provides a basis to observe trends in their emission behaviour and to indicate average deterioration factors for the different road types.

1.3 TNO policy with respect to publication of data

TNO takes the care in generating data and in communication on the findings of its studies to the various stakeholders. It is beneficial to ensure no errors are made in the testing and problems are addressed early.

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 a large number of conditions, that have a strong influence on test results, vary from trip to trip.

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

As part of TNO’s constructive contribution to the on-going public debate about the real-world NO_x emissions of diesel cars, TNO has decided 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

Information regarding the selection and the basic specifications of the selected vehicles can be found in Chapter 2. This chapter also provides detailed information about emission limit values, the used test cycles and the test equipment.
Chapter 3 presents an overview of the test results for the six tested vehicles, followed by conclusions and discussion in Chapter 4. Chapter 5 gives recommendations for further research.

All test results of the individual vehicles as well as the specification of the chassis dynamometer as used during the tests are part of the Appendices.

2 Test programme

This chapter presents the most important characteristics of the test programme as performed. The measurement methods are described in more detail in the TNO methodology report [TNO 2016a]. The tests were performed on a chassis dynamometer mainly to have reliable particulate mass measurements. This is not yet possible in on-road testing.

2.1 Tested vehicles

2.1.1 Vehicle selection

Starting point for the selection of vehicles to be tested was the actual Dutch fleet composition of September 2017. The number of vehicles to be tested within this project was limited to twelve. Selection was done in such a way that the test vehicles represent the largest part of older vehicles present in the Dutch fleet. Most of the selected vehicles (see Table 2-1) belong to the group of highest sales vehicles.

2.1.2 Vehicle specifications

In Table 2-1 and Figure 2-1 some basic data of the selected vehicles are specified. All selected vehicles have a registration date between 1998 and 2012 and mileages between 154,800 and 254,100 km.

Table 2-1: Twelve tested Euro 2, Euro 3, 4 and 5 passenger cars. All vehicles have a Three-Way Catalyst.

No	Brand	Model	Euro Class	Power [kW]	Registration Date	Odometer [km]	Empty Mass [kg]
1	Citroën	Xsara	3	80	14-10-2005	154,800	1,141
2	Toyota	Aygo	5	50	20-06-2012	193,500	780
3	Ford	Focus	3	74	12-07-2001	254,100	1,093
4	Volkswagen	Polo	4	44	30-01-2001	198,900	996
5	Opel	Corsa	4	55	30-03-2001	219,400	935
6	Fiat	Punto	4	59	23-05-2003	206,000	910
7	Fiat	Punto	4	59	23-11-2002	249,300	910
8	Opel	Corsa	4	55	18-09-2003	163,400	935
9	Renault	Megane Scenic	4	82	19-12-2005	219,900	1,345
10	BMW	325i	4	160	29-06-2005	236,800	1,505
11	Kia	Picanto	3	45	05-11-2004	194,400	836
12	Volkswagen	Golf	2	74	05-03-1998	234,000	1,107

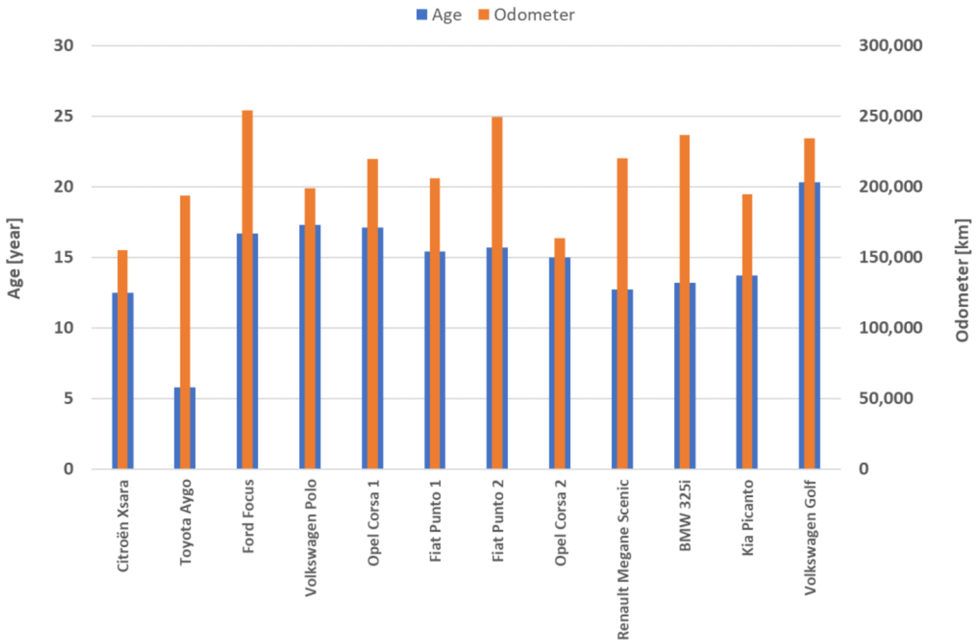


Figure 2-1: Age and odometer of the twelve tested vehicles

2.2 Emission limit values

In Table 2-2 the emission limit values of passenger vehicles and their durability and In Service Conformity mileages are shown. The limit values are based on a New European Driving Cycle (NEDC) with a cold start, the Euro 2 vehicle had to satisfy slightly different test criteria, with part of the cold start excluded from the NEDC test.

Table 2-2: Emission limit values of petrol passenger vehicles.

	Emission limit values of M1 Class 1 petrol vehicles								
Emission	THC	NMHC	CO	NO_x	PM	HC+ NOx	PN	Durability limit	ISC limit
class	[mg/km]						[#/km]	[km]	[km]
Euro 2	-	-	2200	-	-	500	-	80000	-
Euro 3	200	-	2300	150	-	-	-	80000	-
Euro 4	100	-	1000	80	-	-	-	100000	tbr
Euro 5a	100	68	1000	60	5.0	-	-	160000	100000
Euro 5b	100	68	1000	60	4.5	-	-	160000	100000
Euro 6b	100	68	1000	60	4.5	-	6.0E+12	160000	100000
Euro 6c	100	68	1000	60	4.5	-	6.0E+11	160000	100000

2.3 Test cycle and chassis dynamometer settings

High particulates emissions of petrol vehicles are associated with poor air-fuel mixing, higher engine speeds, high engine loads and lubricant consumption of the engine. As the test programme is set up to assess the risks of high PM and PN emissions within the group of older petrol vehicles, the tests are conducted with engine loads that are at the higher end of the spectrum of normal vehicle use in the Netherlands. This means that the engine loads in the test are higher than what is common for the type-approval tests. This is achieved by setting the driving resistance and test mass on the high side of normal use. The applied values are comparable to carrying two passengers and, for example, the use of C- or D-energy label tyres.

Table 2-3: The settings of the chassis dynamometer for the test mass and driving resistance.

Trade mark	Type	Empty mass	Inertia	F0	F1	F2
		[kg]	[kg]	[N]	[N/(km/h)]	[N/(km²/h²)]
Citroën	Xsara	1141	1450	130	0.00	0.040
Ford	Focus	1093	1450	130	0.00	0.040
Toyota	Aygo	780	1130	130	0.00	0.040
VW	Polo	996	1350	130	0.00	0.040
Opel	Corsa 1	935	1350	130	0.00	0.040
Fiat	Punto 1	910	1350	130	0.00	0.040
Fiat	Punto 2	910	1130	130	0.00	0.040
Opel	Corsa2	935	1130	130	0.00	0.040
Renault	Megane Scenic	1345	1450	130	0.00	0.040
BMW	325i	1505	1650	130	0.00	0.040
Kia	Picanto	836	1130	130	0.00	0.040
Volkswagen	Golf	1107	1450	130	0.00	0.040

For all tests the vehicles were soaked at 14 °C. All chassis dynamometer tests are carried out with a test cell temperature of 14 °C. This is close to the average Dutch temperature of 11 ˚C.

Vehicles are tested on the CADC-130 driving cycle[5] (Figure 2.1 and Table 2.4), which is considered representative of more aggressive driving within the spectrum of normal driving. The variant of the CADC-cycle used, has a maximum velocity of 130 km/h. Therefore, all in all the power demand on the vehicles is on the high side, and the emissions may be somewhat higher than can be expected from average driving. The need of this high demand lies in the fact that emissions may increase rapidly with engine demand and therefore average driving does not necessarily result in average emissions.

Table 2-4: The parameters of the CADC driving cycle.

	Distance [km]
Urban	4.4
Rural	16.4
Motorway	23.7
CADC total	44.5

The Citroën, Toyota and Ford vehicles were subjected to three complete CADC tests (1 cold start and two warm starts) and the Volkswagens, Opels, Fiats, Renault,

[5] For more information on TNO test methods for laboratory and on-road testing see: TNO 2016 R11178, "Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme", V.A.M. Heijne et al., 2016

BMW and Kia were subjected to one complete CADC test start with an additional urban part (fourth phase).

Since particulate matter is collected on a filter, the tests of three cars have been repeated three times to collect sufficient particulate matter for an accurate filter particulate mass determination. Rather than collecting the emissions of a full CADC cycle on a single filter, the urban, rural and motorway part are collected on separate filters to have representative particulate mass results for each of these traffic situations.

The filters were of pure quartz. These filters can be used for elemental carbon determination using the SUNSET[6] method from the EUSAAR. In this method of determination the filters are heated up to 800 ˚C. Other types of filters cannot withstand such temperatures, and the filter material itself might contaminate the results.

Moreover, cold starts, when the engine itself is at the ambient temperature, may lead to additional particulates emissions. Cold starts occur mainly in urban driving situations. In the tests cold starts are included in the result of the urban test.
For all vehicles only a single cold start was performed.

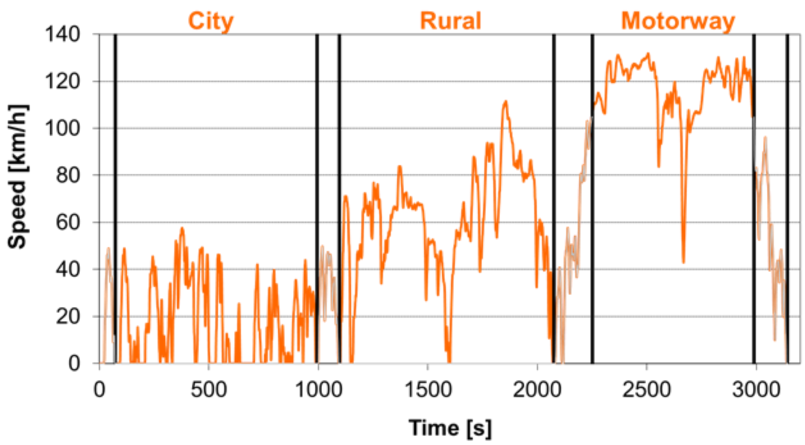


Figure 2-2: Common Artemis Driving Cycle (CADC).

2.4 Test equipment

The specifications of the chassis dynamometer and test equipment are reported in Appendix M.

[6] F. Cavalli et al., *Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protocol*, Atmos. Meas. Tech. (2010) 3 p.79-89.

3 Emission test results

The emission tests were performed between October 2017 and August 2018. The overall results for all tested vehicles are reported in the following sections. Detailed reports of the test results per vehicle can be found in Appendices A to L of this report.

3.1 On Board Diagnostic data

In Table 3-1 the OBD and MIL status of the twelve vehicles are reported. These readings are taken before the actual start of the dynamometer emission test programme.
The Opel Corsa 1 has an OBD failure code (EGR valve position failure) which is related to the exhaust emissions. The Opel dealer did not advise the owner of this vehicle to have the error seen to. The emission test of this vehicle will show the possible effect on emissions, while having an OBD failure code.
During the CADC emission test the BMW 325i had a failure code P0015 (camshaft position sensor). After the CADC test the vehicle was offered to the BMW dealer and the diagnostic test of this vehicle did not yield any emission related failure codes.

Table 3-1: OBD and MIL status of the tested vehicles

		Euro class	Odometer	Calibration ID	MIL	OBD failure codes
			[km]			
Citroën	Xsara	3	154,800	9656393499	Off	No
Toyota	Aygo	5	193,500	Unknown	Off	No
Ford	Focus	3	254,100	KP AL 0A 4 HEX	Off	No
Volkswagen	Polo	4	198,900	Unknown	Off	No
Opel	Corsa 1	4	219,400	Unknown	On	Yes (PO1405)
Fiat	Punto 1	4	206,000	1037363518001000	Off	No
Fiat	Punto 2	4	249,300	1037363520001000	Off	No
Opel	Corsa 2	4	163,400	Unknown	Off	No
Renault	Megane Scenic	4	219,900	8200525773 / 8200581419	Off	No
BMW	325i	4	236,800	7555361/ 7557659 / 3E A7 54 9A / 1A D8 FF 74	Off	Yes (P0015)*
Kia	Picanto	3	194,400	SAH4IS00	Off	No
Volkswagen	Golf	2	234,000	Unknown	Off	No

*Malfunction Indication Light was activated during the chassis dynamometer test

3.2 Overview of CADC test results of all vehicles

Table 3-2 and Figure 3-1 up to Figure 3-13 show CADC test results of the twelve tested vehicles. These results are compared with the type approval limits of the NEDC test. A conformity factor (CF) of 1 means that the real-world test result is equal to the NEDC type approval limit value. For PM there are no requirements for these vehicles, the emission limit for GDI's is taken as standard.

Table 3-2: Test results and Conformity Factors (CF) of twelve tested vehicles on the basis of CADC test results with a cold start and NEDC type approval limit values. Note: Euro 3 and 4 PM conformity factors are based on a limit value of 5 mg/km. The PM of the last six vehicles* are determined with the extended CADC (urban-rural-motorway-urban).

	Euro Class	CO		THC		NO_x		PM	
		[mg/km]	CF	[mg/km]	CF	[mg/km]	CF	[mg/km]	CF
Citroën Xsara	3	719	0.3	8	0.0	39	0.3	0.1	0.0
Toyota Aygo	5	4135	4.1	25	0.3	17	0.3	1.1	0.2
Ford Focus	3	2476	1.1	97	0.5	254	1.7	2.3	0.5
VW Polo	4	2500	2.5	53	0.5	96	1.2	1.5	0.3
Opel Corsa1	4	724	0.7	23	0.2	375	4.7	3.9	0.8
Fiat Punto 1	4	5133	5.1	138	1.4	1234	15.4	3.7	0.7
Fiat Punto 2*	4	2317	2.3	25	0.3	30	0.4	3.5	0.7
Opel Corsa 2*	4	6187	6.2	86	0.9	275	3.4	3.6	0.7
Renault Megane Scenic*	4	1028	1.0	16	0.2	17	0.2	2.8	0.6
BMW 325i*	4	2021	2.0	130	1.3	1059	13.2	4.4	0.9
Kia Picanto*	3	6545	2.8	29	0.1	18	0.1	9.1	1.8
Volkswagen Golf*	2	1098	0.5	88	-	172	-	3.5	0.7

For each emission component the table and figures show a large spread in emission performance per vehicle. The elevated CO emissions are related to the test conditions (relatively high load). Six out of twelve vehicles have a high or very high NO_x emission (172 – 1234 mg/km), two vehicles had an active malfunction (EGR valve failure and camshaft position timing). Eight vehicles exceed CO limit values, two vehicles exceed THC limit values, six vehicles exceed NO_x limit values. One Euro 3 vehicle has a fairly high PM emission of 9.1 mg/km but PM limit values are not applicable for this Euro 3 vehicle.

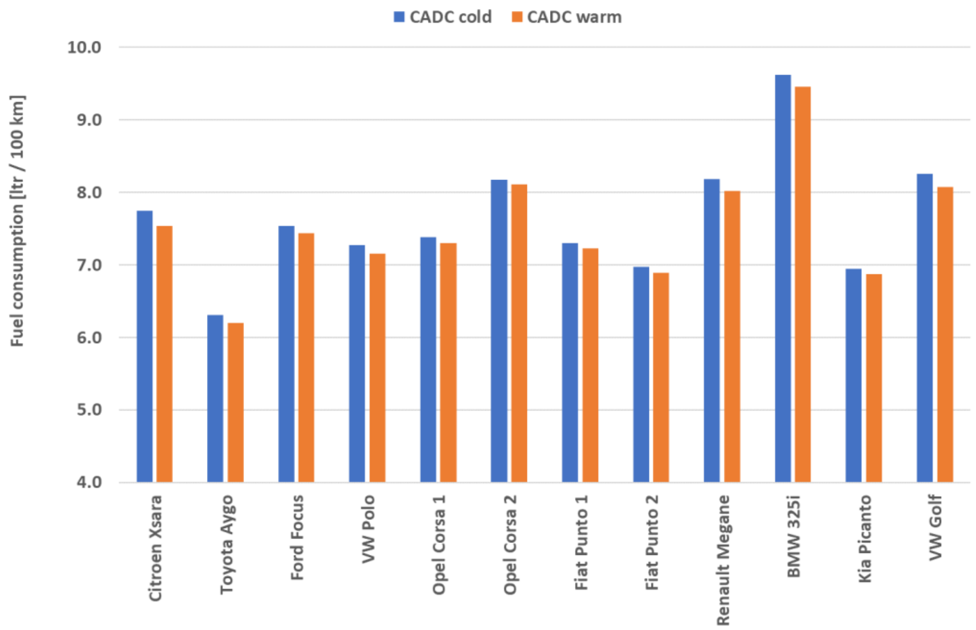


Figure 3-1: Fuel consumption of twelve gasoline vehicles with high mileages in CADC tests with cold and warm start

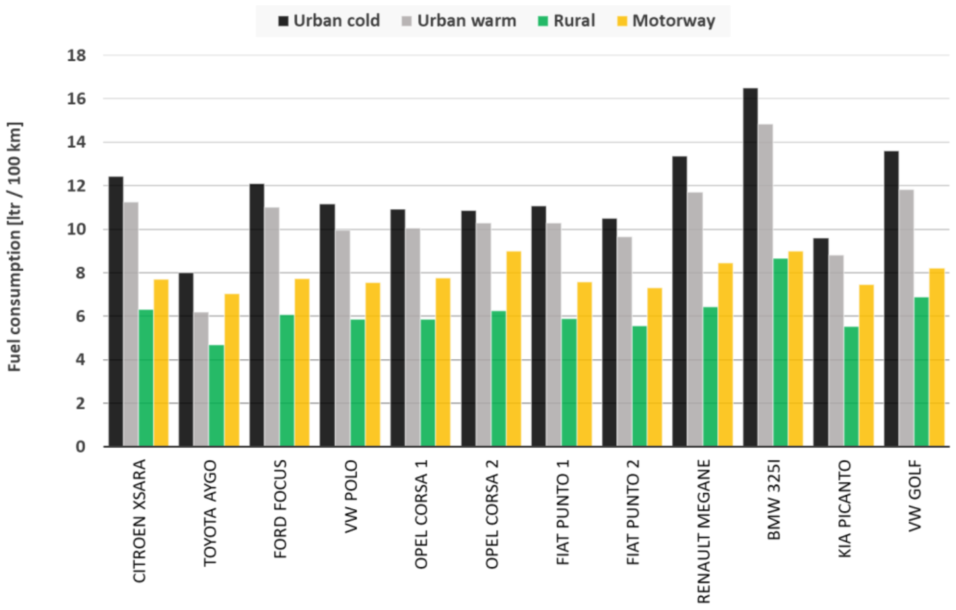


Figure 3-2: Fuel consumption of twelve gasoline vehicles with high mileages in urban conditions with cold and warm start, rural and motorway conditions of a CADC emission test.

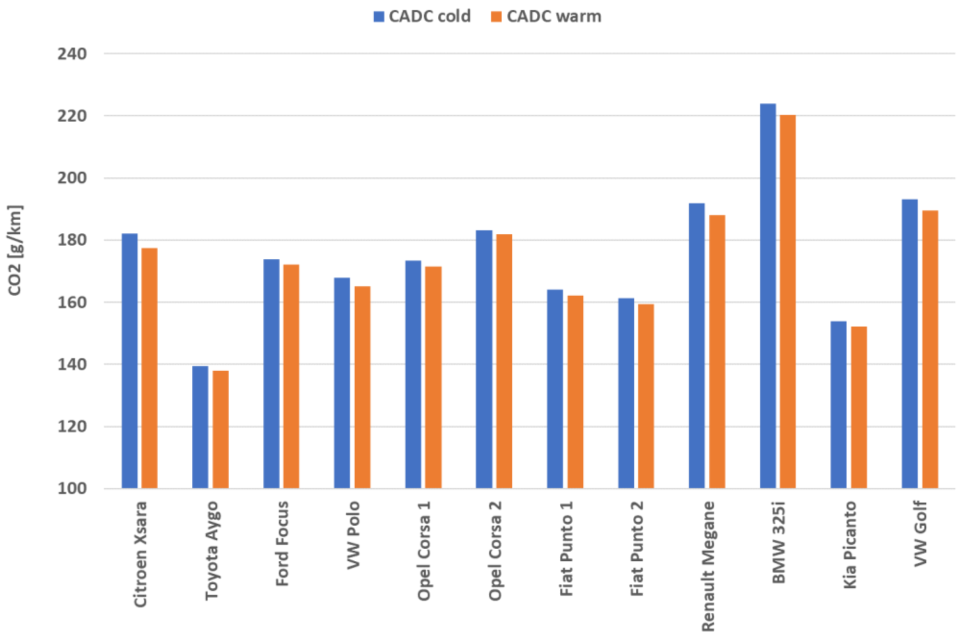


Figure 3-3: CO_2 emission of twelve gasoline vehicles with high mileages in CADC tests with cold and warm start

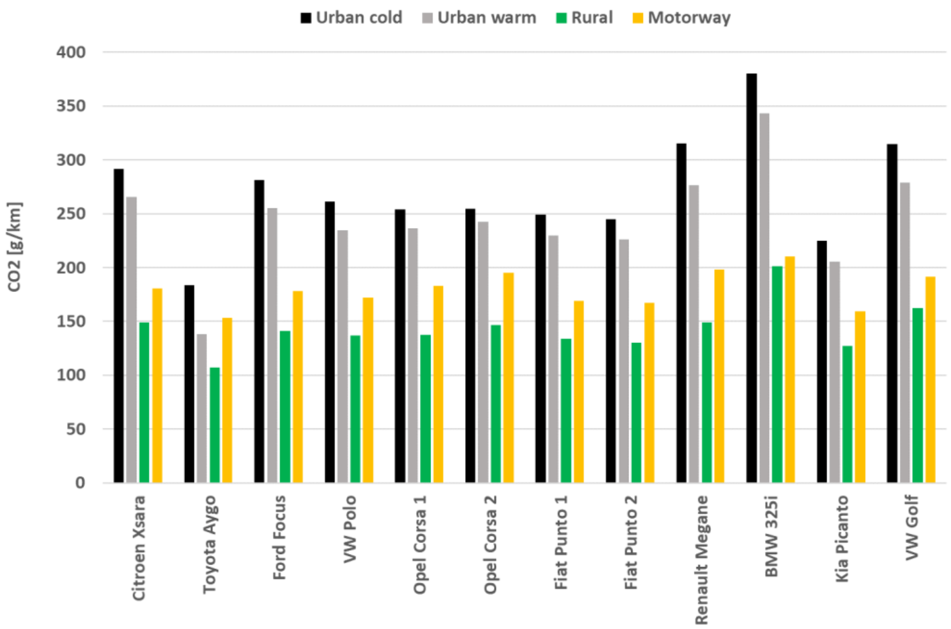


Figure 3-4: CO_2 emission of twelve gasoline vehicles with high mileages in urban conditions with cold and warm start, rural and motorway conditions of a CADC emission test.

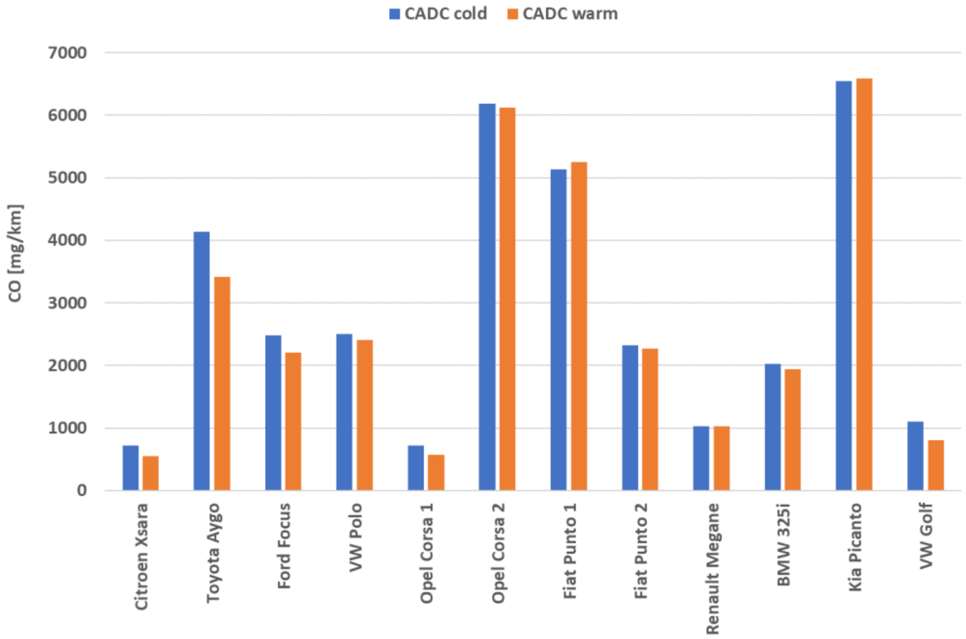


Figure 3-5: CO emission of twelve gasoline vehicles with high mileages in CADC tests with cold and warm start

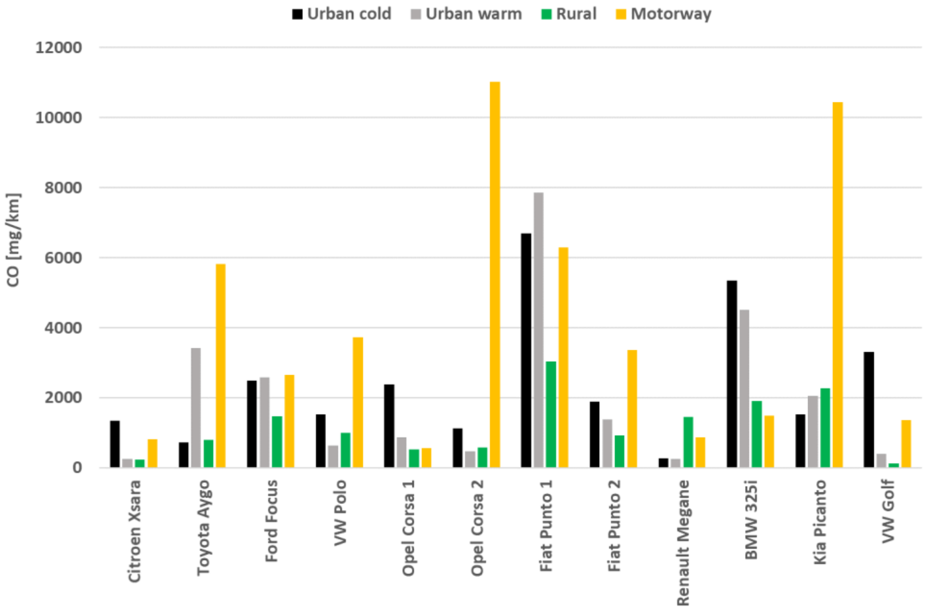


Figure 3-6: CO emission of twelve gasoline vehicles with high mileages in urban conditions with cold and warm start, rural and motorway conditions of a CADC emission test.

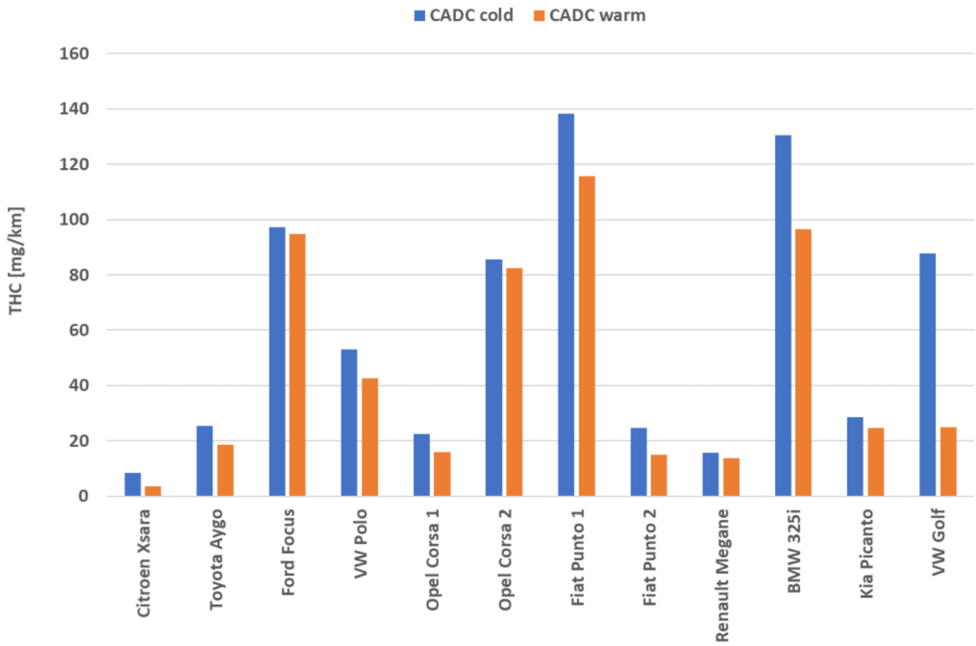


Figure 3-7: THC emission of twelve gasoline vehicles with high mileages in CADC tests with cold and warm start

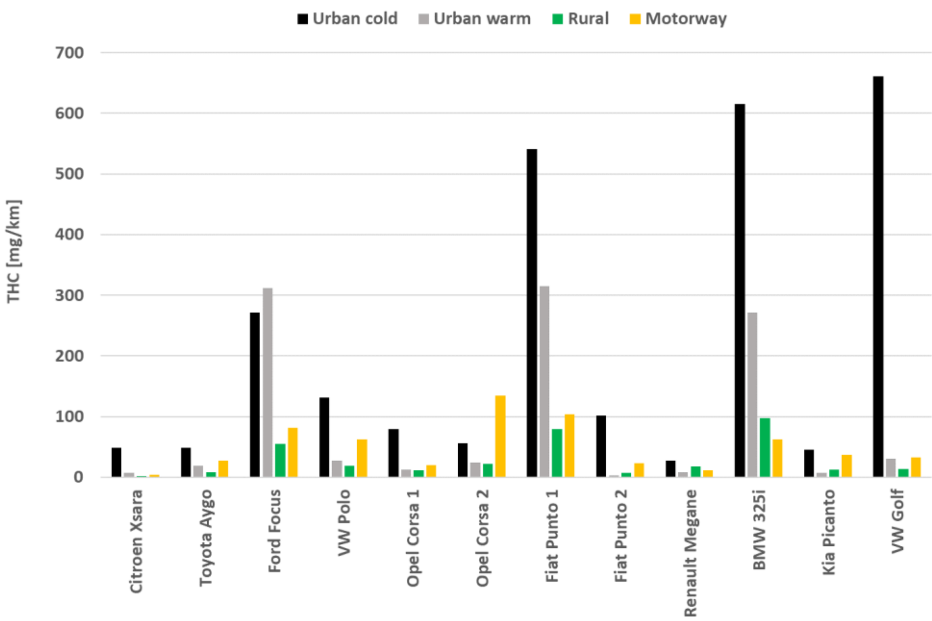


Figure 3-8: THC emission of twelve gasoline vehicles with high mileages in urban conditions with cold and warm start, rural and motorway conditions of a CADC emission test.

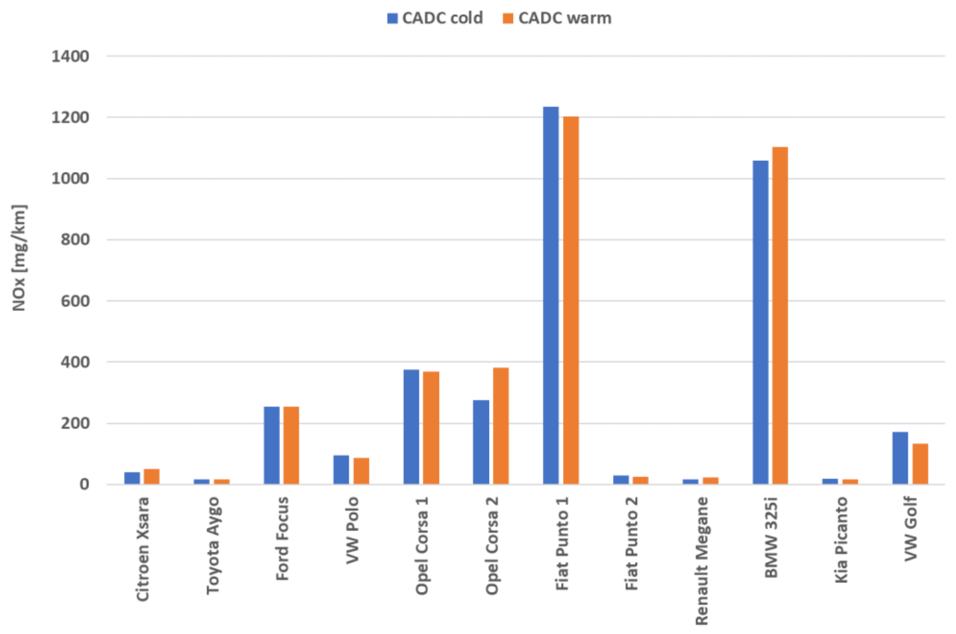


Figure 3-9: NO_x emission of twelve gasoline vehicles with high mileages in CADC tests with cold and warm start

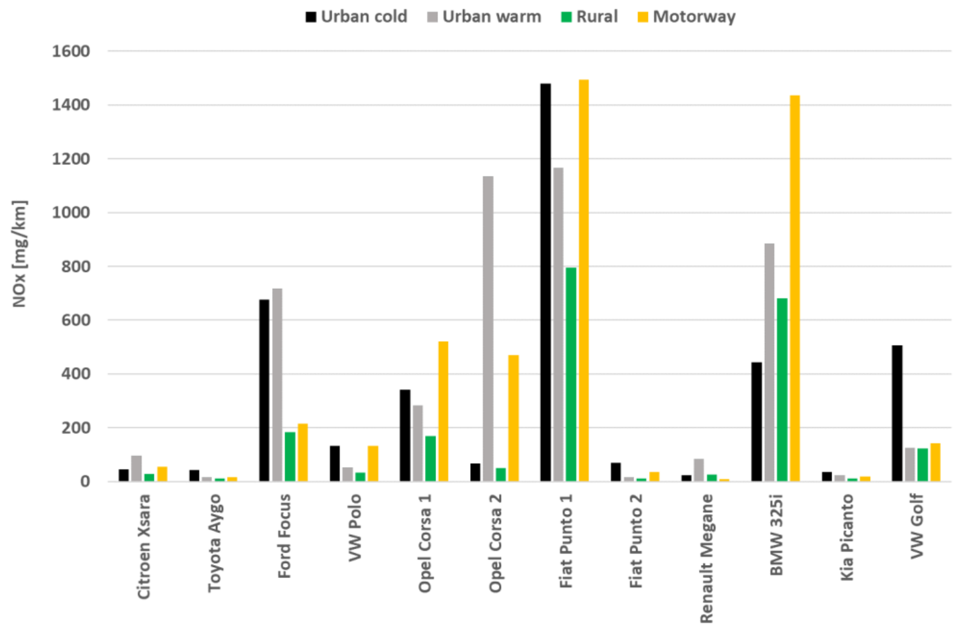


Figure 3-10: NO_x emission of twelve gasoline vehicles with high mileages in urban conditions with cold and warm start, rural and motorway conditions of a CADC emission test.

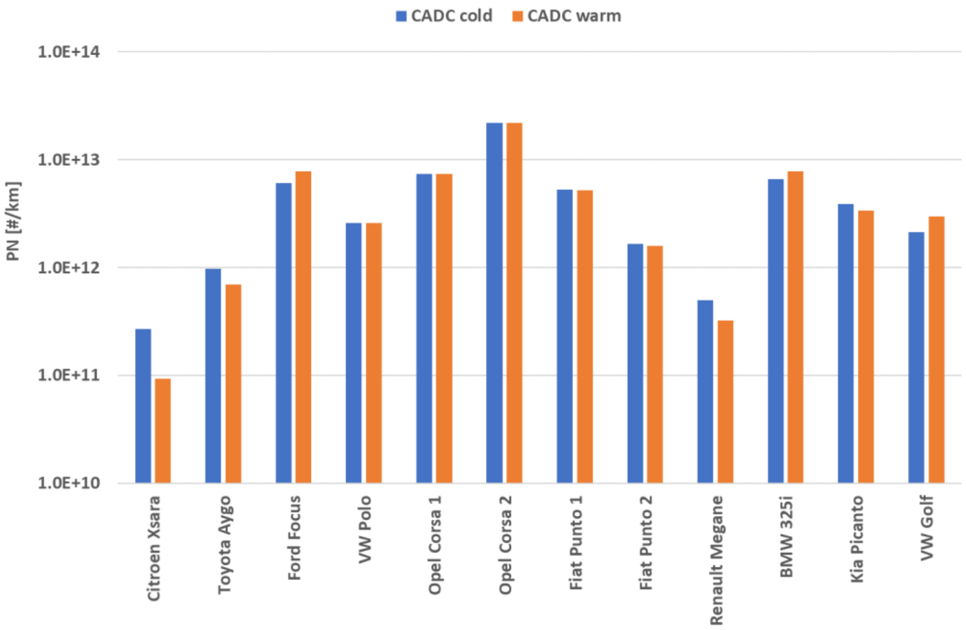


Figure 3-11: Particulate Number (PN) emission of twelve gasoline vehicles with high mileages in CADC tests with cold and warm start

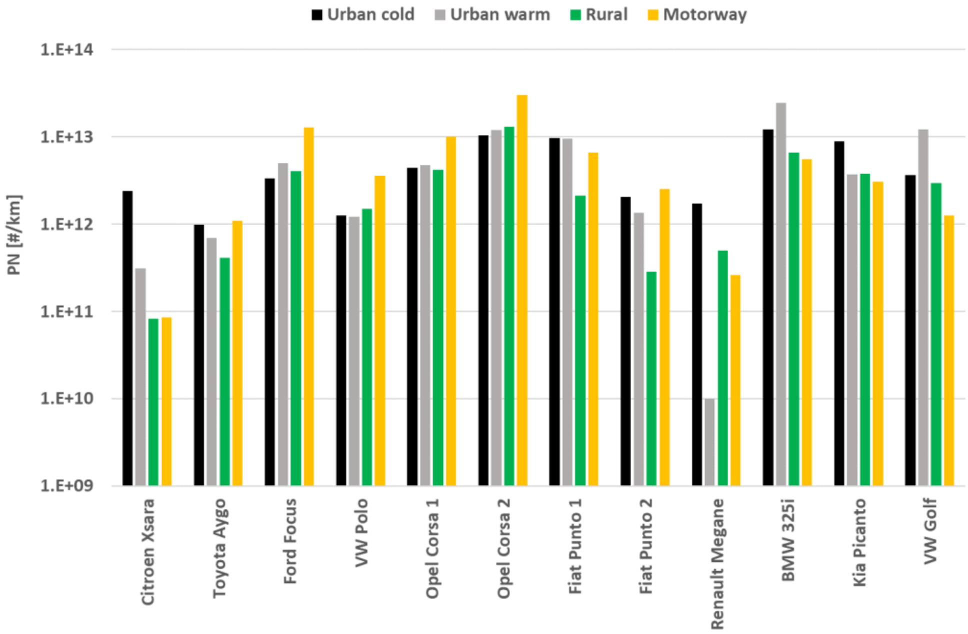


Figure 3-12: Particulate Number (PN) emission of twelve gasoline vehicles with high mileages in urban conditions with cold and warm start, rural and motorway conditions of a CADC emission test.

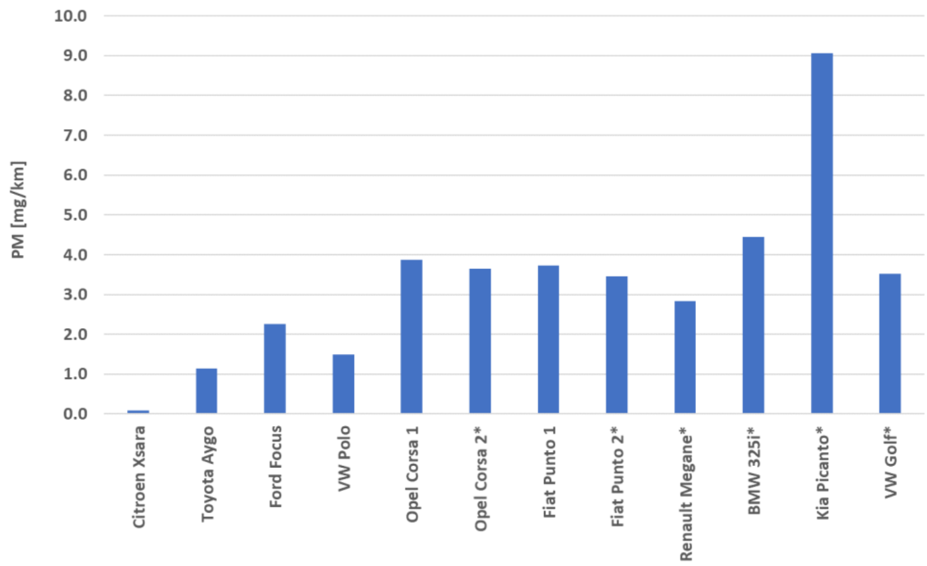


Figure 3-13: Particulate mass (PM) emission of twelve gasoline vehicles with high mileages in urban conditions with cold and warm start, rural and motorway conditions of a CADC emission test. The PM of the six * vehicles are determined with the extended CADC (urban-rural-motorway-urban).

4 Analyses of test results

4.1 Background knowledge of a three-way catalyst and lambda controller

In order to understand the measured emission behaviour of all tested vehicles first some background knowledge of the three-way catalyst and the lambda control strategy is given.

Three-way catalysts will convert CO and HC to CO_2 and H_2O when the catalyst runs in its temperature window and sufficient O_2 is available for oxidation. These lean mixture conditions are available when the so-called lambda value exceeds 0.995. However NO_x is reduced in the warm catalyst when sufficient CO is available with rich mixtures at lambda values lower than 0.995. In the left part of Figure 4-1 the relationship of lambda and conversion of emissions in a three way catalyst is shown. Optimal conversion of CO, THC and NO_x emissions can be realised in a very narrow lambda window which can be established with a so-called lambda controller which contains a lambda sensor.

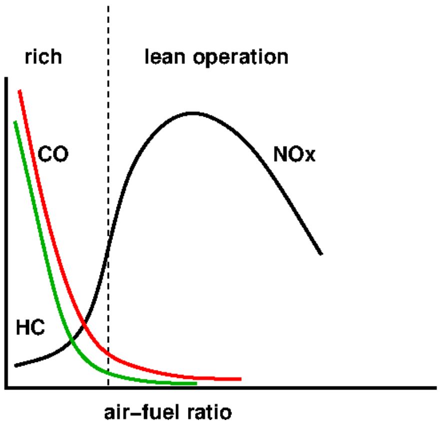


Figure 4-1: The typical emissions of a petrol engine. In lean operation, on the right, NO_x emissions are high. In rich operation on the left hydrocarbon and CO emissions are high. In between, at the dashed line, HC, CO, and NO_x are produced in the right balance to be converted in a three-way catalyst into harmless products.

Both conditions, rich and lean, are realised with the lambda controller which oscillates between a rich and lean mixture. The normal lambda operating window of lambda controlled engine with a three-way catalyst is in the range of 0.99 to 1.00. At higher engine loads mixture enrichment is applied, lambda can be around 0.80.

The determination of the mixture quality around a lambda value of 1.00 is measured by the lambda sensor which is basically an oxygen balance sensor. The output signal of the lambda sensor is 50 to 950 mV and a very steep switch of the sensor output signal occurs at lambda 1.00. A small shift of this sensor measuring signal, which can be caused by deterioration, may lead to an effective average leaner mixture, a shift in the pollutant emissions towards high NO_x, and a decreased conversion of the three way catalyst.

The four potential main causes for increased NOx emissions are:
- A failing EGR system

- A failing lambda sensor
- A failing air-fuel control system
- Catalyst aging and deterioration

4.2 PTI test results

Nine vehicles were subjected to a regular Periodic Technical Inspection emission test (in Dutch named ‘APK’). In this four gas test at low idle speed CO, CO_2, THC and O_2 volumetric emissions are measured and lambda is calculated on the basis of these four emission components. All nine tested vehicles (the five vehicles with increased and very high CADC NO_x emissions were included) passed the test which has a CO limit value and a required lambda window of 0.97 – 1.03.
The BMW 325i with a CADC NO_x emission of 1059 mg/km was subjected to a diagnostic test in a BMW service shop. This test did not yield any emission related fault code. The current PTI emission test performed on nine vehicles and even one diagnostic test in a service shop don’t provide appropriate information for a representative NO_x assessment.

4.3 NOx test results of simple and chassis dynamometer emission tests

Simple emission tests:
Knowing the test results of the CADC and regular PTI four gas test of the first set of six vehicles, it was decided to perform additional simple emission tests at low idle speed and at 50 km/h with the second set of six vehicles on the chassis dynamometer. In appendices G to L the detailed emissions at low idle speed in the CADC tests and in simple emission tests are reported.
The CO, CO_2 and O_2 volumetric concentrations of the two test methods are similar. The measured HC emissions of the two test methods are very different, this is probably caused by the test set up (with or without sample conditioning at 180 °C).
The measured NO_x emission at low idle speed in the CADC tests of all tested vehicles is in a range of 0 to 46 ppm, this indicates a proper working three-way catalyst at these conditions.

In figure 4.2 the relationship of the CADC (with cold start) NO_x emission of all tested vehicles and NO_x volumetric concentrations at different idle speeds and at a constant velocity of 50 km/h are shown. At 50 km/h the measured volumetric NO_x concentrations are higher than at low idle speed. However, none of the NO_x measurements at low idle speed or at 50 km/h show a clear relationship with the NO_x emissions in the CADC tests.

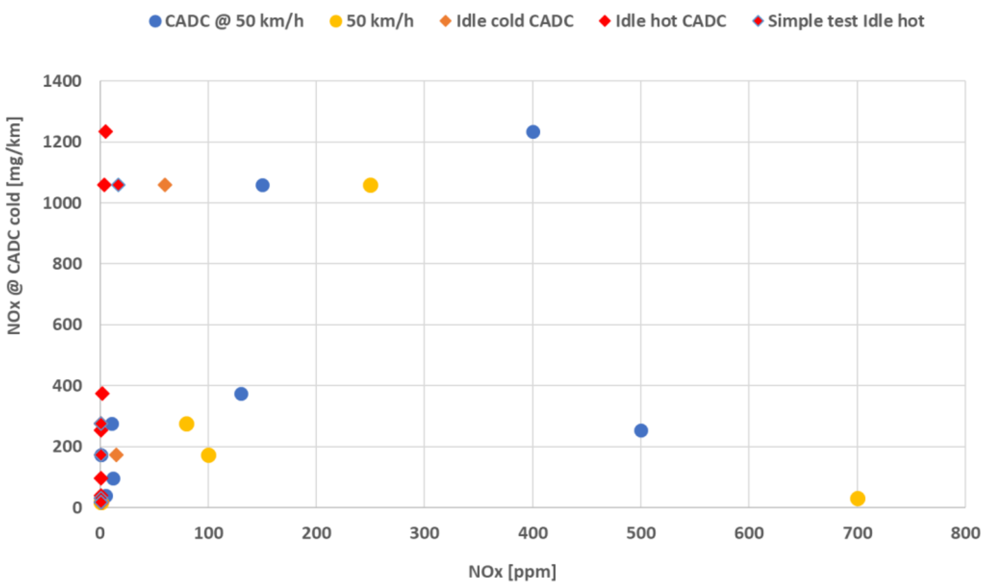


Figure 4-2: Relationship of different NO_x concentrations of simple emission tests and CADC NO_x mass emission of the twelve tested vehicles.

4.4 O_2 test results of simple and chassis dynamometer emission tests

Exhaust gas of a stoichiometric gasoline vehicles contains low concentrations of oxygen. Figure 4-3 shows an example of the distribution of measured oxygen concentration in a CADC test of a gasoline engine. This vehicle has a relative share of 67.2% with less than 0.20 vol% oxygen in exhaust gas.

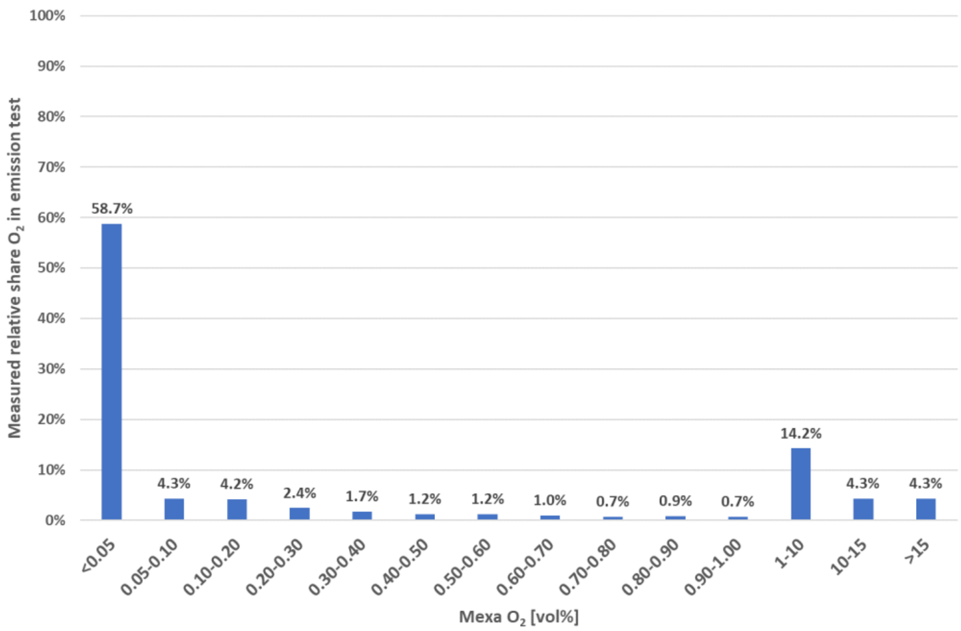


Figure 4-3: Distribution of measured oxygen concentrations in exhaust gas of a CADC test of a stoichiometric gasoline vehicle.

In Figure 4-4 the relationship of the CADC (with cold start) NO_x emission and CADC O_2 share < 0.20 vol% in exhaust gas of the twelve tested vehicles are shown. For most vehicles the share of the measured O_2 concentration below 0.20% in their exhaust gas is more than 60%, detailed figures of O_2 concentrations in exhaust gas of the individual vehicles are reported in appendices A to L.
From the results in Figure 4-4 two vehicles with the highest CADC NO_x emission (above 1000 mg/km) have a relative low O_2 share (30 and 40%) of exhaust gas with less than 0.20 vol% O_2. These vehicles operated with relative lean mixtures which are the primary cause of their high NO_x emission.

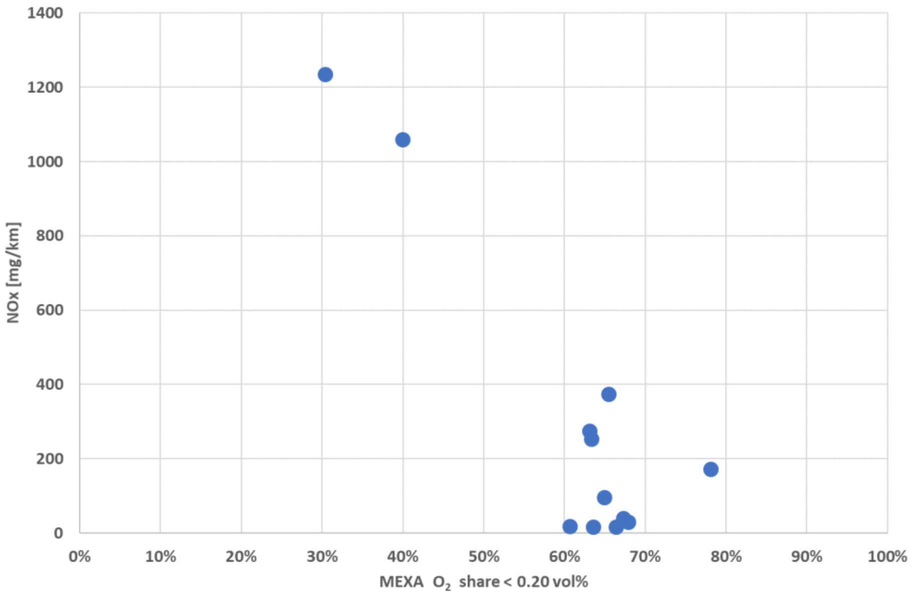


Figure 4-4: Relationship of the measured volumetric CADC O_2 share (< 0.20 vol%) and NOx mass emissions in mg/km of the twelve tested vehicles.

In Figure 4-5 the relationship of the CADC (with cold start) NO_x emission and O_2 volumetric concentration in exhaust gas at low idle speed of all tested vehicles are shown. Detailed figures of O_2 concentrations in exhaust gas in simple emission tests of the individual vehicles are reported in appendices A to L. In appendices G to L O_2 and NO_x emissions of simple emission tests are plotted in figures.
For most vehicles the measured O_2 volumetric concentration at low idle speed is less than 0.30% and the corresponding CADC NO_x emission is less than 400 mg/km. From the results in Figure 4-5 two vehicles with the highest CADC NO_x emission (above 1000 mg/km) have a measured O_2 concentration of 0.42% and 0.90%. The results in figure 4-5 indicate a relationship between the volumetric O_2 concentration at low idle speed and CADC NO_x emissions. The value at 0.3% O_2 in the figure, associated with low NO_x is a deviation from the clear trend, which shows some details have to investigated further.

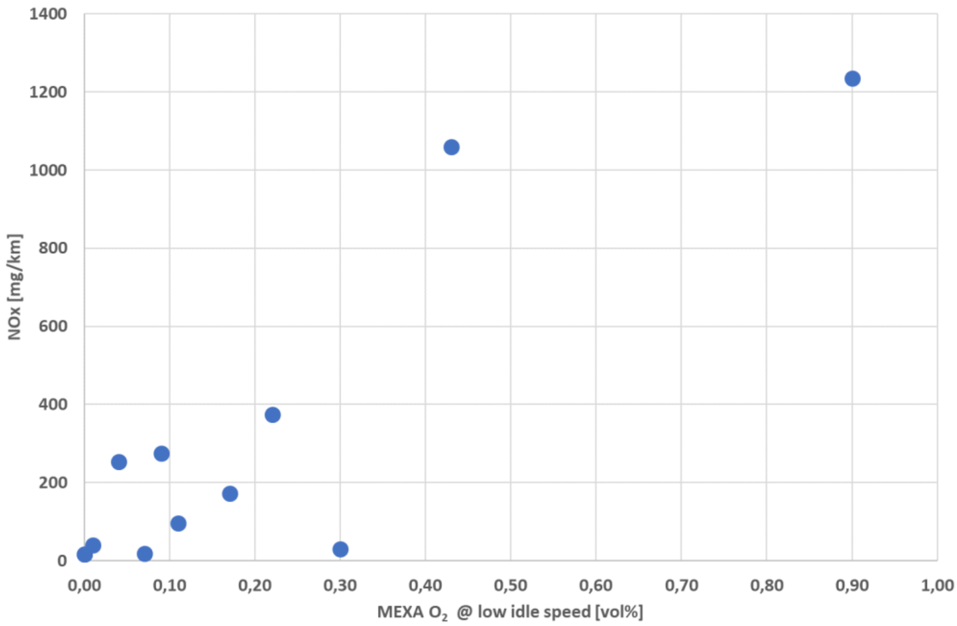


Figure 4-5: Relationship of measured volumetric O_2 concentration at low idle speed and the CADC NO_x emission in mg/km of the twelve tested vehicles.

5 Developing simple on-road emission tests

The three-way catalyst is the first complex emission control system, where the failure of the system will lead to a tenfold or more increase in emissions. Nowadays, almost all emission control technology has this complexity and their malfunctions this impact. Malfunction in 10% of the cases will lead to a doubling of the emissions. Detecting of such malfunctions requires simple measurement techniques, which can be used in the normal, on-road use of the vehicles.

Such alternatives for efficient emission testing of many vehicles are limited. Hence In particular, the choice representative on-road, real-world test methods are limited. One alternative is remote sensing, but given the fact that emissions occur mainly by dynamic driving, the locations suitable for remote sensing are generally less suitable for detecting the incidents of high emissions, as they occur for petrol vehicles, at junctions, overtaking, and in stop-and-go traffic.

For NO_x emissions of diesel vehicles, TNO has developed and validated the SEMS emission measuring system. This system is used for monitoring NO_x emissions on road for diesel passenger cars, vans, and trucks. For petrol vehicles the system has not been tested extensively. One GDI petrol vehicle with elevated NO_x on the chassis dynamometer[7] did show a similar behaviour with SEMS on-road in preliminary tests with the same make and model.

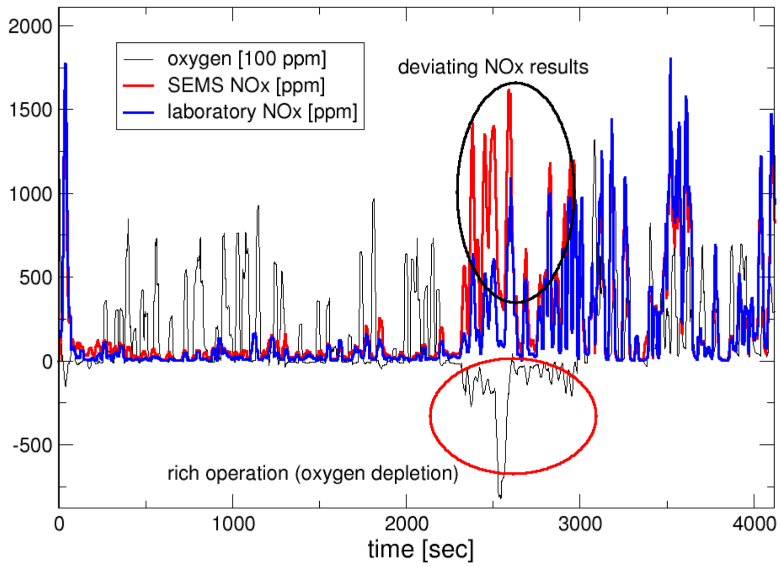


Figure 5-1 The SEMS NO_x signal should be slightly higher because there is less dispersion of the exhaust gas closer to the engine with the dynamic flow. But between 2200 and 3000 seconds in the test, the oxygen is negative, signalling a rich engine operation, with large deviation of the SEMS NO_x signal as a result.

[7] TNO report R11247 Emissions of three common GDI vehicles (2016).

Given the fact that a small fraction of the vehicles show high emissions, the option to investigate with SEMS more simply, more vehicles, was incorporated in the test program of the last six vehicles. Two vehicles were instrumented with SEMS. In one vehicle a Mass Air-Flow measurement system was installed at the air inlet of the engine. In the chassis dynamometer tests one SEMS system was not properly activated. The other SEMS system, on the Opel Corsa, measured the NO_x emissions, parallel to the laboratory equipment. For 75% of the time the results were very similar, but in a part of the test, large deviations occurred. See Figure 5-1. These large deviations are associated with fuel-rich operation of the engine with high concentrations of CO and hydrocarbons, affecting the SEMS reading. From the oxygen signal of the SEMS NO_x sensor, it is clear that a fuel-rich operation occurred. It is even possible to use the oxygen signal to compensate for the overestimation of NO_x in the fuel-rich operation. In the case of this compensation the results are within 10% the same. In small parts the NO_x signal cannot be registered, because of the extensive oxygen depletion. See Figure 5-2.

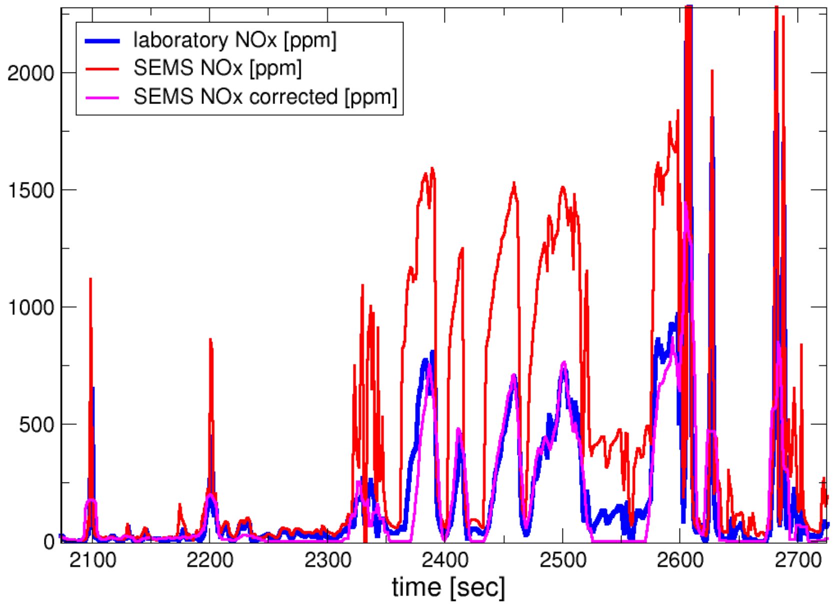


Figure 5-2 Zoom in from the previous plot (Figure 5-2), on the deviating results at rich operation. If the results are corrected with a constant factor for the oxygen depletion (magenta line), in most parts the concentrations match the laboratory results.

In the current state SEMS can be used to detect high NO_x emissions in lean operation for petrol vehicles, which is associated with very high NO_x emissions. For rich operations there are some limitations, which can be resolved in different ways, now under investigation. The SEMS equipment can be used to perform emission monitoring programs in normal use for longer periods. Furthermore, given the very high NO_x concentrations in the case of a defective emission control system, it may be possible to perform a simpler initial screening, by examining the NO_x concentrations, which may go up to several thousand ppms, only in a short test program using SEMS.

6 Conclusions

With the introduction of the three-way catalyst in 1992, petrol cars have become much cleaner than the older petrol- and diesel cars. Euro-3 petrol vehicles, which have to satisfy a more stringent test, reduce the NOx emissions by a factor 20, compared to vehicles without a three-way catalyst. In this study, with real-world tests on the chassis dynamometer, 2 out of 12 vehicles with around 200,000 kilometers on the odometer, have defective emission control technology. The NO_x emissions are tenfold or more higher. In a number of other cases, of the 12 vehicles, NO_x emissions are somewhat elevated.

The high emissions over a real-world test show little correlation with NOx emissions in the simple tests like stationary operation, or at constant speed. Hence, with such tests the problem cannot be established. Moreover, also PTI tests and proper maintenance do not indicate the emission problems with these vehicles.

The high emissions are not correlated with a particular brand or model, nor with the emission class, Euro-2 to Euro-5, age, and specific high mileages. Since the problems also occur in a Euro-5 vehicle, it is expected that this problem may affect the air-quality until 2030, since Euro-5 vehicles are likely to be present on Dutch road until then.

New efficient measurement techniques are required for situations where a small fraction of vehicles contribute significantly to the total emissions.

7 Recommendations

From the current test program the preliminary conclusion is that one out of six vehicles has a defective emission control, leading to a tenfold or more increase of the NOx emission for that vehicle. Based on only two defective vehicles, the actual problem can be non-existent or even double the size. For any confidence, at least nine vehicles must be discovered with such increases in NOx emissions. Together, the fraction of defective vehicles and the increase in emissions determine the magnitude of the problem in the total fleet.

Based on the current study, acceptable confidence requires at least sixty vehicles tested. But given the current uncertainty, and the impact a few vehicles have on the total emission, testing more vehicles will reduce the risk . With less than sixty vehicles the uncertainty in the findings remains large. Such a large test program requires high efficiency in testing, possibly combined with some pre-test screening. The SEMS measurement technology, and improvements thereof, may provide a good way to attain this efficiency.

There are indications, from the two vehicles, that drift in the lambda sensor, controlling the operation of the three-way catalyst, is the main culprit of very high NOx emissions. However, other possible causes, and combinations thereof, are also possible.

With the uncovering of more vehicles with a defective emission control, and high NOx emissions, further investigation is possible. The options to detect a) defects more simply and directly, b) the causes of the problems, and c) the solutions to fix the defects, can be taking into account. This will provide the options to take appropriate measure to resolve this problem.

8 References

[TNO 2016a] Heijne et al., *Assessment of road vehicle emissions: methodology of the Dutch in-service testing programme*, TNO report 2016 R11178

[TNO 2016b] Ligterink, N.E., *Emissions of three common GDI vehicles*, TNO report 2016, R11247

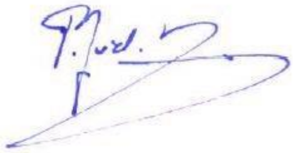
[PBL 2017] Kleijn et al., *Methods for calculating the emissions of transport in the Netherlands*, Task Force on Transportation of the Dutch Pollutant Release and Transfer Register, 2017

9 Abbreviations

CADC	Common Artemis Driving Cycle
CF	Conformity Factor
NEDC	New European Driving Cycle
MIL	Malfunction Indication Light
OBD	On Board Diagnosis
PTI	Periodic Technical Inspection

10 Signature

The Hague, 8 October 2018 TNO

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A Test results Citroën Xsara, Euro 3

In Table A-1 the specifications of the tested Citroën Xsara are reported.

Table A-1: Vehicle specifications of the Citroën Xsara.

Trade Mark	[-]	Citroën
Type	[-]	Xsara
Body	[-]	Station wagon
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	VF7N2NFU173920273
Engine Calibration ID	[-]	9656393499
Swept Volume	[cm^3]	1587
Max. Power	[kW]	80
Euro Class	[-]	Euro 3
Vehicle Empty Mass	[kg]	1141
Odometer	[km]	154,711
Registration Date	[dd-mm-yy]	14-10-05

Test results of the Citroën Xsara are presented in Table A-2.

Table A-2: Test results of the Citroën Xsara

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100 km]
CADC cold1	8	719	182.0	39	25	6	***0.1***	2.7E+11	7.75
CADC hot1	4	575	176.4	51	33	2	***0.1***	8.2E+10	7.50
CADC hot2	3	522	178.5	48	31	2	***0.1***	1.0E+11	7.58
Urban cold 1	49	1342	291.8	46	25	41	0.2	2.4E+12	12.44
Urban hot 1	9	184	262.9	124	80	5	0.2	2.7E+11	11.13
Urban hot 2	6	318	267.9	70	42	3	0.2	3.5E+11	11.35
Rural cold 1	2	182	152.9	22	9	1	0.2	7.0E+10	6.48
Rural hot 1	1	81	147.9	27	17	1	0.2	4.4E+10	6.26
Rural hot 2	2	378	150.0	32	20	1	0.2	1.2E+11	6.37
Motorway cold 1	6	973	181.7	50	32	3	0.0	8.1E+10	7.75
Motorway hot 1	4	987	180.2	55	34	3	0.0	9.7E+10	7.69
Motorway hot 2	4	660	181.4	56	35	3	0.0	7.3E+10	7.71

Overall emission image of the Citroën Xsara:
The measured CO, THC, NOx and PM CADC emissions of the Euro 3 Citroën Xsara with 155,000 km are below the Euro 3 NEDC limit values and even pass the Euro 6c limit values. From this vehicle no oil consumption data are available.

On the basis of the overall emission performance of this Citroën Xsara no deterioration effects can be identified.

Cold start emissions of the Citroën Xsara:
In the CADC test with cold start the measured CO and THC emissions are elevated in the urban and rural part. This emission behaviour can be marked as normal because after the cold start, the engine runs some time with a rich air-fuel mixture and the three way catalyst is not active because it operates below the light-off temperature.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-1 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Citroen Xsara are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 67.2%.

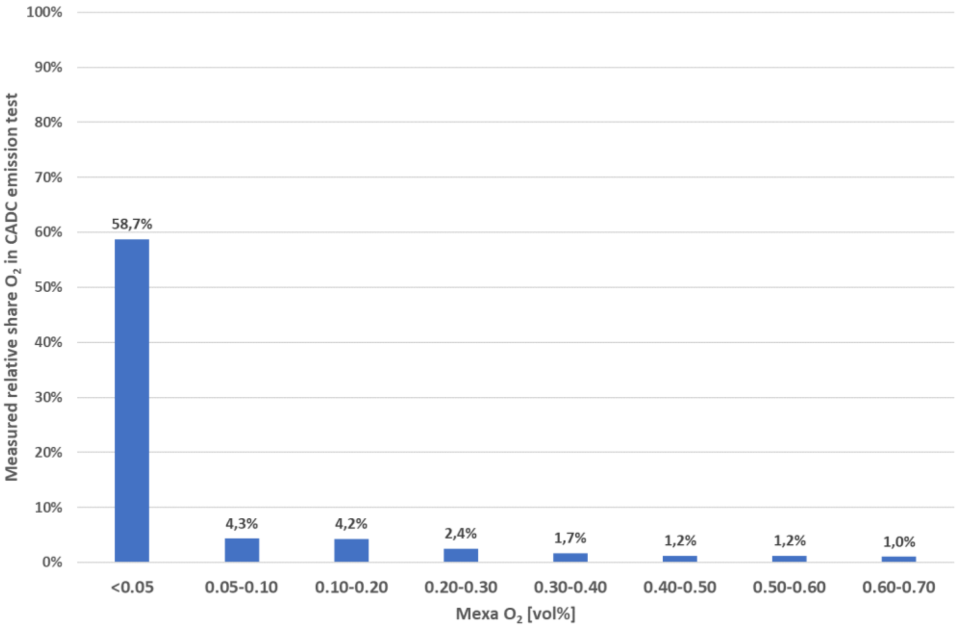


Figure 10-1: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Citroen Xsara.

B Test results Toyota Aygo, Euro 5

In Table B-1 the specifications of the tested Toyota Aygo are reported.

Table B-1: Vehicle specifications of the Toyota Aygo

Trade Mark	[-]	Toyota
Type	[-]	Aygo
Body	[-]	Hatchback
Vehicle Class	[-]	M1
Fuel	[-]	petrol
Vehicle Identification Number	[-]	JTDKG12C80N629817
Swept Volume	[cm^3]	998
Max. Power	[kW]	50
Euro Class	[-]	Euro 5
Vehicle Empty Mass	[kg]	780
Odometer	[km]	192,515
Registration Date	[dd-mm-yy]	20-06-12

Test results of the Toyota Aygo are presented in Table B-2.

Table B-2: Test results of the Toyota Aygo

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100 km]
CADC cold1	25	4135	139.4	17	11	20	***1.1***	9.7E+11	6.31
CADC hot1	19	3423	137.6	17	11	15	***1.1***	7.0E+11	6.18
CADC hot2	18	3404	138.2	17	11	14	***1.1***	6.9E+11	6.21
Urban cold 1	48	719	183.4	42	27	45	0.1	9.9E+11	7.99
Urban hot 1	14	204	170.9	42	27	12	0.1	6.6E+11	7.41
Urban hot 2	11	238	170.6	53	34	9	0.1	5.7E+11	7.40
Rural cold 1	8	862	107.4	11	7	7	0.1	4.2E+11	4.70
Rural hot 1	7	759	106.6	11	7	6	0.1	3.9E+11	4.66
Rural hot 2	8	851	107.6	11	7	7	0.1	4.3E+11	4.71
Motorway cold 1	33	7053	153.4	17	11	24	2.1	1.6E+12	7.12
Motorway hot 1	28	5867	152.9	17	11	21	2.1	1.1E+12	7.02
Motorway hot 2	27	5776	153.3	14	9	20	2.1	1.1E+12	7.03

Overall emission image of the Toyota Aygo:
The measured THC, NOx and PM CADC emissions of the Euro 5 Toyota Aygo with 192,515 km are below the Euro 5 NEDC limit values.
The measured CO emission on the highway is 5867 – 7053 mg/km which is caused by the high applied engine load. The measured CO emission of 204 to 862 mg/km in the urban and rural parts are at regular levels. For this vehicle no oil consumption data are available.

On the basis of the overall emission performance of this Toyota Aygo no deterioration effects can be identified.

Cold start emissions of the Toyota Aygo:
In the CADC test with cold start the measured CO and THC emissions are elevated in the urban part. This emission behaviour can be marked as normal because after the cold start the engine runs some time with a rich air-fuel mixture and the three way catalyst is not active because it operates below the light-off temperature.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-2 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Toyota Aygo are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 66.4%.

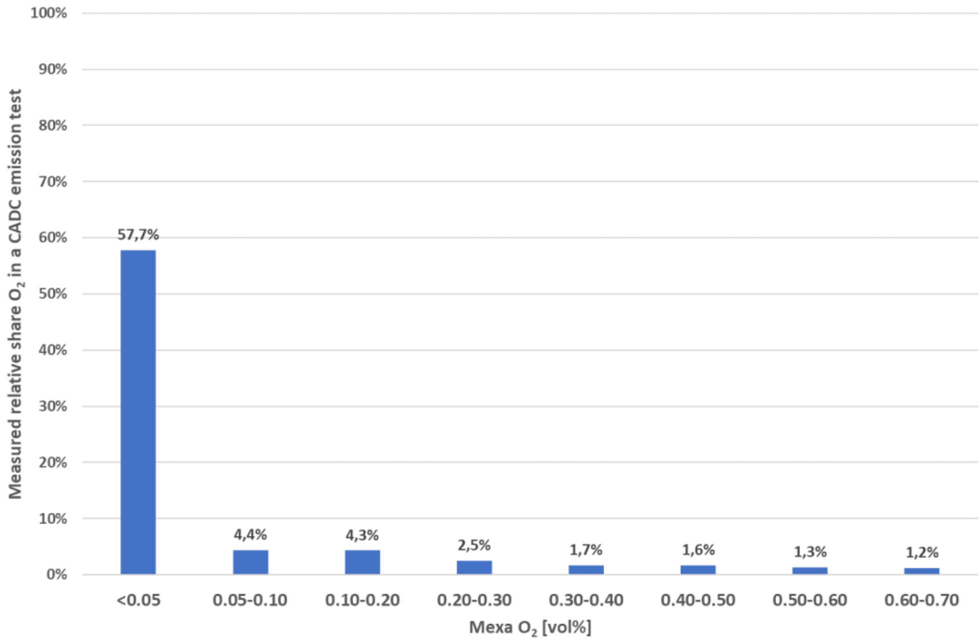


Figure 10-2: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Toyota Aygo.

C Test results Ford Focus, Euro 3

The specifications of the tested Ford Focus are given in table C-1.

Table C-1: Vehicle specifications of the Ford Focus.

Trade Mark	[-]	Ford
Type	[-]	Focus
Body	[-]	Stationwagon
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	WF0NXXGCDN1M28182
Engine Calibration ID	[-]	KP AL 0A 4 HEX
Swept Volume	[cm^3]	1596
Max. Power	[kW]	74
Euro Class	[-]	Euro 3
Vehicle Empty Mass	[kg]	1093
Odometer	[km]	253,425
Registration Date	[dd-mm-yy]	12-07-01

The test results of the Ford Focus are presented in Table C-2.

Table C-2: Test results of the Ford Focus.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100 km]
CADC cold1	97	2476	173.9	254	165	79	**2.3**	6.1E+12	7.53
CADC hot1	92	2290	171.0	225	146	74	**2.3**	5.1E+12	7.39
CADC hot2	98	2122	173.1	282	184	79	**2.3**	1.0E+13	7.47
Urban cold 1	272	2489	281.5	676	435	230	3.7	3.3E+12	12.11
Urban hot 1	280	2509	255.7	617	392	240	3.7	4.6E+12	11.02
Urban hot 2	344	2638	254.3	818	527	304	3.7	5.5E+12	10.98
Rural cold 1	46	1074	143.2	222	144	33	1.1	4.0E+12	6.13
Rural hot 1	60	1725	142.1	174	112	45	1.1	3.7E+12	6.13
Rural hot 2	50	1203	139.8	192	124	36	1.1	4.3E+12	6.00
Motorway cold 1	100	3442	175.1	196	127	83	2.8	9.6E+12	7.65
Motorway hot 1	79	2640	175.1	188	121	64	2.8	7.6E+12	7.59
Motorway hot 2	85	2657	180.9	244	157	66	2.8	1.8E+13	7.84

Overall emission image of the Ford Focus:
The measured THC CADC emissions of the Euro 3 Ford Focus with 253,425 km is 92-98 mg/km and below the Euro 3 NEDC limit value of 200 mg/km.
The measured CO emission in the CADC tests with a cold start is 2476 mg/km which is just above the NEDC limit value of 2300 mg/km. The PM emissions vary from 1.1 to 3.7 mg/km and are probably mainly caused by the substantial oil consumption of the engine which is 1 litre per 3200 km (281 mg/km).
The NO_x emission in the cold CADC test is 254 mg/km and is more than 1,7 times of the NEDC limit value of 150 mg/km. On the basis of the overall emission performance of this Ford Focus significant NO_x deterioration effects can be identified.

Cold start emissions of the Ford Focus:
The CADC tests with cold and warm start show similar emissions.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-3 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Ford Focus are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 63.3%.

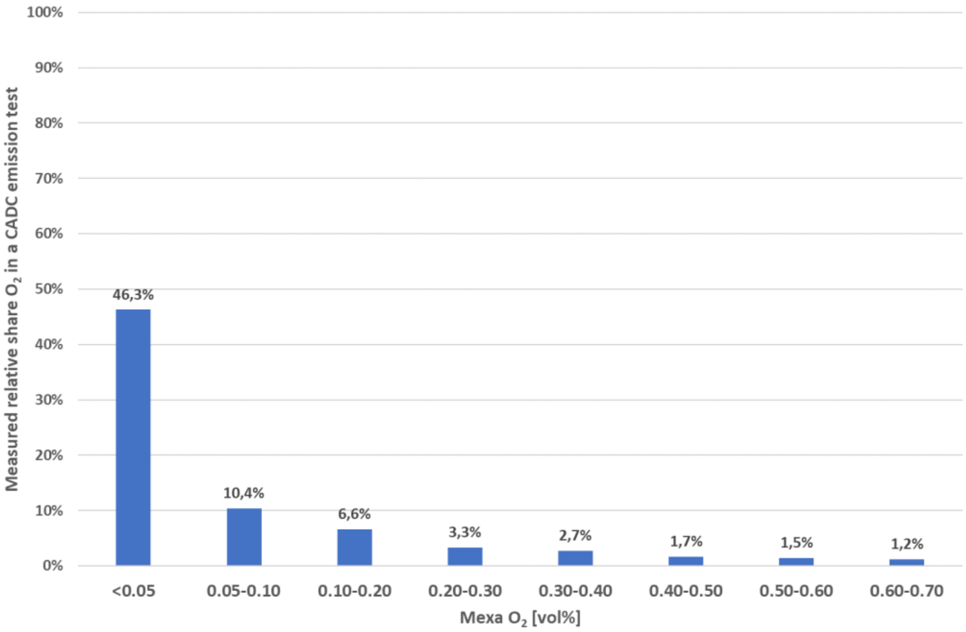


Figure 10-3: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Ford Focus.

D Test results Volkswagen Polo, Euro 4

The specifications of the tested Volkswagen Polo are given in table D-1.

Table D-1: Vehicle specifications of the Volkswagen Polo.

Trade Mark	[-]	Volkswagen
Type	[-]	Polo
Body	[-]	Hatchback
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	WVWZZZ6NZ1Y1163422
Swept Volume	[cm^3]	1390
Max. Power	[kW]	44
Euro Class	[-]	Euro 4
Vehicle Empty Mass	[kg]	996
Odometer	[km]	198,900
Registration Date	[dd-mm-yy]	30-01-2001

The test results of the Volkswagen Polo are presented in table D-2.

Table D-2: Test results of the Volkswagen Polo.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	53	2500	168	96	60	35	1.5	2.6E+12	7.27
CADC hot	43	2411	165	88	55	26	-	2.6E+12	7.15
Urban cold	131	1525	261.1	133	81	109	2.3	1.25E+12	11.16
Urban hot	27	627	234.3	52	30	12	-	1.2E+12	9.95
Rural	19	992	136.7	33	21	12	0.1	1.5E+12	5.85
Motorway	62	3725	172.1	132	83	38	2.3	3.57E+12	7.53

Overall emission image of the Volkswagen Polo:
The measured THC CADC emissions of the Euro 4 VW Polo with 198,900 km is 53 mg/km and below the Euro 4 NEDC limit value of 100 mg/km.
The measured CO emission of 2500 mg/km in the cold CADC test exceeds the Euro 4 NEDC limit of 1000 mg/km. The measured CO emission on the highway is 3725 mg/km which is caused by the applied high engine load. The measured NO_x emission of 96 mg/km in the CADC test exceeds slightly the Euro 4 NEDC limit of 80 mg/km. The overall PM emission is 1,5 mg/km which can be marked as low. The measured oil consumption of the Volkswagen Polo is around1 litre per 5000 km (180 mg/km).

On the basis of the overall emission performance of this VW Polo, no significant deterioration effects can be identified.

Cold start emissions of the Volkswagen Polo:
In the CADC test with cold start the measured CO and THC emissions are elevated in the urban part. This emission behaviour can be marked as normal because after the cold start the engine runs some time with a rich fuel-air mixture and the catalyst is not active because it operates below the light-off temperature.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-4 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Volkswagen Polo are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 65.0%.

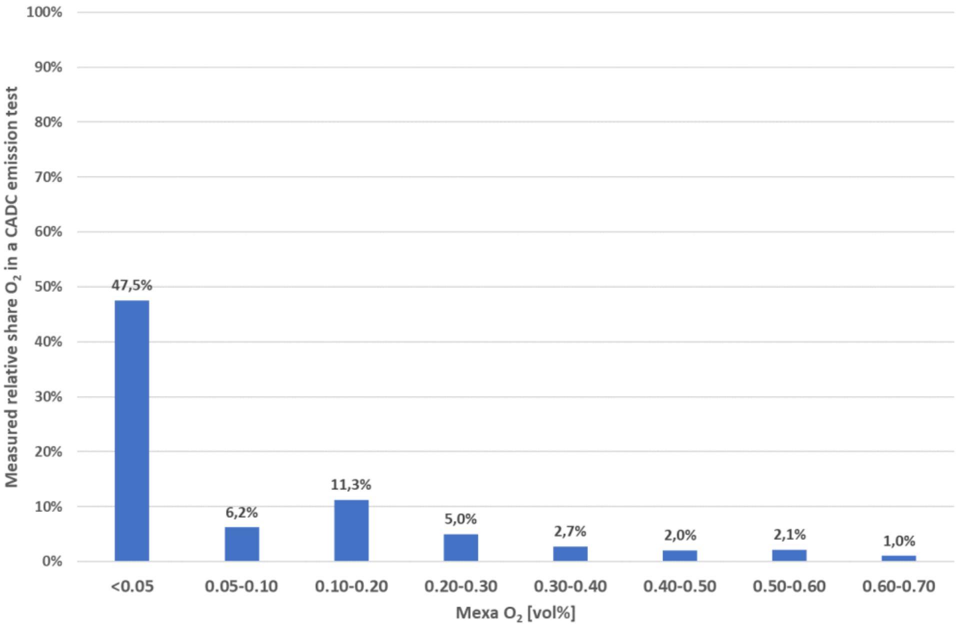


Figure 10-4: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Volkswagen Polo.

E Test results Opel Corsa 1, Euro 4

The specifications of the tested Opel Corsa are given in table E-1.

Table E-1: Vehicle specifications of the Opel Corsa.

Trade Mark	[-]	Opel
Type	[-]	Corsa
Body	[-]	Hatchback
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	W0L0XCF6818088435
Swept Volume	[cm^3]	1199
Max. Power	[kW]	55
Euro Class	[-]	Euro 4
Vehicle Empty Mass	[kg]	935
Odometer	[km]	219,400
Registration Date	[dd-mm-yy]	30-3-2001

The test results of the Opel Corsa are presented in Table E-2.

Table E-2: Test results of the Opel Corsa.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	23	724	173.4	375	240	20	3.9	7.3E+12	7.38
CADC hot	16	572	171.6	369	237	14	-	7.3E+12	7.30
Urban cold	79	2383	254.1	341	214	70	10.9	4.4E+12	10.913
Urban hot	12	861	236.1	283	191	9	-	4.7E+12	10.044
Rural	11	523	137.8	170	110	10	3.8	4.2E+12	5.863
Motorway	20	551	182.8	522	334	18	2.6	1.0E+13	7.769

Overall emission image of the Opel Corsa 1:
The measured THC and CO CADC emissions of the Euro 4 Opel Corsa with 219,400 km are below the Euro 4 NEDC limit values. However the NO_x emission of 375 mg/km is more than 4 times higher than the limit value of 80mg/km. This is probably caused by the EGR (Exhaust Gas Recirculation) valve failure which is indicated by the OBD. The overall PM emission of 3,9 mg/km and in urban traffic 10.9 mg/km which is fairly high. From this vehicle no oil consumption data are available.

On the basis of the overall emission performance of this Opel Corsa clear NO_x deterioration effects can be identified. In daily operation this vehicle was running with the EGR valve failure malfunction. Apparently the dealer did not advise the customer to repair the EGR valve failure. The error had no effect on the driveability of the vehicle.

Cold start emissions of the Opel Corsa 1:
In the CADC test with cold start the measured CO and THC emissions are elevated in the urban part. This emission behaviour can be marked as normal because after the cold start the engine runs some time with a rich fuel-air mixture and the three way catalyst is not active because it operates below the light-off temperature.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-5 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Opel Corsa 1 are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 65.5%.

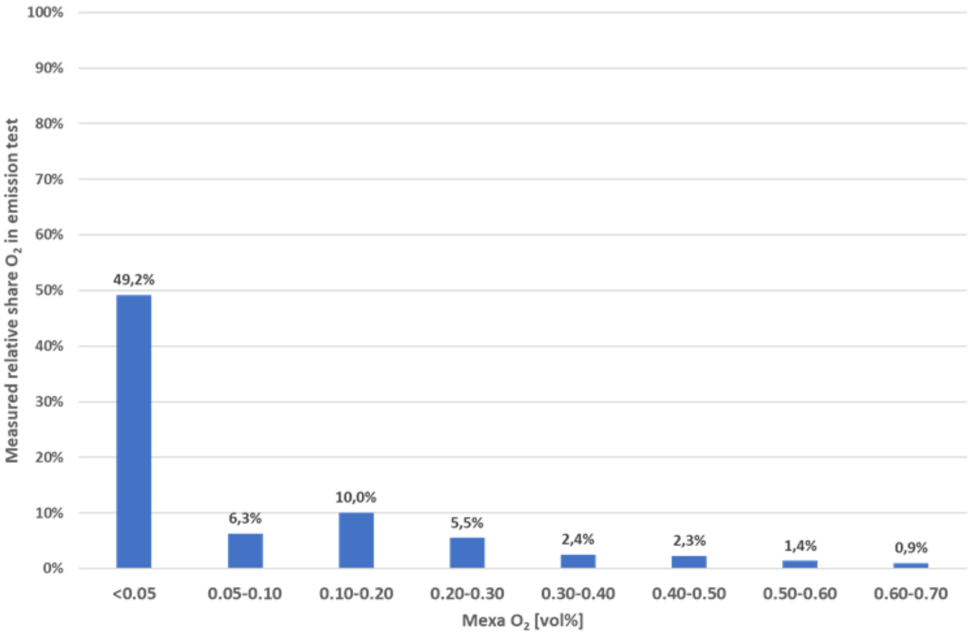


Figure 10-5: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Opel Corsa 1.

F Test results Fiat Punto 1, Euro 4

The specifications of the tested Fiat Punto are given in table F-1.

Table F-1: Vehicle specifications of the Fiat Punto.

Trade Mark	[-]	Fiat
Type	[-]	Punto
Body	[-]	Hatchback
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	ZFA18800000586797
Engine Calibration ID	[-]	1037363518001000
Swept Volume	[cm^3]	1242
Max. Power	[kW]	59
Euro Class	[-]	Euro 4
Vehicle Empty Mass	[kg]	910
Odometer	[km]	206,000
Registration Date	[dd-mm-yy]	23-5-2003

The test results of the Fiat Punto are presented in table F-2.

Table F-2: Test results of the Fiat Punto 1.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	138	5133	164.1	1234	800	138	3.7	5.2E+12	7.30
CADC hot	116	5247	162.2	1203	784	116	-	5.2E+12	7.23
Urban cold	541	6695	249.3	1480	962	541	17.8	9.7E+12	11.06
Urban hot	315	7848	229.8	1165	797	315	-	9.6E+12	10.29
Rural	79	3035	134.0	794	519	79	2.7	2.1E+12	5.88
Motorway	104	6292	169.1	1493	964	104	1.8	6.6E+12	7.59

Overall emission image of the Fiat Punto 1:
The measured THC CADC emission of 138 mg/km of the Euro 4 Fiat Punto with 206,000 km is higher than the Euro 4 NEDC limit value of 100 mg/km. Especially the THC emission of 541 mg/km in the urban part is relatively high. The measured CO emission in the CADC tests with a cold start is 5133 mg/km and is probably mainly caused by the relative high applied load of the chassis dynamometer.
The NOx emission in the cold CADC test is 1234 mg/km and is more than 15 times higher than the NEDC limit value of 80 mg/km. The PM emission over the CADC parts varies from 1.8 to 17.8 mg/km. The high urban PM emission of 17.8 mg/km is possibly caused by the relative high oil consumption of the engine which is around 1 litre per 4000 km (225 mg/km). The maintenance file of the vehicle was available and up to an odometer reading of 190,000 km the vehicle was maintained well.

On the basis of the overall emission performance of this Fiat Punto significant NO_x, THC and PM deterioration effects can be identified.

Cold start emissions of the Fiat Punto 1:
The CADC test with cold and warm start have similar CO, NO_x and PN emissions, The THC emission of the urban test with cold start is 40% higher than this emission with a warm start.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-6 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Fiat Punto 1 are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 30.3%. This relative share of 30.3% shows that the engine of this vehicle operates with relative lean air-fuel mixtures which is a primarily cause of the high CADC NOx emission of 1234 mg/km.

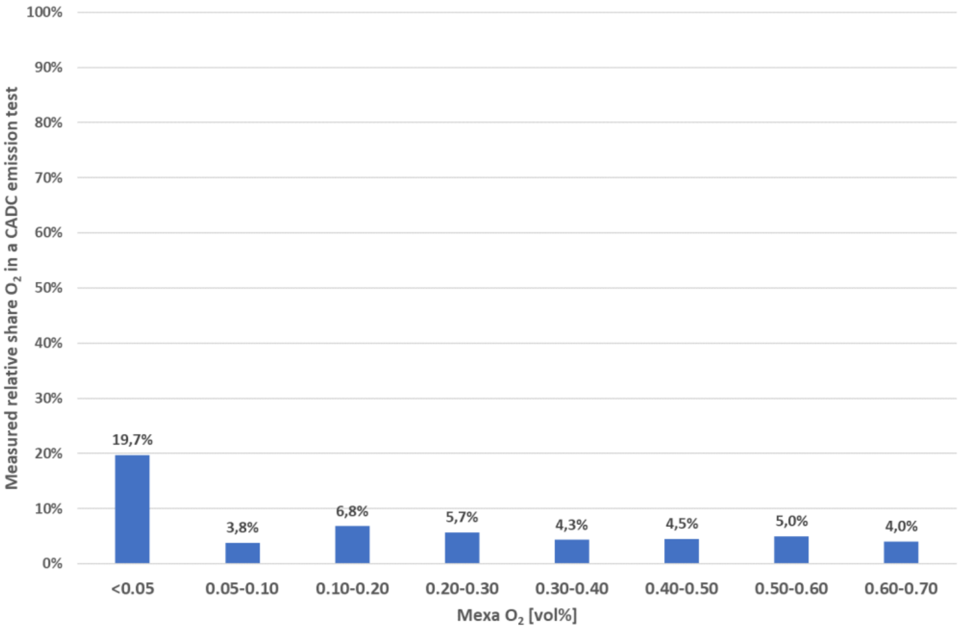


Figure 10-6: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Fiat Punto 1.

G Test results Fiat Punto 2, Euro 4

The specifications of the tested Fiat Punto are given in table G-1.

Table G-1: Vehicle specifications of the Fiat Punto 2.

Trade Mark	[-]	Fiat
Type	[-]	Punto
Body	[-]	Hatchback
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	ZFA188000-00517829
Engine Calibration ID	[-]	1037363520001000
Swept Volume	[cm^3]	1242
Max. Power	[kW]	59
Euro Class	[-]	Euro 4
Vehicle Empty Mass	[kg]	910
Odometer	[km]	249,300
Registration Date	[dd-mm-yy]	23-11-2002

The test results of the Fiat Punto 2 are presented in table G-2.

Table G-2: Test results of the Fiat Punto 2.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	25	2317	161.2	30	58	20	-	1.6E+12	6.98
CADC hot	15	2267	159.4	25	16	11	-	1.6E+12	6.89
Urban cold	101	1881	244.9	70	430	92	-	2.0E+12	10.49
Urban hot	3	1378	226.1	17	11	3	-	1.3E+12	9.65
Rural	7	926	130.2	12	8	6	-	2.8E+11	5.57
Motorway	23	3360	167.1	35	23	16	-	2.5E+12	7.29
CADC-Long (urban-rural-motorway-urban)							3.5		

Overall emission image of the Fiat Punto 2:
The measured THC CADC emission of 25 mg/km of the Euro 4 Fiat Punto with 249,300 km is below the Euro 4 NEDC limit value of 100 mg/km. The measured CO emission in the CADC tests with a cold start is 2317 mg/km and is probably mainly caused by the relative high applied load of the chassis dynamometer.
The NOx emission in the cold CADC test is 30 mg/km and is below the Euro 4 NEDC limit value of 80 mg/km. The PM emission over the four CADC parts is 3.5 mg/km.
The maintenance file of the vehicle was available and up to an odometer reading of 218,400 km the vehicle was maintained well.

Cold start emissions of the Fiat Punto 2:
The CADC test with cold and warm start have similar CO, NOx and PN emissions, The THC emission of the urban test with cold start is higher than this emission with a warm start.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-7 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Fiat Punto 2 are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 67.9%.

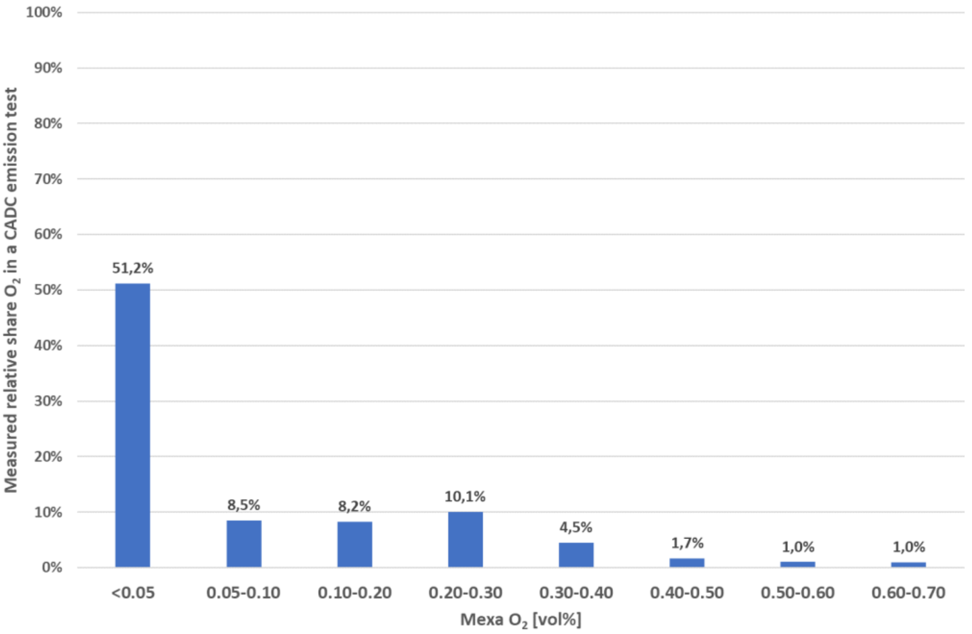


Figure 10-7: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Fiat Punto 2.

Simple emission test of the Fiat Punto 2:
In Figure 10-8 the results of a simple emission test are shown. NOx emissions are measured at low idle speed (2 times) and at 50 km/h. At low idle speed the NOx concentration is < 1 ppm and at 50 km/h the NOx concentration is in the range of 73 – 1023 ppm.

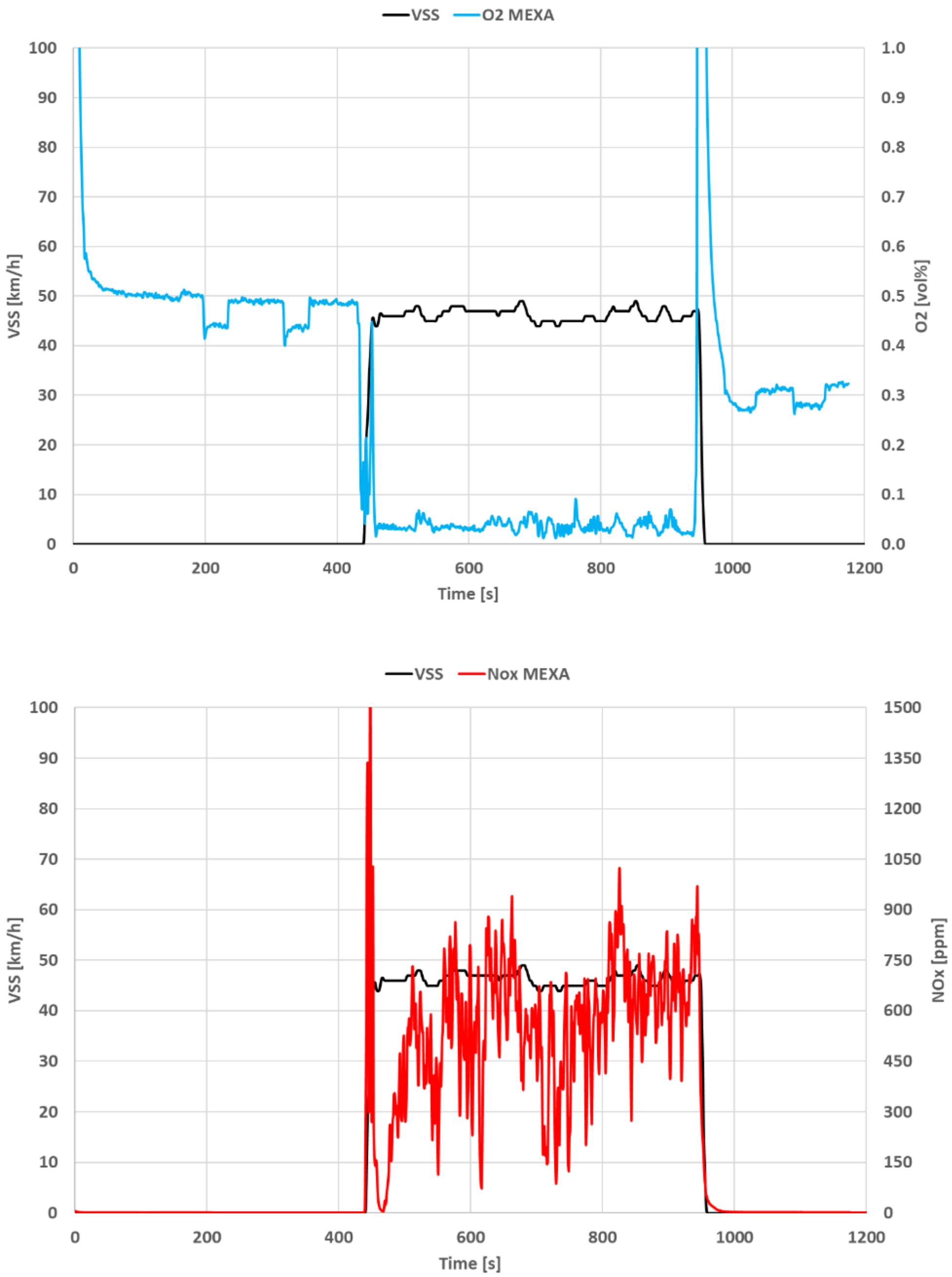


Figure 10-8: O_2 and NO_x emissions in a simple emission test at low idle speed, 50 km/h and low idle speed of the Fiat Punto 2.

H Test results Opel Corsa 2, Euro 4

The specifications of the tested Opel Corsa are given in table H-1.

Table H-1: Vehicle specifications of the Opel Corsa 2.

Trade Mark	[-]	Opel
Type	[-]	Corsa
Body	[-]	Hatchback
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	WOLOXCF6846005933
Swept Volume	[cm^3]	1199
Max. Power	[kW]	55
Euro Class	[-]	Euro 4
Vehicle Empty Mass	[kg]	935
Odometer	[km]	163,400
Registration Date	[dd-mm-yy]	18-09-2003

The test results of the Opel Corsa 2 are presented in Table H-2.

Table H-2: Test results of the Opel Corsa 2.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	86	6187	183.2	275	175	59	-	2.2E+13	8.17
CADC hot	82	6122	181.9	382	244	56	-	2.2E+13	8.11
Urban cold	56	1130	254.7	68	40	37	-	1.0E+13	10.853
Urban hot	24	469	242.4	1135	736	10	-	1.2E+13	10.285
Rural	22	569	146.7	51	33	9	-	1.3E+13	6.245
Motorway	135	11018	195.0	469	298	98	-	3.0E+13	8.995
CADC-Long (urban-rural-motorway-urban)							3.6		

Overall emission image of the Opel Corsa 2:

The measured THC CADC emission of the second Euro 4 Opel Corsa with 163,400 km is below the Euro 4 NEDC limit value. However the NOx emission of 275 mg/km is more than 3 times higher than the limit value of 80mg/km. Furthermore is the CO emission on the motorway 11,0 g/km and in the urban parts 6,1 – 6,2 g/km and is probably mainly caused by the relative high applied load of the chassis dynamometer. The measured NOx emission in the warm urban part is 1135 mg/km and seems to be caused by a shifted air-fuel control setting. The overall PM emission of 3,6 mg/km is elevated. From this vehicle no oil consumption data are available.

On the basis of the overall emission performance of this Opel Corsa clear NOx deterioration effects can be identified. The error had no effect on the driveability of the vehicle.

Cold start emissions of the Opel Corsa 2:
The CADC test with cold and warm start have similar CO, THC, NOx and PN emissions.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-9 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Opel Corsa 2 are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 65.5%.

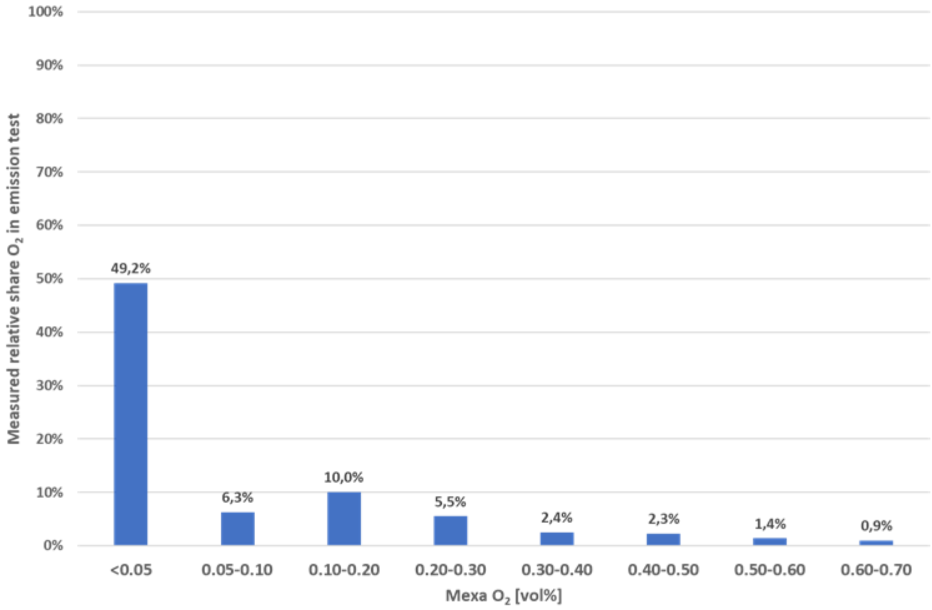


Figure 10-9: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Opel Corsa 2.

Simple emission tests of the Opel Corsa 2:

In Figure 10-10 the results of a simple emission test are shown. NOx emissions are measured at low idle speed (2 times) and at 50 km/h. At low idle speed the NOx concentration is < 2 ppm and at 50 km/h the NOx concentration is in the range of 1 – 122 ppm.

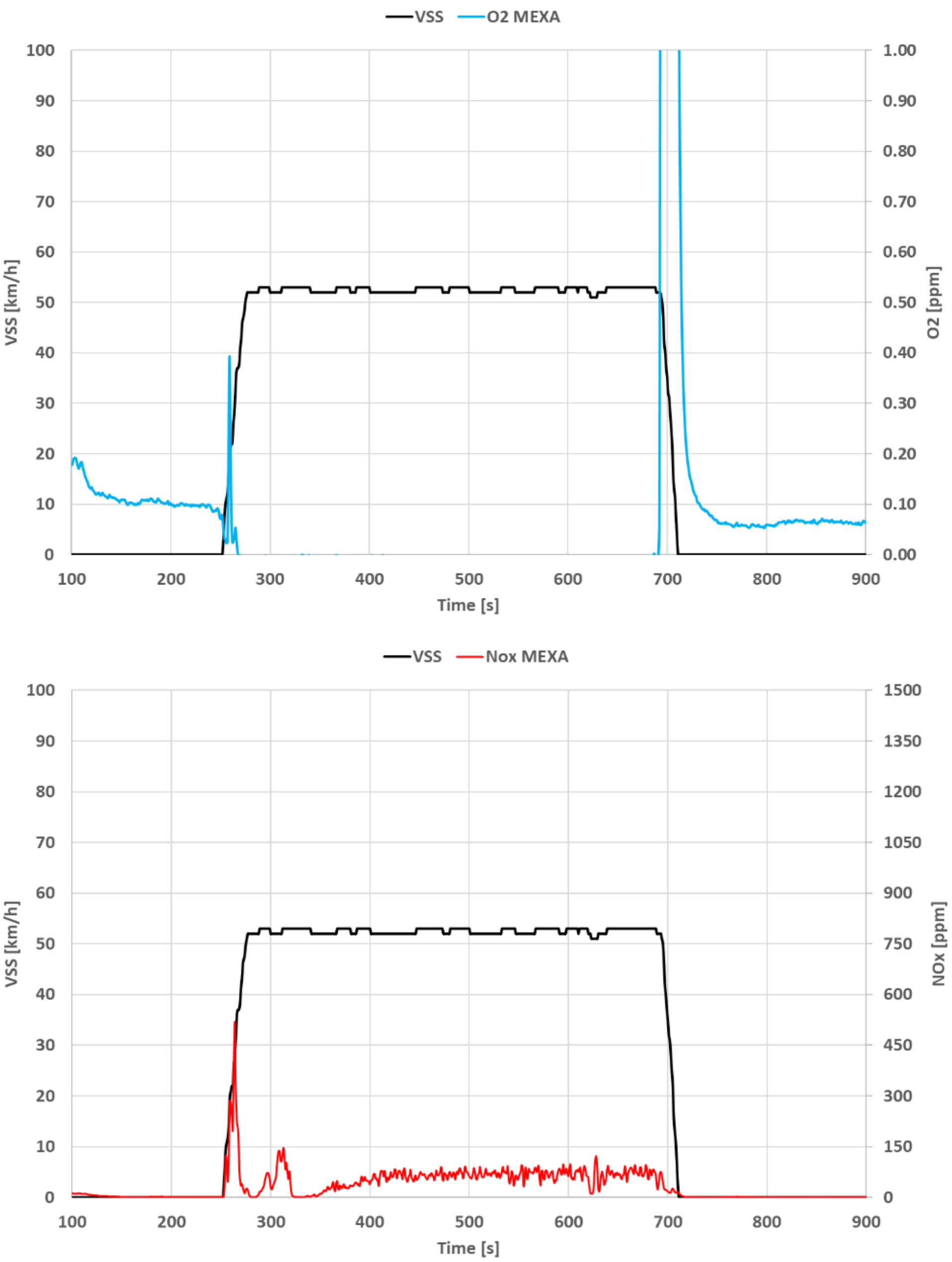


Figure 10-10: O_2 and NOx emissions in a simple emission test at low idle speed, 50 km/h and low idle speed of the Opel Corsa 2

I Test results Renault Megane Scenic, Euro 4

The specifications of the tested Renault Megane Scenic are given in table I-1.

Table I-1: Vehicle specifications of the Renault Megane Scenic .

Trade Mark	[-]	Renault
Type	[-]	Megane Scenic
Body	[-]	Multi-Purpose vehicle
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	VF1JM1ROA34982052
Swept Volume	[cm^3]	1598
Max. Power	[kW]	82
Euro Class	[-]	Euro 4
Vehicle Empty Mass	[kg]	1345
Odometer	[km]	219,900
Registration Date	[dd-mm-yy]	19-12-2005

The test results of the Renault Megane Scenic are presented in Table I-2.

Table I-2: Test results of the Renault Megane Scenic.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	16	1028	191.8	17	11	11	-	4.9E+11	8.18
CADC hot	14	1025	188.0	23	14	9	-	3.2E+11	8.02
Urban cold	27	272	315.1	24	16	17	-	1.7E+12	13.35
Urban hot	9	243	276.4	84	53	4	-	1.0E+10	11.70
Rural	18	1459	149.3	27	17	13	-	5.0E+11	6.41
Motorway	12	872	198.2	9	5	8	-	2.6E+11	8.44
CADC-Long (urban-rural-motorway-urban)							2.8		

Overall emission image of the Renault Megane Scenic:
The measured CO, THC, NOx and PM CADC emissions of the Euro 3 Renault Megane Scenic with 219,900 km are below the Euro 3 NEDC limit values and even pass the Euro 6c limit values. From this vehicle no oil consumption data are available.

On the basis of the overall emission performance of this Renault Megane Scenic no deterioration effects can be identified.

Cold start emissions of the Renault Megane Scenic:
In the CADC test with cold start the measured THC and PN emissions are elevated in the urban part. This emission behaviour can be marked as normal because after the cold start, the engine runs some time with a rich air-fuel mixture and the three way catalyst is not active because it operates below the light-off temperature.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-11 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Renault Megane Scenic are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 63.6%.

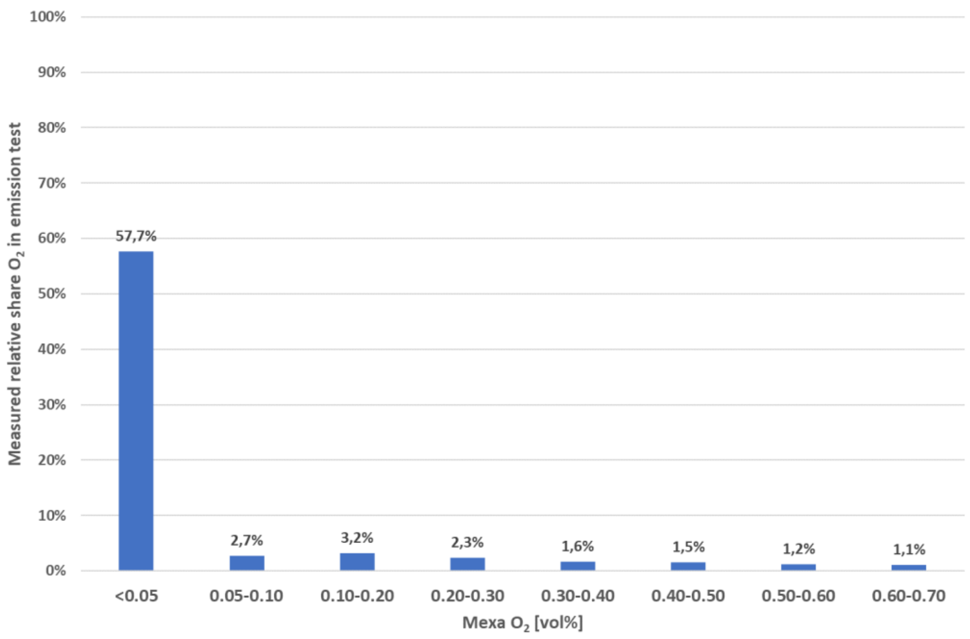
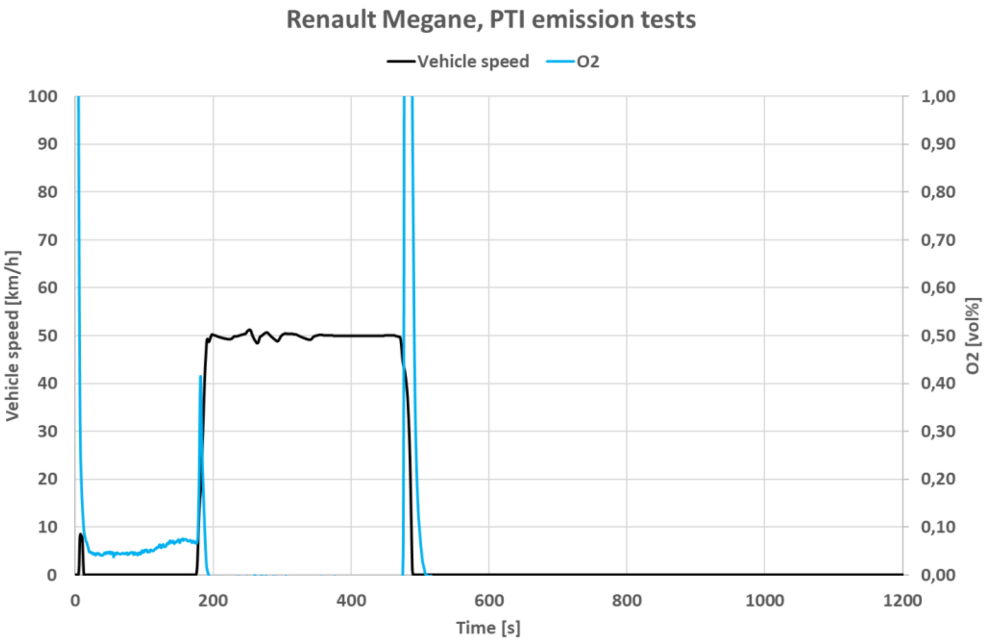


Figure 10-11: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Renault Megane Scenic.

Simple emission test of the Renault Megane Scenic:
In Figure 10-12 the results of a simple emission test are shown. NOx emissions are measured at low idle speed (2 times) and at 50 km/h. At low idle speed the NOx concentration is < 1 ppm and at 50 km/h the NOx concentration is < 1 ppm.



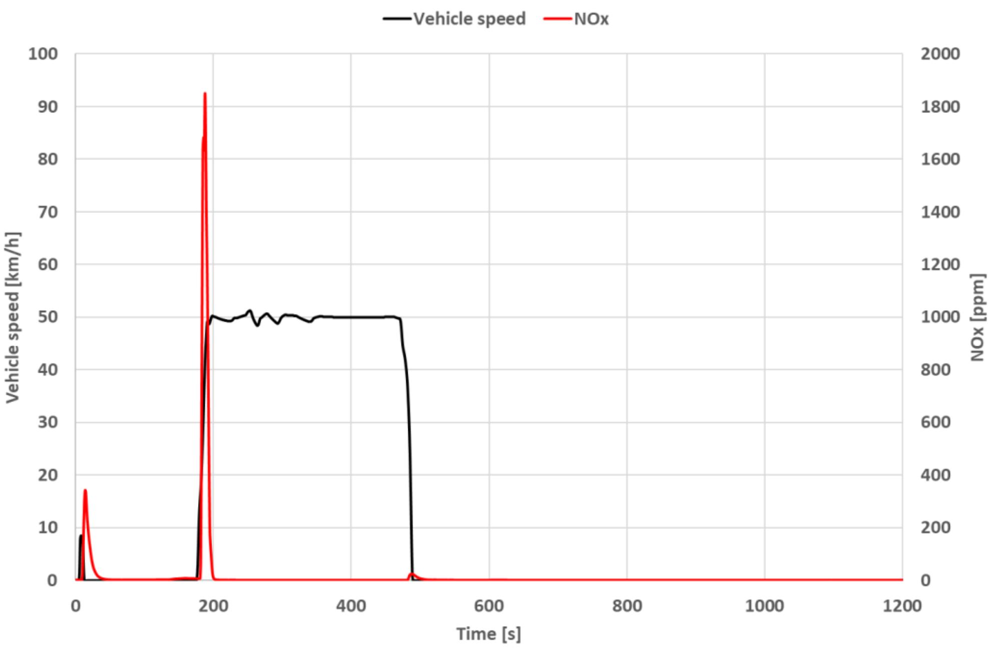


Figure 10-12: PTI chassis dynamometer O_2 and NOx emission test at low idle speed, 50 km/h and low idle speed of the Renault Megane Scenic

J Test results BMW 325i, Euro 4

The specifications of the tested BMW 325i are given in table J-1.

Table J-1: Vehicle specifications of the BMW 325i .

Trade Mark	[-]	BMW
Type	[-]	325i
Body	[-]	Sedan
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	WBAVB11040KT55775
Swept Volume	[cm^3]	2498
Max. Power	[kW]	160
Euro Class	[-]	Euro 4
Vehicle Empty Mass	[kg]	1405
Odometer	[km]	236,800
Registration Date	[dd-mm-yy]	29-06-2005

The test results of the BMW 325i are presented in Table J-2.

Table J-2: Test results of the BMW 325i.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	130	2021	223.9	1059	678	110	-	6.6E+12	9.62
CADC hot	96	1941	220.3	1103	706	77	-	7.8E+12	9.46
Urban cold	616	5336	379.8	442	285	562	-	1.2E+13	16.50
Urban hot	271	4506	343.0	884	569	225	-	2.4E+13	14.84
Rural	98	1905	201.4	682	438	77	-	6.6E+12	8.66
Motorway	63	1483	210.3	1435	917	49	-	5.6E+12	9.00
CADC-Long (urban-rural-motorway-urban)							4.4		

Overall emission image of the BMW 325i:
The measured THC CADC emission of 130 mg/km of the Euro 4 BMW 325i with 236,800 km is higher than the Euro 4 NEDC limit value of 100 mg/km. Especially the THC emission of 616 mg/km in the urban part is relatively high. The measured CO emission in the CADC tests with a cold start is 5336 mg/km and is probably mainly caused by the relative high applied load of the chassis dynamometer.
The NOx emission in the cold CADC test is 1059 mg/km and is more than 13 times higher than the NEDC limit value of 80 mg/km. The PM emission over the CADC parts is 4.4 mg/km. From this vehicle no oil consumption data are available. The maintenance file of the vehicle was not available.

On the basis of the overall emission performance of this BMW 325i significant NO_x, THC and PM deterioration effects can be identified.

Cold start emissions of the BMW 325i:
The CADC test with cold and warm start have similar CO, NO_x and PN emissions, The THC emission of the urban test with cold start is more than two times higher than this emission with a warm start.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-13 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the BMW 325i are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 40.0%. This relative share of 40% shows that the engine of this vehicle operates with relative lean air-fuel mixtures which is a primarily cause of the high CADC NOx emission of 1059 mg/km.

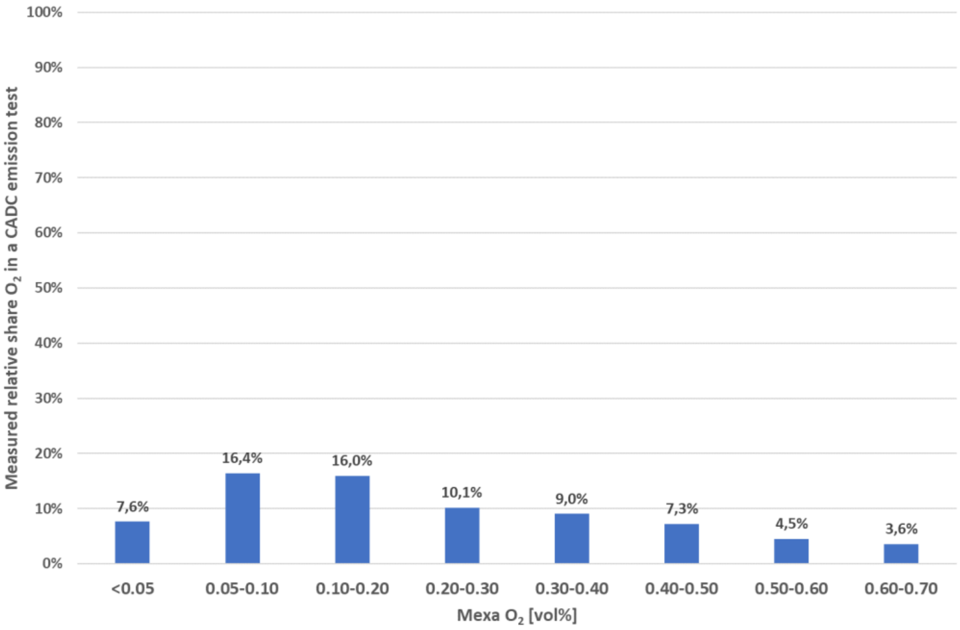
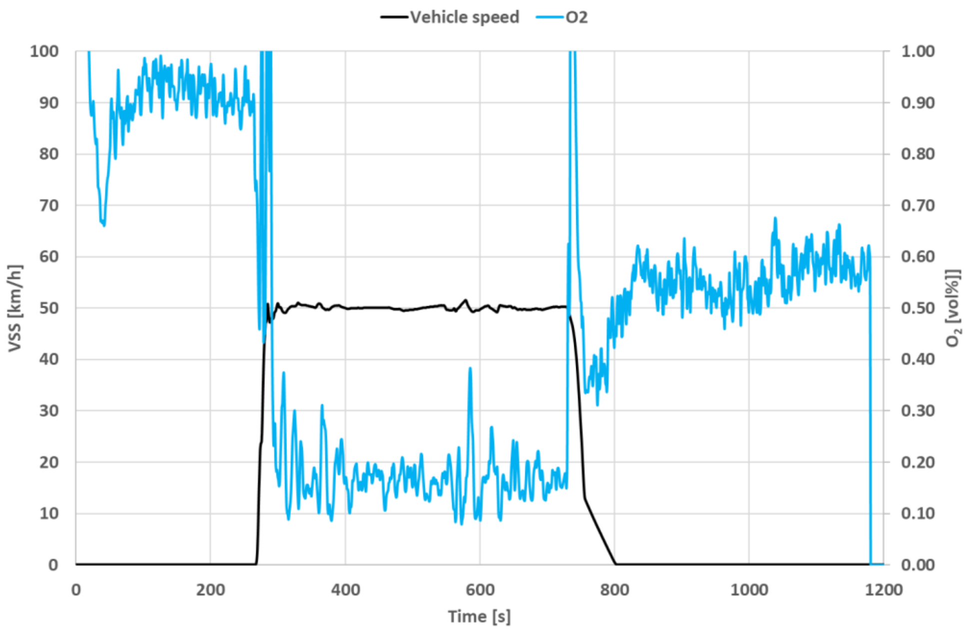


Figure 10-13: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the BMW 325i.

PTI emission test of the BMW 325i:

In Figure 10-14 the results of a simple emission test are shown. NOx emissions are measured at low idle speed (2 times) and at 50 km/h. At low idle speed the NOx concentration is 4 - 55 ppm and at 50 km/h the NOx concentration is 124 - 480 ppm.



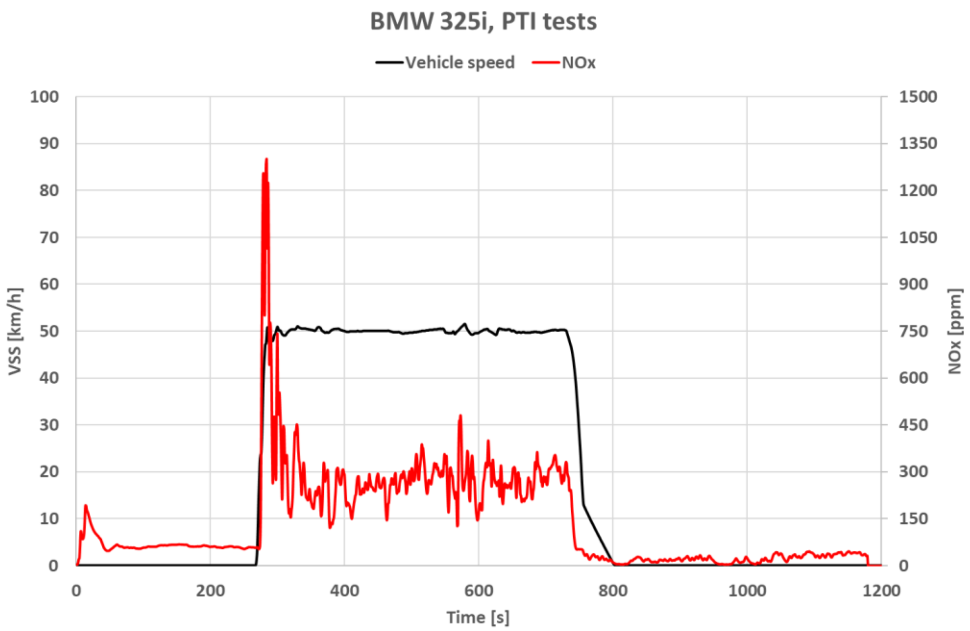


Figure 10-14: PTI chassis dynamometer O_2 and NOx emission test at low idle speed, 50 km/h and low idle speed of the BMW 325i.

After the chassis dynamometer test the vehicle was offered to the BMW dealer and the diagnostic test of this vehicle didn't yield any emission related failure codes.

K Test results Kia Picanto, Euro 3

The specifications of the tested Kia Picanto are given in table K-1.

Table K-1: Vehicle specifications of the Kia Picanto .

Trade Mark	[-]	Kia
Type	[-]	Picanto
Body	[-]	Multi-Purpose Vehicle
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	KNEBA24424 49042
Swept Volume	[cm^3]	999
Max. Power	[kW]	45
Euro Class	[-]	Euro 3
Vehicle Empty Mass	[kg]	836
Odometer	[km]	194,400
Registration Date	[dd-mm-yy]	05-11-2004

The test results of the Kia Picanto are presented in Table K-2.

Table K-2: Test results of the Kia Picanto.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	29	6545	153.9	18	11	20	-	3.9E+12	6.95
CADC hot	25	6592	152.1	17	11	17	-	3.4E+12	6.87
Urban cold	45	1522	224.6	35	21	38	-	8.9E+12	9.61
Urban hot	7	2046	205.3	24	15	5	-	3.7E+12	8.82
Rural	12	2262	127.0	12	8	9	-	3.8E+12	5.52
Motorway	37	10441	159.4	19	12	24	-	3.0E+12	7.44
CADC-Long (urban-rural-motorway-urban)							9.1		

Overall emission image of the Kia Picanto:
The measured THC, NOx and PM CADC emissions of the Euro 3 Kia Picanto with 194,400 km are below the Euro 3 NEDC limit values.
The measured CO emission on the highway is 10,441 mg/km which is caused by the high applied engine load. The measured CO emission of 1522 to 2262 mg/km in the urban and rural parts are at regular levels. Although this Euro 3 vehicle has no PM limit value the measured PM emission of 9.1 mg/km is high. For this vehicle no oil consumption data are available.

On the basis of the overall emission performance of this Kia Picanto only PM deterioration effects can be identified.

Cold start emissions of the Kia Picanto:
In the CADC test with cold start the measured THC emission is elevated in the urban part. This emission behaviour can be marked as normal because after the cold start the engine runs some time with a rich air-fuel mixture and the three way catalyst is not active because it operates below the light-off temperature.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-15 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Kia Picanto are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 60.6%.

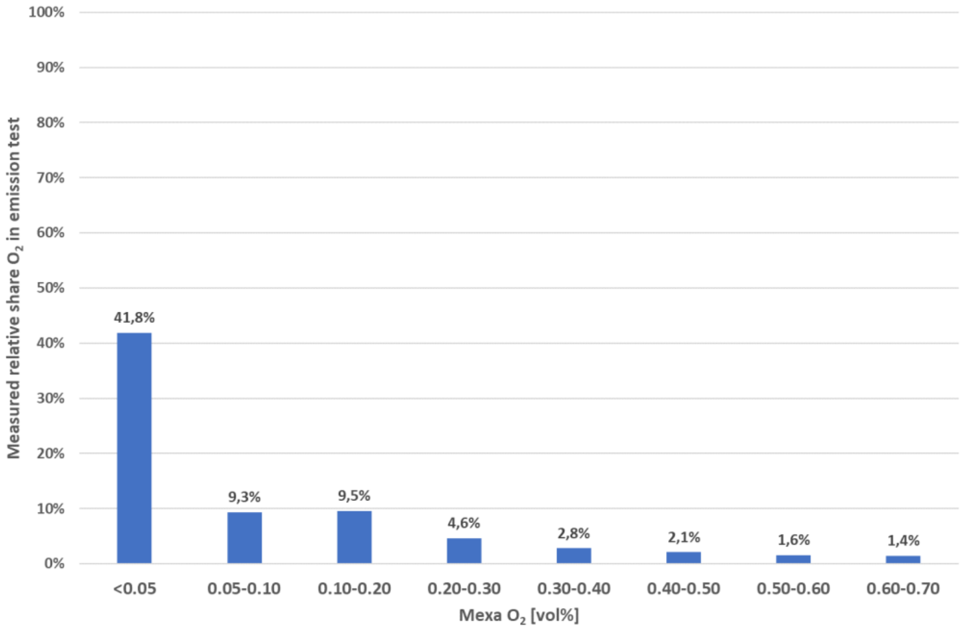


Figure 10-15: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Kia Picanto

PTI emission test of the Kia Picanto:
In Figure 10-16 the results of a simple emission test are shown. NOx emissions are measured at low idle speed (2 times) and at 50 km/h. At low idle speed the NOx concentration is < 2 ppm and at 50 km/h the NOx concentration is 1 - 450 ppm. At 50 km/h the NO_x concentration is not stable.

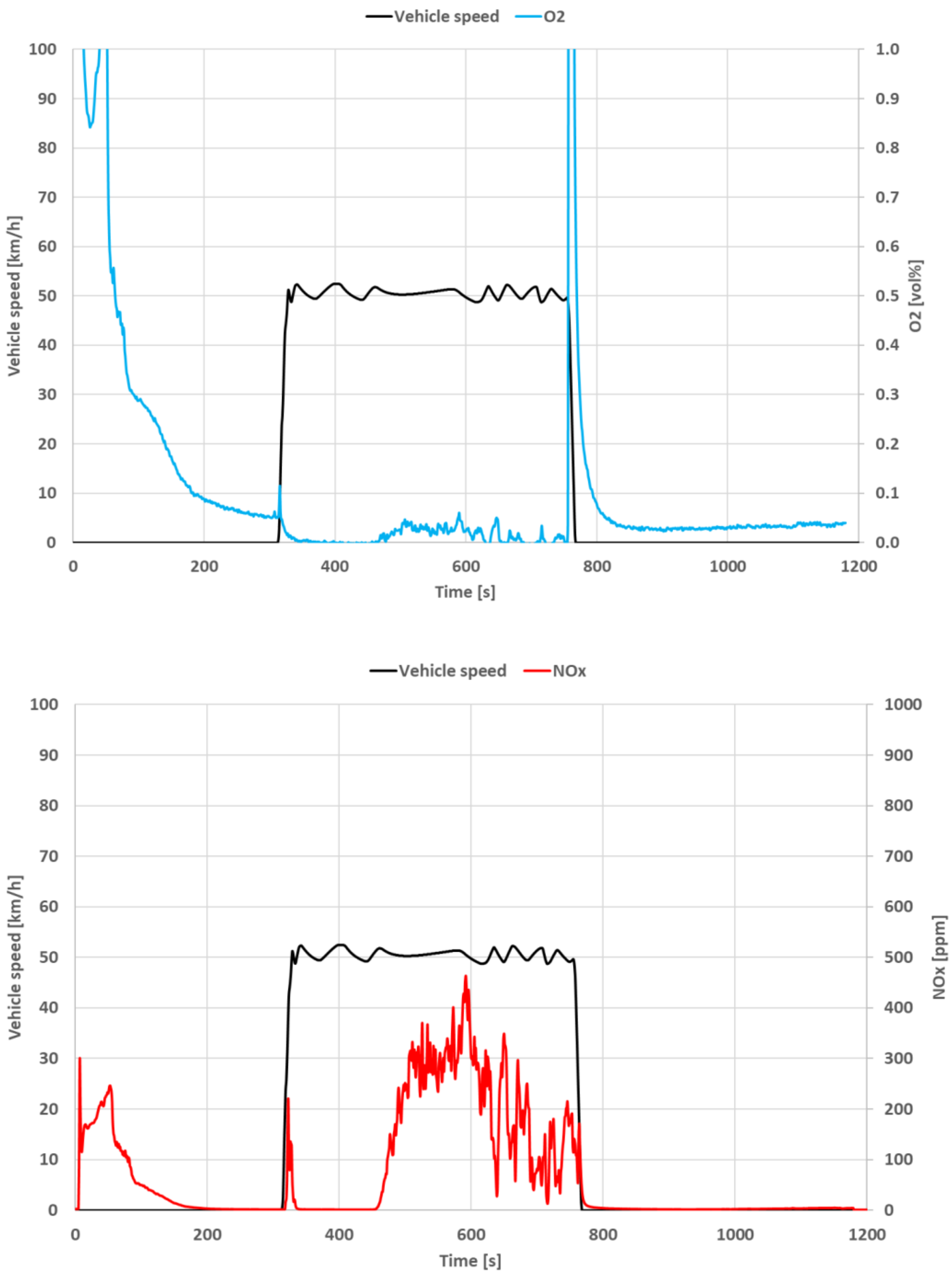


Figure 10-16: PTI chassis dynamometer O_2 and NOx emission test at low idle speed, 50 km/h and low idle speed of the Kia Picanto.

L Test results Volkswagen Golf, Euro 2

The specifications of the tested Volkswagen Golf are given in table L-1.

Table L-1: Vehicle specifications of the Volkswagen Golf.

Trade Mark	[-]	Volkswagen
Type	[-]	Golf
Body	[-]	Hatchback
Vehicle Class	[-]	M1
Fuel	[-]	Petrol
Vehicle Identification Number	[-]	WVWZZZ1JZW007583
Swept Volume	[cm^3]	1595
Max. Power	[kW]	74
Euro Class	[-]	Euro 2
Vehicle Empty Mass	[kg]	1107
Odometer	[km]	234,000
Registration Date	[dd-mm-yy]	05-03-1998

The test results of the Volkswagen Golf are presented in Table L-2.

Table L-2: Test results of the Volkswagen Golf.

	THC	CO	CO2	NOx	NO	NMHC	PM	PN	FC
	[mg/km]		[g/km]	[mg/km]				[#/km]	[l/100km]
CADC cold	88	1098	193.1	172	109	80	-	2.1E+12	8.25
CADC hot	25	807	189.6	134	85	19	-	3.0E+12	8.07
Urban cold	661	3315	314.7	507	322	626	-	3.7E+12	13.62
Urban hot	30	398	279.0	127	81	20	-	1.2E+13	11.83
Rural	13	126	162.4	123	79	10	-	2.9E+12	6.88
Motorway	32	1354	191.6	143	90	26	-	1.3E+12	8.20
CADC-Long (urban-rural-motorway-urban)							3.5		

Overall emission image of the Volkswagen Golf:
The measured THC+NOx and CO CADC emissions of the Euro 2 VW Golf with 234,000 km are below the Euro 2 NEDC limit values.
The measured THC emission in the urban part with cold start is 661 mg/km and is fairly high. However the type approval test procedure of Euro 2 vehicles doesn’t contain cold start emissions; Only 40 seconds after the start of the engine the emission sampling system was started.
The engine oil consumption of this vehicle is 1 litre per 7000 km.

On the basis of the overall emission performance of this Volkswagen Golf no deterioration effects can be identified.

Cold start emissions of the Volkswagen Golf:
In the CADC test with cold start the measured THC, NOx and CO emissions are elevated in the urban part. This emission behaviour can be marked as normal because after the cold start the engine runs some time with a rich air-fuel mixture and the three way catalyst is not active because it operates below the light-off temperature. Furthermore the emission sampling of type approval test of Euro 2 vehicles starts after 40 seconds of idle operation.

Detailed investigation of the measured O_2 concentrations:
From the measured O_2 concentrations in raw exhaust gas an impression of the lambda control strategy can be obtained. In Figure 10-17 the measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Volkswagen Golf are plotted. The relative share of the measured O_2 concentration below 0.20 vol% is 78.1%.

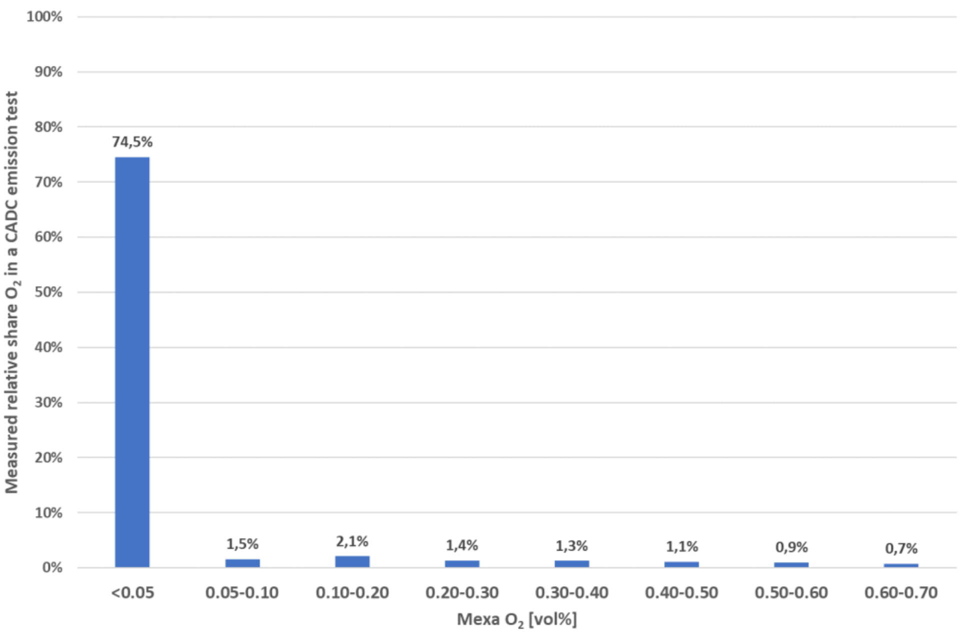
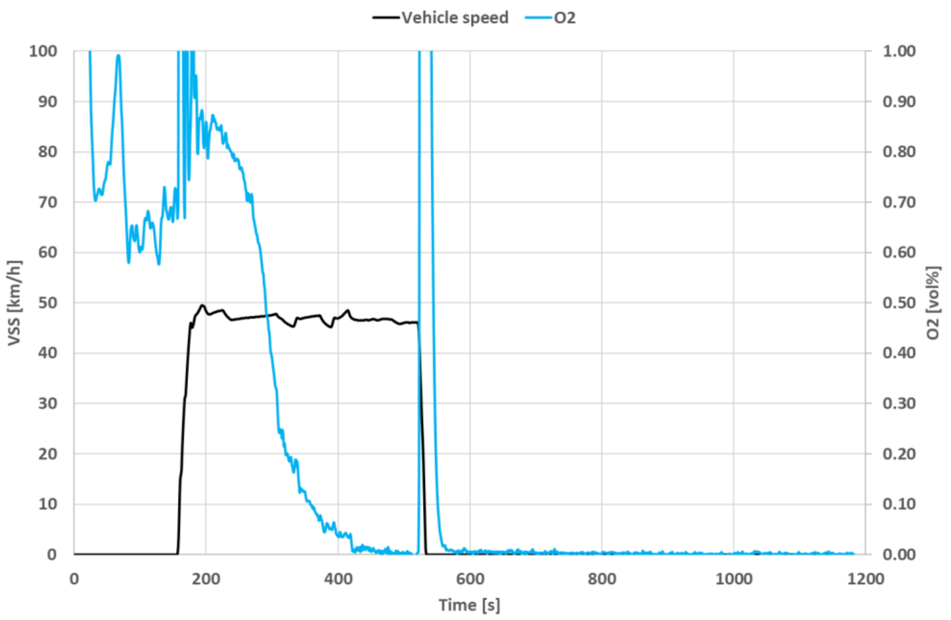


Figure 10-17: Measured relative shares of the O_2 concentration in exhaust gas of a CADC test of the Volkswagen Golf.

PTI emission test of the Volkswagen Golf:

In Figure 10-18 the results of a simple emission test are shown. NOx emissions are measured at low idle speed (2 times) and at 50 km/h. At low idle speed the NOx concentration is < 1 ppm and at 50 km/h the NOx concentration is 25 - 1505 ppm. After 250 seconds @ 50 km/h the NOx concentration stabilises around 30 – 120 ppm.



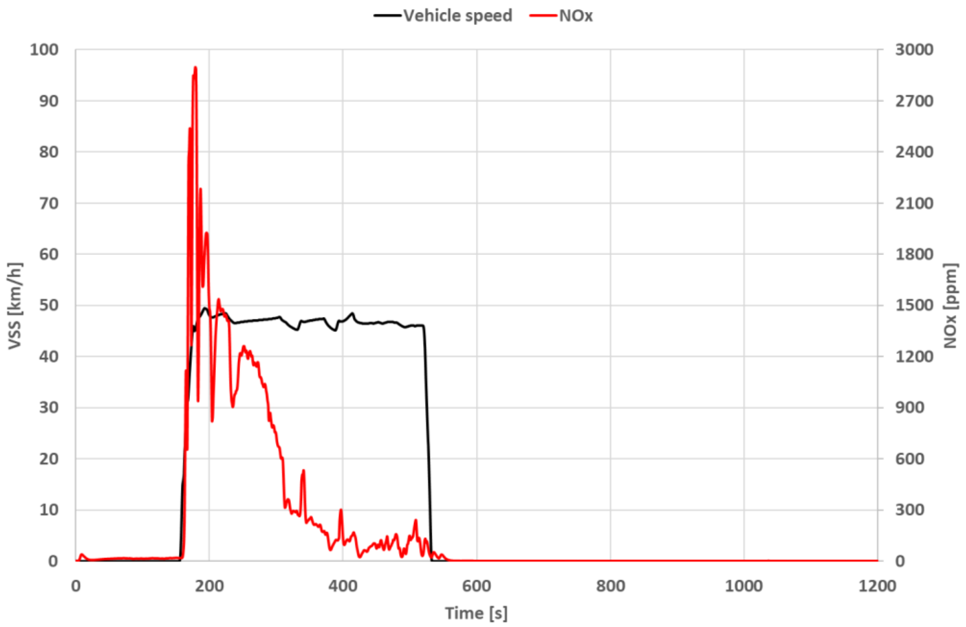


Figure 10-18: PTI chassis dynamometer O_2 and NOx emission test at low idle speed, 50 km/h and low idle speed of the Volkswagen Golf.

M Volumetric emissions at low idle speed

	Citroen Xsara		Toyota Aygo		VW Polo	
	CADC	*PTI*	*CADC*	*PTI*	*CADC*	*PTI*
CO [vol%]	0.00	-	0.00	-	0.01	-
CO_2 [vol%]	15.28	-	15.27	-	14.91	-
O_2 [vol%]	0.01	-	0.00	-	0.11	-
THC(C1) [ppm]	1	-	1	-	2	-
NOx [ppm]	1	-	4	-	0	-
Lambda [-]	1.00	-	1.00	-	1.00	-

	Ford Focus		Fiat Punto 1		Opel Corsa 1	
	CADC	*PTI*	*CADC*	*PTI*	*CADC*	*PTI*
CO [vol%]	0.12	0.02	0.11	0.10-0.18	0.02	0.01-0.03
CO_2 [vol%]	15.1	14.8-14.9	14.7	14.7-14.9	15.3	15.1
O_2 [vol%]	0.04	0.04-0.09	0.90	0.17-0.19	0.22	0.02-0.08
THC(C1) [ppm]	59	54-372	34	510-672	1	36-120
NOx [ppm]	0	-	11	-	3	-
Lambda [-]	1.00	1.00	1.04	1.00	1.01	1.00

	Kia Picanto		Fiat Punto 2		Opel Corsa 2	
	CADC	*PTI*	*CADC*	*PTI*	*CADC*	*PTI*
CO [vol%]	0.03	0.01	0.07	0.01	0.00	0.00
CO_2 [vol%]	15.26	15.23	14.94	14.97	15.3	15.25
O_2 [vol%]	0.07	0.04	0.30	0.28	0.09	0.05
THC(C1) [ppm]	2	15	1	2	0	27
NOx [ppm]	0	3	0	1	0	1
Lambda [-]	1.00	1.00	1.01	1.02	1.00	1.00

	Renault Megane		BMW 325i		VW Golf	
	CADC	*PTI*	*CADC*	*PTI*	*CADC*	*PTI*
CO [vol%]	0.00	0.01	0.22	0.00	0.08	0.00
CO_2 [vol%]	15.31	15.27	14.93	14.89	14.85	15.13
O_2 [vol%]	0.00	0.00	0.43	0.53	0.17	0.00
THC(C1) [ppm]	1	155	65	64	0	30
NOx [ppm]	2	0	5	46	1	0
Lambda [-]	1.00	0.99	1.01	1.02	1.01	1.00

N Specification of the chassis dynamometer

The laboratory performs accredited emission tests according to ISO 17025 standards.

The following measuring equipment is installed on the chassis dynamometer test bench:

Chassis Test Cell

Air conditioning
Weiss Umwelttechnik
cooling perfomance 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 CH4,
separate EGR-Analyser

MEXA ONE C2-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.

- **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 C2-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 m^3/min to 18 m^3/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 analog 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.