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**TNO report**

**TNO 2019 R11859**

# Research into $NO_x$ emission behaviour of a Suzuki Vitara Euro 6b diesel

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# Summary

In an emission study reported by the Netherlands Vehicle Authority (RDW) in July 2017 [RDW 2017], the first exploratory emission tests for the Suzuki Vitara Euro 6b diesel were conducted. The results gave rise to further research.

In 2018, the Netherlands Vehicle Authority (RDW) commissioned TNO to carry out an emission study of the Suzuki Vitara Euro 6b diesel. The goal of this follow-up study was to identify and describe the $NO_x$ emission behaviour of the Suzuki Vitara, measured using 2 different vehicles with 2 engine calibrations (indicated with engine calibration 1: before the service update and engine calibration 2: after the service update). To this end, several partial objectives were formulated and emission measurements were taken on an RDW test track, on a chassis dynamometer and on public roads.

When taken together, the results of the performed measurements provide a good overview of the emission behaviour of the tested vehicle and the differences in emissions before and after the update of the engine calibration software. 24 Partial conclusions based on the performed measurements have been included below. Some partial conclusions can be characterised as findings.

*Partial conclusion 1:*
The Suzuki Vitara Euro 6b diesel, tested in the 2017 RDW study, and the second Suzuki Vitara Euro 6b diesel, tested in this study, both equipped with engine calibration 1, highly exceed the $NO_x$ limit value of 80 mg/km in emissions tests on the test track (up to more than 10 times). It also appears that the $NO_x$ emission at an ambient temperature of 4-11 °C is twice as high as in the same tests carried out at an ambient temperature of 20-26 °C.

*Partial conclusion 2:*
The results of NEDC tests with a cold start of the Suzuki Vitara Euro 6b diesel with engine calibration 1 that were carried out on the test track, show that the $NO_x$ emission is strongly dependent on the ambient temperatures and the preconditioning test that was conducted. With an ambient temperature above 20 °C and a standard preconditioning cycle (3* EUDC), an $NO_x$ emission of 157-191 mg/km is measured in an NEDC test on the test track. The only circumstances under which the $NO_x$ limit value of 80 mg/km is not exceeded in an NEDC test on the test track, is with an ambient temperature above 20 °C and an adjusted preconditioning cycle.

*Partial conclusion 3:*
In the EUDC preconditioning tests of the Suzuki Vitara Euro 6b diesel with engine calibration 1, the LNT is regenerated, by default, three times at speeds of 80 - 100 km/h. As a result, the $NO_x$ storage capacity of the LNT is maximised at the start of an emission test. During the emission test, the $NO_x$ can be buffered and, when driving at a speed of 100 km/h, partly converted into harmless components. Incomplete LNT regenerations in the preconditioning test lead to an increased $NO_x$ emission in the subsequent emission test.

*Partial conclusion 4:*
The thermal condition of the engine with engine calibration 1 has a different effect on $NO_x$ emissions at different ambient temperatures. With an ambient temperature of 6°C the $NO_x$ emission decreases in an NEDC test with a warm start compared to an NEDC test with a cold start, while at a temperature of 26 °C the $NO_x$ emission increases. The ambient temperature seems to have a bigger influence on the $NO_x$ emissions than the thermal condition of the engine.

*Partial conclusion 5:*
In UDC tests of the Suzuki Vitara Euro 6b diesel with engine calibration 1 and a cold engine start, and with an ambient temperature above 20 °C, it appears that over time the $NO_x$ emissions of the engine abruptly rise from 300 to 450 mg per ECE cycle. The timing of this sudden increase in $NO_x$ emissions varies in the different tests, but no explanation for this has been found. The increase in $NO_x$ emissions is probably caused by the active controls of the EGR system, which regulates the quantity of EGR. This is investigated further with the vehicle with engine calibration 2. These results are reported in chapter 5 of this report. Other engine parameters (such as the fuel injection strategy) may also influence the $NO_x$ emissions. These have not been examined. In UDC tests with a warm start at an ambient temperature above 20 °C, the $NO_x$ emissions are consistent at a level between 350-530 mg per ECE cycle and the EGR recirculation appears to be stable.

*Partial conclusion 6:*
With the same ambient temperatures and the same preconditioning cycles, the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 1 in 4*UDC tests on the test track and on the chassis dynamometer appears to be almost identical. From this it can be concluded that the emission behaviour of the vehicle on the chassis dynamometer and on the test track correspond and can be reproduced, and that the different types of measuring equipment produce similar results.

*Partial conclusion 7:*
In tests at relatively constant speeds of the Suzuki Vitara with engine calibration 1, the emission behaviour is not reproducible; the NOx emissions can differ by more than a factor of 2. The measured oxygen concentrations in the exhaust gas vary, this indicates different controlling of the EGR systems. Sometimes there is a rise in NOx emissions as well. Furthermore, the regeneration behaviour of the LNT in this test cannot be explained.

*Partial conclusion 8:*
In RDE tests with engine calibration 1, the $NO_x$ emission is dependent on the ambient temperature. Substantially higher $NO_x$ emissions were measured at an ambient temperature of 13 °C, than at an ambient temperature of 26 °C (691 versus 420 mg/km).

*Partial conclusion 9:*
In an NEDC test with engine calibration 1, which is carried out according to the type-approval test requirements on the chassis dynamometer, the $CO_2$ emissions are 114.9 – 117.2 g/km, which is 8 - 11% higher than the value specified by the manufacturer. The measured $NO_x$ emission is 64.9 - 83.1 mg/km and is on average 7% below the Euro 6 limit value. This test vehicle with engine calibration 1 meets the Euro 6 $NO_x$ limit values.

*Partial conclusion 10:*
The results of NEDC tests on the chassis dynamometer with engine calibration 1 and different driving resistance curves, show that $CO_2$ emissions increase as the driving resistance increases. An increase in the driving resistance results in an increase in the engine load, which, in this testing programme, leads to an increase in $CO_2$ emissions from 115 to 152 g/km (+ 32%). The $NO_x$ emission varies between 65 and 168 mg/km and has no direct relationship with increasing driving resistance.

*Partial conclusion 11:*
The $CO_2$ and $NO_x$ emissions of the Suzuki Vitara with engine calibration 1, measured by the SEMS mobile measurement system, deviate slightly from the test results determined according to the legal measuring method on the chassis dynamometer. These deviations are 0.6 - 4.4% for $CO_2$ and -2.3 – 2.6% for $NO_x$. For the partial conclusions that relate to the $NO_x$ emissions in this study, the above-mentioned differences in measurement results of the SEMS system and the legal method on the chassis dynamometer do not have any impact, since all these deviations are small.

*Partial conclusion 12:*
The driving resistance curve of the test vehicle on the test track in Lelystad is roughly 1.5 to 5.2 times higher than the driving resistance curve determined by the manufacturer. The absolute difference in driving resistance force is 300 - 400 N over the speed range of 10-130 km/h. This difference is largely caused by the turns in the test track.

*Partial conclusion 13:*
The results of NEDC tests with a cold start of the Suzuki Vitara Euro 6b diesel with engine calibration 2 that were carried out on the test track with ambient temperatures of 13 - 23 °C, show that the $NO_x$ emission increases if the ambient temperatures drop. Furthermore, the number and duration of the LNT regenerations in the preconditioning test influences the $NO_x$ emissions in the NEDC test. With an ambient temperature above 20 °C and a standard preconditioning cycle (3* EUDC), an $NO_x$ emission of 200 mg/km is measured in an NEDC test on the test track.

*Partial conclusion 14:*
In 3*EUDC preconditioning tests with engine calibration 2, the LNT is regenerated three times. For unknown reasons, these LNT regenerations sometimes do not (fully) take place. This same regeneration behaviour has been observed in engine calibration 1 (see paragraph 4.1.3). This means that the $NO_x$ buffer capacity varies at the start of an emission test and this influences the $NO_x$ emissions from the emission test.

*Partial conclusion 15:*
The NEDC $NO_x$ emissions with a cold start of engine calibration 2 are substantially higher than the $NO_x$ emissions of an NEDC test with a warm start. This difference mainly arises in the first 500 s of the NEDC test.

*Partial conclusion 16:*
In UDC tests of the Suzuki Vitara Euro 6b diesel with engine calibration 2 and a cold engine start on the test track and the chassis dynamometer, and with an ambient temperature above 20 °C, it appears that over time the $NO_x$ emissions of the vehicle abruptly rise from approximately 150 to 450 mg per ECE cycle. The time of this sudden rise in $NO_x$ emissions lies within the 12th to 14th ECE cycle of a UDC test.

The increase in $NO_x$ emissions is (partly) caused by the adjusted method of controlling the EGR system, which regulates the quantity of EGR. Other engine parameters (such as the fuel injection strategy) may also influence the $NO_x$ emissions. These have not been examined.

*Partial conclusion 17:*
With the same ambient temperatures and the same preconditioning cycles, the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 2 in 4*UDC tests on the test track and on the chassis dynamometer appears to be almost identical. From this it can be concluded that the emission behaviour of the vehicle on the test track can be reproduced on the chassis dynamometer, that the emission behaviour on the chassis dynamometer and on the test track are almost identical, and that the different types of measuring equipment produce similar results.

*Partial conclusion 18:*
In tests with a cold start and constant speeds of 110 and 130 km/h there is a strongly varying $NO_x$ emission. After the cold start, the $NO_x$ emission is around 800 mg/km. This drops after 2 minutes by switching on the low-pressure EGR system to 230 mg/km and then drops to 43 mg/km after the fourth minute due to an LNT regeneration. After the eighth minute the low pressure EGR system partially closes and the average $NO_x$ emission rises to 272 - 293 mg/km and then rises to 446 mg/km when the LNT regenerations are no longer conducted from the 28th minute onwards. It is unclear why the LNT regenerations no longer take place then. This was not examined further.

*Partial conclusion 19:*
In four RDE tests with engine calibration 2 and with average ambient temperatures of 15 to 19°C, the measured $CO_2$ emissions are 129 - 137 g/km and the $NO_x$ emissions are 399 to 619 mg/km. This spread of emissions is normal and fits the nature of RDE tests that may have a certain variation in execution.

*Partial conclusion 20:*
In an NEDC test with engine calibration 2, which is carried out according to the type-approval test requirements on the chassis dynamometer, the $CO_2$ emissions are 118.5 g/km, which is 12% higher than the type-approval value specified by the manufacturer. The measured $NO_x$ emission is 63.5 mg/km, this is 21% below the Euro 6 limit value. This test vehicle with engine calibration 2 meets the Euro 6 NOx limit values.

*Partial conclusion 21:*
The results of NEDC tests on the chassis dynamometer with engine calibration 2 and different driving resistance curves, show that $CO_2$ emissions increase as the driving resistance increases. An increase in the driving resistance (RL1 to RL5) results in an increase in the engine load, which leads to an increase in $CO_2$ emissions from 119 to 175-178 g/km (+ 48%). At the same time, the $NO_x$ emissions also increase from 64 to 120-141 mg/km (+ 87% to + 120%).

*Partial conclusion 22:*
The $CO_2$ and $NO_x$ emissions of the Suzuki Vitara with engine calibration 2, measured by the SEMS mobile measurement system, deviate slightly from the test results determined according to the legal measuring method on the chassis dynamometer. These deviations are 6.6 to 9.0% for $CO_2$ and -2.3 to 2.6% for $NO_x$.

For the partial conclusions that relate to the $NO_x$ emissions in this study, the above-mentioned differences in measurement results of the SEMS system and the legal method on the chassis dynamometer do not have any impact, since all these deviations are small.

*Partial conclusion 23:*
The measured overpressure to which the $NO_x$-$O_2$ sensor, which is mounted after the LNT, is exposed in this test program is small (maximum 4 kPa) and the corresponding correction of the measured $NO_x$ concentration is 1.5 - 2.7%, based on the pressure measurements. The occuring pressures at the two $NO_x$-$O_2$ sensors do explain part of the remaining constant differences in $NO_x$ emissions as measured before and after the LNT. The pressure sensor may not be able to fully follow the peak values.
The measurements after the LNT are at lower overpressures and were validated against the laboratory results. The measurement before the LNT should be considered as more of an indication, with greater measurement inaccuracy, due to the measurement conditions before the LNT.

*Partial conclusion 24:*
The $NO_x$ emissions of the Suzuki Vitara Euro 6b diesel with engine calibrations 1 and 2 are similar in many tests and circumstances. This has been determined on both the chassis dynamometer and the test track. Engine calibration 2 appears to regenerate the LNT more frequently at constant speeds only during the first 1800 s after the cold start and changes the control strategy of the low pressure EGR system at a later time than with engine calibration 1.

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# 1 Introduction

## 1.1 Background

In an emission study from RDW that was reported on in July 2017 [RDW 2017], the first exploratory emission tests were conducted for a Suzuki Vitara Euro 6b diesel. The emission tests were carried out on a test track at RDW in Lelystad at an ambient temperature of 20 to 26 °C. The measured $NO_x$ emissions on the test track varied from 126 to 361 mg/km, see Figure 1-1. These appear to be 1.8 - 3.6 times higher than the permitted $NO_x$ emissions in the type-approval test of 80 mg/km. Three tests were then carried out on the chassis dynamometer at an ambient temperature of 25 °C and 14 °C as well. $NO_x$ emissions of 90 mg/m were only measured in the NEDC type-approval test. In the NEDC test with a warm engine start, the $NO_x$ emission was 274 mg/km and in a test with a cold start at an ambient temperature of 14 °C, the $NO_x$ emission was 377 mg/km.

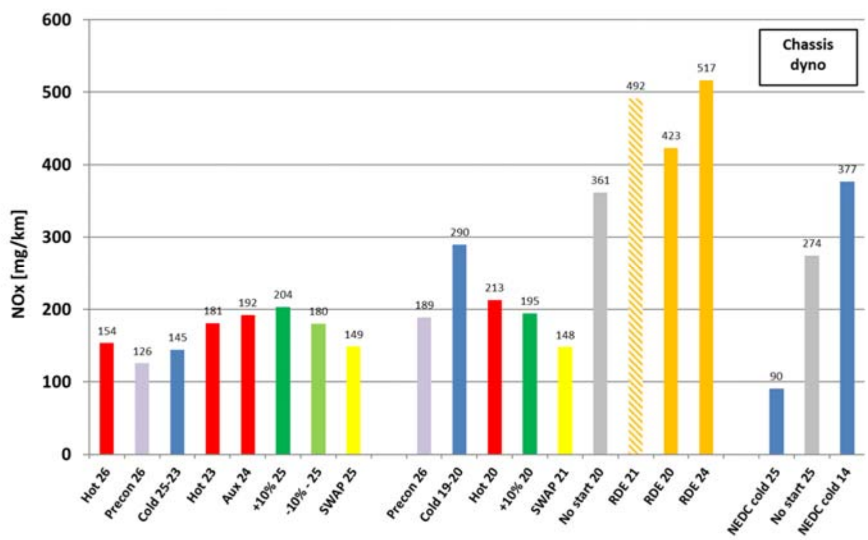


Figure 1-1: $NO_x$ test results from initial exploratory measurements in a RDW study from 2017 on a Suzuki Vitara Euro 6b diesel. The diesel particulate filter has been regenerated in the RDE test using the shaded bar.

Subsequently, the test results were discussed by the RDW with the manufacturer Suzuki and the following was reported [RDW 2017]:

*"During the discussion, Suzuki endorsed the test results of the RDW. Suzuki stated that the measured emission values are the result of a combination of chosen technology, used components, and the adjustment of systems.*

*Suzuki explained the emission strategy of the vehicles. For the explanation of how the engine works, Suzuki asked the engine manufacturer (Fiat Chrysler Automotive - FCA) to participate in the discussion. FCA was unable to provide any explanation about the findings that the duration of activation of the engine has an effect on the operation of the exhaust gas recirculation system. FCA denied that there is a time-related switch present in the vehicle. The RDW indicated that the time the engine is running cannot be an element to protect the engine and that this is unacceptable. FCA has also indicated that the Italian Ministry of Transport, which is responsible for the type approval issued, has also carried out tests and that no time-related switch has been found.*

*The RDW also asked Suzuki and FCA to provide an explanation of the emission control system and whether an adjustment of the exhaust gas recirculation system is used. Suzuki and FCA have indicated that this system will not be deactivated based on the ambient temperature. However, modulation is used based on the ambient temperature. Although, according to Suzuki and FCA, there is no need for vehicle modification, Suzuki has indicated that a software update is available for various vehicles, including the Suzuki Vitara, which is also being implemented in current production and rolled out for the existing fleet. The RDW then indicated that it wanted to test this update in order to check the consequences for actual* $NO_x$ *emissions. In addition, it is important to determine whether or not the time that the engine runs after the update has an influence on the emission behaviour.*

*In January 2017, a vehicle was tested by the RDW in the FCA test laboratory in Italy with the proposed software update. This test was then repeated in the Netherlands with a different random vehicle that had the software update. This test was conducted at the RDW test centre."*
In 2018, RDW commissioned TNO to conduct an emission study of the Suzuki Vitara Euro 6b diesel with the original and updated engine calibrations. The most important reason for this follow-up study is to map out the $NO_x$ emission behaviour of this vehicle with both engine calibrations. The measured emission behaviour with the original engine calibration shows increased $NO_x$ emissions under on-road driving conditions.

Mapping the actual emission behaviour is one of the elements necessary to be able to determine if an illegal manipulation instrument is present. It must be emphasised that this TNO study does not make a statement regarding whether a manipulation instrument (defeat device) is present in the vehicle.

This report presents the measurements of the actual emission behaviour of two Suzuki Vitaras Euro 6b diesel with the two engine calibrations: the one from before and after the software update. This vehicle model received a European type-approval (e4 * 715/2007 * 136/2014W * 0658 * 00) from the Netherlands Vehicle Authority (RDW) on 9 January 2015. The letter W in the type-approval number refers to the Euro 6b emission standard. Euro 6b means that the emissions need to meet certain standard values, as is described in Regulation 136/2014.

## 1.2 Objectives

The main objective of this research is to map out the $NO_x$ emission behaviour of a Suzuki Vitara Euro 6 diesel with the original engine calibration and with the engine calibration that has been updated by Suzuki/FCA (previously referred to as “service update”).
To this end, this study has the following eleven partial objectives:

1. Verification of the exhaust emissions in the type-approval test on a chassis dynamometer.
2. Verification of the driving resistance curve.
3. Determination of the effect of different driving resistance curves on exhaust emissions.
4. Determination of the exhaust emissions in a type-approval test and in other emission tests on a test track.
5. Investigation into the EGR regulation strategies used.
6. Investigation into the emission behaviour during the warm-up phase of the engine.
7. Determining average on-road emissions in Real Driving Emission (RDE) tests on public roads.
8. Determining the effect of the two different engine calibrations on the vehicle emissions.
9. Determination of the effect of different ambient and cooling water temperatures on the vehicle emissions for the two engine calibrations.
10. Investigation into the emission behaviour of the vehicle with both engine calibrations in relation to the (cumulative) parameters, such as operating time, fuel consumption, distance travelled, and speed.
11. Determining the influence of different preconditioning cycles on the results of an emission test.

It must be emphasised that the study does not aim to investigate the presence of a manipulation instrument (defeat device), as prohibited by law, in the vehicle. Therefore, no conclusions will be made in this in the report.
The report does provide information for further addressing this type of issue.

## 1.3 Approach

In this study, the test activities were conducted on two Suzuki Vitara Euro 6b diesel vehicles. One vehicle had engine calibration 1 and the other vehicle had engine calibration 2. The research is based on emission tests that were conducted on an RDW test track in Lelystad and on a chassis dynamometer at Horiba Europe GmbH in Oberursel. A few RDE tests were also conducted on public roads. The schedule of the conducted activities is shown in Table 1-1.

Table 1-1: Schedule of research activities

| Date of period | Activity |
|---|---|
| March 2018 | Instrumentation of vehicle 1 |
| March - June 2018 | Conducting vehicle 1 emission tests on the test track |
| August 2018 | Chassis dynamometer test programme, vehicle 1 |
| October 2018 | Conducting vehicle 1 emission tests on the test track |
| June 2019 | Instrumentation of vehicle 2 |
| June - November 2018 | Conducting vehicle 2 emission tests on the test |
| December 2018 - January 2019 | Chassis dynamometer test programme, vehicle 2 |
| February - May 2019 | Conducting vehicle 2 emission tests on the test track |
| January - July 2019 | Report |

## 1.4 Reading guide

In chapter 2 of this report, general information will first be provided on the different parts of an emission test procedure, given its specialised nature.
Chapter 3 describes the data of the tested vehicle, the test equipment used, the test locations, the test cycles and the fuel used.
The test results of the vehicle with engine calibration 1 are reported in chapter 4 and in chapter 5 the test results of the vehicle with engine calibration 2 are presented.
In chapter 6 the results of engine calibration 1 and 2 are compared.
Following a discussion in chapter 7, the conclusions are presented in chapter 8.
The report also includes Appendices A to D.

# 2 Technical background and interpretation

Given the specialised nature of emissions tests on road vehicles, this chapter will explain the different parts of an emissions test. In certain parts of this chapter, reference is made to the researched vehicle (Suzuki Vitara). The information in this chapter is intended as background information. The description of the actual research can be found in chapters 1 and 3 to 6.

## 2.1 Emission test methods

Emission tests can be conducted in test labs or on the road. These two test methods are used for different goals.

- In test labs, chassis dynamometers allow for test conditions to be set and kept constant. The measuring equipment is used in a fixed setup, which results in defined measuring conditions, ensuring relatively high measuring accuracy. This results in high reproducibility of emission tests and enables comparisons to be made between tests carried out in different labs.
- On the road, conditions can vary significantly in a short space of time, due to wind force, direction of travel, and angles of inclination of the road, but also as a result of external temperatures and driving style (calm versus sporty and steering wheel position while cornering). Because of this, the results of road tests show more variation than those on a chassis dynamometer. Emissions in on-road conditions can have a wider spread and are, therefore, difficult to reproduce.
- Attempts can be made to simulate the laboratory test on the road. This was done in this research. For that reason, a lot of attention was given to the factors that cause the variation between laboratory conditions and deviations from these.

Applying the statutory emission measurement method on the road requires an increase in emission requirements. Until 2017, vehicles with a type approval for emissions were only tested on a chassis dynamometer. This is also the case for the Suzuki Vitara Euro 6b diesel tested in this study.
Independent parties can perform emission tests (RDE tests) on the road for new vehicle models that were released after 1 September 2019 with a Euro 6d temp type-approval, as part of the type-approval requirements. But, more importantly, the manufacturer declares that the Euro-6d meets these RDE requirements in a wide range of circumstances and usage situations. An independent party has the option of checking the information on which the type-approval authority must base their decision.

In this Suzuki Vitara study, emission tests were carried out on a chassis dynamometer and on the road.

## 2.2 Type-approval test on a chassis dynamometer

An NEDC (see section 2.3) type-approval test for determining the exhaust gas emissions, which every new vehicle type up to Euro 6b had to undergo, is conducted on a chassis dynamometer, see Figure 2-1.

The reason for this is that the test conditions are well defined and such a test can, in principle, be conducted by any test laboratory with very similar results, resulting in high reproducibility.

A complete procedure for determining the vehicle emissions contains the following 8 steps:

1. Determining the driving resistance curve of the vehicle on the road (coast-down test).
2. Installing the vehicle on the chassis dynamometer.
3. Warming up the vehicle in the NEDC test cycle to be performed.
4. Adjusting the driving resistance curve on the chassis dynamometer.
5. Conducting a repeated EUDC pre-conditioning cycle.
6. Conditioning the vehicle (soak) by leaving the vehicle stationary for 6-30 hours in a conditioned room of 20-30 °C.
7. Conducting the NEDC emission test on the chassis dynamometer.
8. Checking the driving resistance curve in this chassis dynamometer setting.

Figure 2-1: A Suzuki Vitara on the chassis dynamometer.

## 2.3 Test cycle in the type-approval

A defined test cycle in the type-approval test is a condition for reproducible test results. For the Suzuki Vitara Euro 6b diesel the NEDC test (New European Driving Cycle) is applicable. In Figure 2-2, the speed pattern of the NEDC test cycle is shown. This test cycle is started with a cold engine and lasts 1180 seconds. An equivalent distance of 11 kilometres is covered during the test. The tested Suzuki Vitara has an automatic gearbox, which means that switching the gears in the emissions test does not require any active action from the test driver.
An NEDC test starts with a cold engine, the coolant and oil temperature are then stabilised between 20 and 30 °C. This is called a test with a cold start. In this study, tests with a "warm start" have been conducted for a variety of reasons. In such tests, the coolant temperature is higher than 70 °C at the start of the emission test. The NEDC test consists of a city cycle, the UDC (Urban Driving Cycle), and an out of town road cycle, the EUDC (Extra Urban Driving Cycle).

The UDC is made up of four repetitions of the ECE test, which in turn consists of three separate accelerations up to 15, 35 and 50 km/h. An ECE test is 941 metres long. The EUDC test is 6955 metres long.

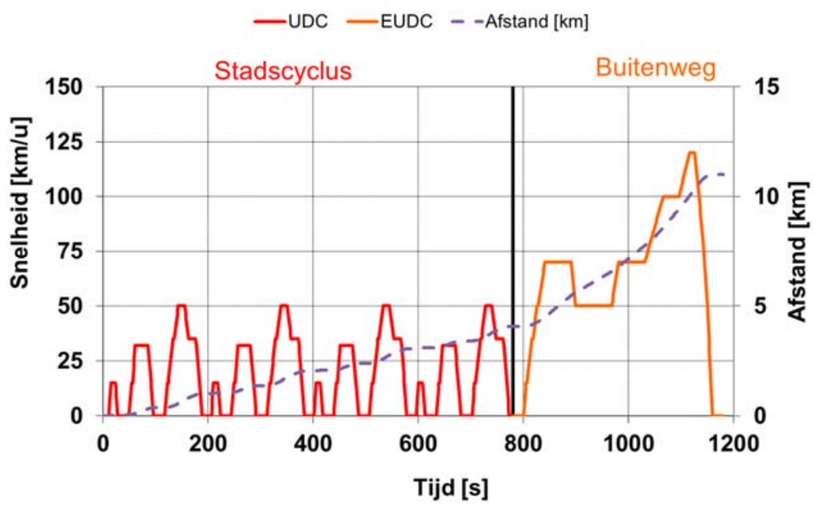


Figure 2-2: NEDC test cycle used in the type-approval on the chassis dynamometer with urban and out of the town road cycle parts.

## 2.4 Driving resistance and vehicle weight

The driving resistance and weight of the vehicle are simulated on the chassis dynamometer and are established per vehicle type. Both are determined in accordance with statutory requirements/procedures in the type-approval test.

To determine the weight of the vehicle, it is weighed in a defined condition (e.g. with a full fuel tank and an additional fixed weight for the driver). From this follows the reference mass that leads to an inertia value or moment of inertia that is set on the chassis dynamometer.

The driving resistance consists of rolling resistance and air resistance. This is determined on a flat stretch of road by allowing the vehicle to roll from a high speed (130 km/h) to a low speed (10 km/h) while measuring the speed trend over time. In Figure 2-3 an example of the results of this speed measurement are shown. Based on this speed curve, the driving resistance can be calculated which is then set on the chassis dynamometer using three parameters, an example of which is shown in Table 2-1.
The total driving resistance force (F total, in Newton) at constant speeds (v) is calculated with the following equation.

$F\ (total) = F0 + F1 * v + F2 * v^2$

Table 2-1: Example of the adjustment parameters of the driving resistance curve on the dynamometer

| Parameter | Unit | Value |
|---|---|---|
| F0 | [N] | 100 |
| F1 | [N/(km/h)] | 3.50 |
| F2 | [N/(km$^2$/h$^2$)] | 0.035 |

Determining the driving resistance curve outside according to the legally prescribed procedure generally produces relatively favourable results. This is because the test is often performed under ideal conditions (the driving resistance values are relatively low). Determining the driving resistance curve in more practical situations often provides substantially higher results. This difference is one of the causes of the variations between emissions measured in the laboratory and those measured on the road with the same vehicle.

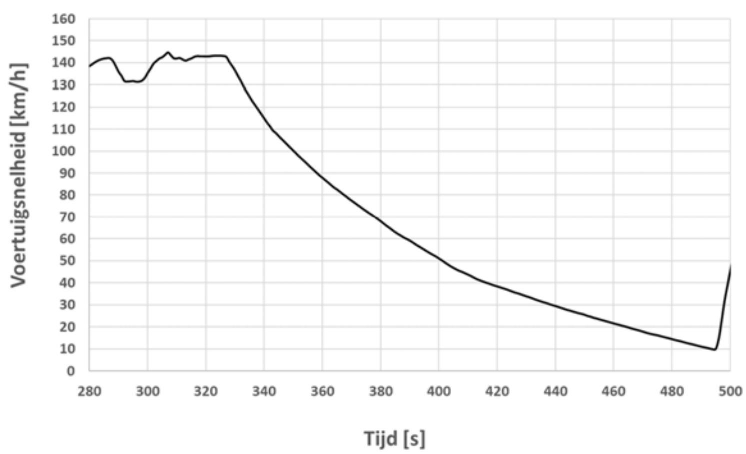


Figure 2-3: Example of a test result to determine the driving resistance of a vehicle. This test is repeated a number of times (not shown here). Y-axis: vehicle speed, X-axis: time in seconds.

## 2.5 Preconditioning test and vehicle conditioning

A type-approval test on a chassis dynamometer requires high reproducibility and repeatability of the emission test. The engine also needs to be cold at the start of the test. To achieve this, the preconditioning and subsequent conditioning of the vehicle have been defined. Preconditioning takes place by driving a test cycle on the chassis dynamometer prior to the type-approval test. For the Suzuki Vitara Euro 6 diesel, a 3*EUDC preconditioning test is applicable, see Figure 2-4.
This test cycle lasts 1200 seconds, during which a distance of approximately 21 kilometres is driven.

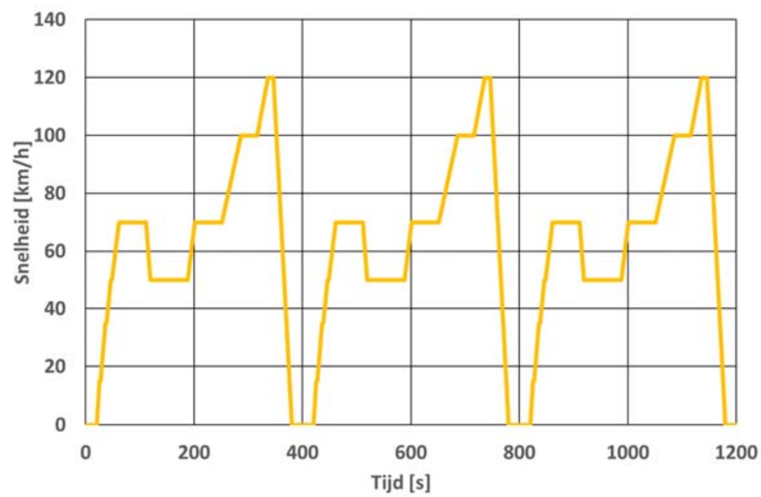


Figure 2-4: Test Cycle (3*EUDC) for preconditioning of the Suzuki Vitara.

After preconditioning, the vehicle is placed in a conditioning room with a regulated temperature (20 to 30 °C) and the vehicle cools down for 6 to 36 hours.

In practice, the preconditioning test is often performed on the day prior to the emission test and vehicle conditioning takes place during the night prior to the type-approval test.

## 2.6 Limit values of the type-approval test on a dynamometer

The European legislation of road vehicles set out in the directives EC 715/2007 and EC 692/2008 stipulates, among other things, limit values for CO, THC, $NO_x$, PM and, as of Euro-5b, PN emissions in a type-approval test. In Table 2-2, the limit values which apply to the Suzuki Vitara Euro 6b diesel under investigation are shown.

Table 2-2: Limit values for the emissions of the Suzuki Vitara Euro 6b diesel

| CO | $NO_x$ | THC+$NO_x$ | PM | PN |
|---|---|---|---|---|
| [mg/km] | [mg/km] | [mg/km] | [mg/km] | [#/km] |
| 500 | 80 | 170 | 4.5 | $6.0 * 10^{11}$ |

The $CO_2$ emissions are not limited in the aforementioned European directives but are measured and specified for each vehicle type. For the tested Suzuki Vitara Euro 6b diesel, the specified $CO_2$ emissions in the NEDC test cycle are 106 g/km.

## 2.7 Other applied test cycles

In addition to the NEDC tests, the following emission tests were conducted during this study:

- Tests with constant driving speeds (50, 80, 100, 110, 120 and 130 km/h).
- UDC tests, see Figure 2-5.

The first 780 seconds of the NEDC test cycle has a speed pattern of up to 50 km/h. This part of the NEDC (see Figure 2-2) is referred to as the UDC test (Urban Driving Cycle). The UDC test consists of four equal parts (four ECE test cycles with a duration of 195 seconds). By repeating these ECE tests, an overview of the emission behaviour over time can be obtained. If the engine is warm and stable, each repetition should generate the same emissions.
The UDC test was repeated four times during the tests conducted and in this case, consists of 16 ECE cycles with a total duration of 3120 seconds.

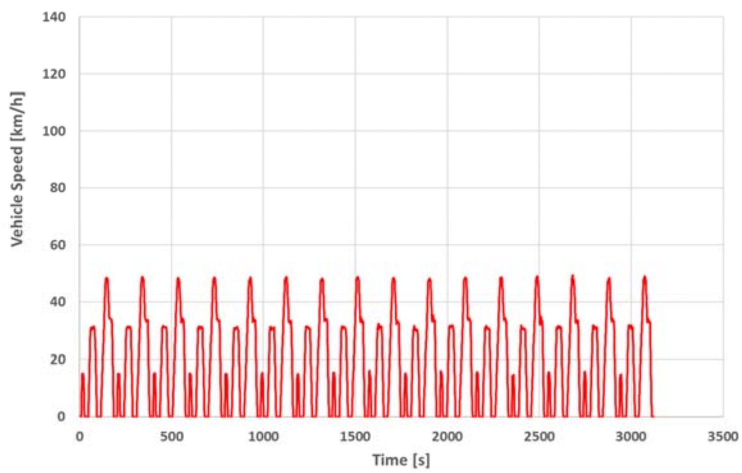


Figure 2-5: 4*UDC test cycles, 16 kilometres in total

## 2.8 Road tests, measuring equipment, and emissions in practice

In recent decades, it has become apparent that practical emissions on the road can be much higher than emissions measured in the laboratory. This particularly applies to $CO_2$ and $NO_x$ emissions. In 2017, this led to new legislation that also requires road emission testing. The vehicle is then equipped with special mobile measuring equipment, also called the Portable Emission Measurement System (PEMS). This test cycle is called a Real Driving Emission (RDE) test. An RDE test takes 90-120 minutes and is performed in the city, on out of the town roads and on motorways.

PEMS measuring equipment has various exhaust gas analysers and their operation is very complex and time-consuming. TNO has PEMS systems at its disposal, but has also developed a simpler measurement system, called the Smart Emission Measurement System (SEMS). This system is based on a combination of existing sensors and our internally developed data logger. The SEMS system has been used by TNO for many years for many emission measurements and was also used in this project.

The quality of the tests with mobile measuring equipment on the road is less than that of chassis dynamometer measurements, but can be used effectively, particularly in combination with validation on a chassis dynamometer. The performance of the SEMS system is also checked in correlation experiments, in which SEMS is used together with certified laboratory equipment. A mobile measurement setup makes it possible to measure on-road emissions.

In comparison with chassis dynamometer tests, the emissions measured during road tests can vary more strongly, due to the following elements, among other things:

- On the road the conditions may vary. The most important conditions are: the type of road surface, the angle of inclination of a road, the bend radius, the wind force and wind direction, the external temperature, the air humidity, and any precipitation.
- Additionally, driving conditions may vary considerably in practice, such as vehicle load, use of the vehicle (air conditioning, use of electrical components, open or closed windows), driving style (calm versus sporty), speed and traffic conditions.

Therefore, emission tests on the road are not significantly worse than chassis dynamometer tests, but differ from them and have more variation in environmental conditions and driving conditions.

# 3 Test vehicle data and research methodology

## 3.1 Vehicle data

The data of the two tested Suzuki Vitaras are shown in Table 3-1. The vehicles have been maintained during their lifetime in accordance with the manufacturer's instructions. As the test vehicles are less than five years old and have driven less than 100,000 km during the test programme, they must meet the "In-Service Conformity" requirements.


Table 3-1: Data of the tested Suzuki Vitara

| | | |
|---|---|---|
| Make & Type | [-] | Suzuki Vitara |
| Class | [-] | Passenger vehicle |
| Vehicle class | [-] | M |
| Fuel | [-] | Diesel |
| Chassis numbers | [-] | 1. TSML YD81S00124642<br>2. TSML YD81S00183218 |
| Engine displacement | [$cm^3$] | 1598 |
| Max. Power | [kW] | 88 |
| Gear box | | Manual 6v |
| Emission class | [-] | Euro 6b |
| Emission systems | | Low and high-pressure EGR system<br>Lean $NO_x$ Trap (LNT), Diesel particulate filter (DPF) |
| Type-approval authority | [-] | RDW |
| Type-approval number | [-] | e4*2007/46*0928*02 |
| Vehicle weight, empty | [kg] | 1205 |
| Mileage of vehicle 1<br>Mileage of vehicle 2 | [km] | 95,068<br>40,500 |
| Date of first registration | | 8 July 2015<br>9 January 2016 |
| Engine calibration 1, before update | | 33980-55P0*0003 |
| Verification number of calibration 1 | | 4F C6 B9 40 |
| Engine calibration 2, after update | | 33980-55P0*0004 |
| Verification number of calibration 2 | | 96 9B 4E CC |

Figure 3-1 provides a schematic overview of the air intake and (emission) exhaust routes, and the applied emission reduction technologies of the engine of the Suzuki Vitara Euro 6b diesel.

The $NO_x$ emissions from this engine are regulated by four technologies or subsystems, these are:

– The fuel injection strategy; the fuel can be administered in multiple partial injections and at different times.
– The high-pressure EGR system: Depending on the EGR control strategy applied, part of the air in the engine is replaced with unfiltered exhaust gas by this system, so that less oxygen is available for the formation of $NO_x$.
– The low-pressure EGR system: depending on the EGR control strategy applied, part of the air in the engine is replaced with filtered and cooled exhaust gas, so that less oxygen is available for the formation of $NO_x$.
– The Lean $NO_x$ Trap (LNT) (also known as NSC), which initially stores $NO_x$ formed in the engine and then partially converts it into harmless components, with the temporary addition of unburned fuel.

The PM/PN or particle emission is largely determined by the filtration efficiency of the diesel particulate filter (also called the DPF). Filtration efficiencies of more than 95% are common under practical conditions.

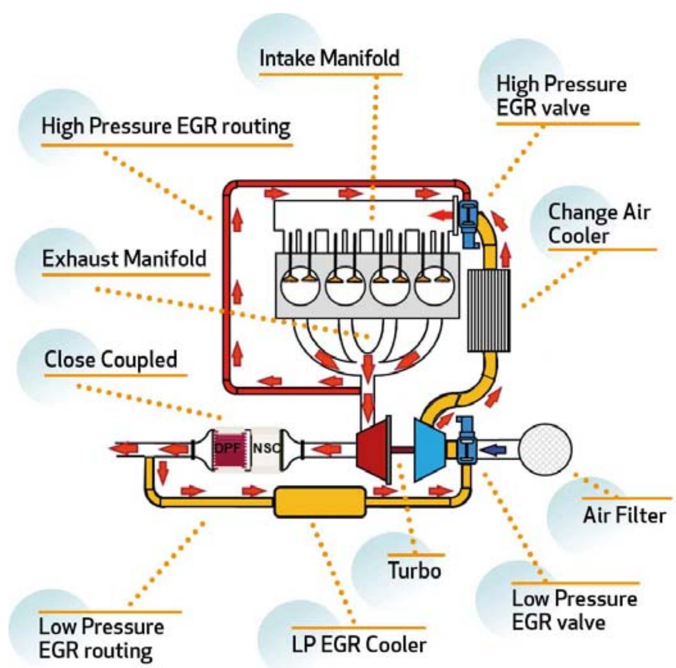


Figure 3-1: Schematic representation of the Euro 6b diesel engine of the Suzuki Vitara with high and low-pressure EGR systems.

## 3.2 Measuring equipment

### *3.2.1 Chassis dynamometer:*

The chassis dynamometer at Horiba Europe GmbH that was used in this test meets the legal requirements for type-approval and is certified for NEDC and WLTP type-approval tests according to ISO 17025. The chassis dynamometer consists of two rollers on which the front and rear axles of the vehicle are placed. In order to measure emissions, the test set-up use a dilution tunnel with Constant Volume Sampler (CVS), sampling bags, and exhaust gas analysers that analyse both diluted and undiluted exhaust gas. The detailed specifications of the chassis dynamometer are provided in Appendix D.


Figure 3-2: Chassis dynamometer and measurement equipment for performing an emissions test

### *3.2.2 Mobile measuring system SEMS*

The measurements that were conducted on and near the RDW test track in Lelystad were performed with an SEMS measurement system. Figure 3-3 shows the schematic of the connection of SEMS to the engine of the Suzuki Vitara.

SEMS test results are based on calibrated $NO_x$-$O_2$ sensors installed in the exhaust system before and after the Lean $NO_x$ Trap (LNT) as well as vehicle data taken from the OBD system. Position data of the test vehicle is also determined via a GPS receiver, which is part of the SEMS. After the test data is stored in a database via a mobile data connection, corrections, signal alignment and calculations take place.This SEMS measurement system has been validated in the test programme on the chassis dynamometer.

An important part of the $NO_x$ reduction is the application of EGR (Exhaust Gas Recirculation) in the engine where part of the exhaust gas is recycled to the cylinder. The Suzuki Vitara is equipped with a high and low-pressure EGR system. To gain insight into the operation of the EGR, the position signals (analogue DC voltage) of the low and high-pressure EGR valves have been logged with SEMS. Additionally, engine signals have been logged which provide insight into the operation of the EGR system.

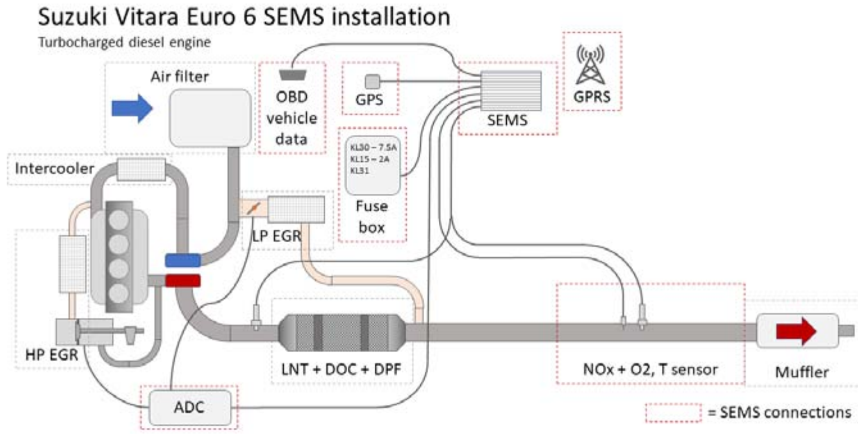


Figure 3-3: Schematic representation of the Euro 6b diesel engine of the Suzuki Vitara and the SEMS measurement system.

## 3.3 Testing locations

### *3.3.1 Chassis dynamometer*

The chassis dynamometer from Horiba Europe GmbH is located in Oberursel (Taunus) in Germany. To perform the dynamometer measurements, the test vehicle was transported to Horiba via car transport.

### *3.3.2 Test Centre Lelystad (TCL)*

The first exploratory emissions tests were conducted on the test track of the RDW in Lelystad, see Figure 3-4. This has a length of 2.8 kilometres, consisting of 1.4 km of straight track and 1.4 km of turns and corners.


Figure 3-4: RDW test track Lelystad (TCL)

### 3.3.3 *RDE route Lelystad*

The RDW has developed an RDE route in the Lelystad area. This has a length of 87 kilometres and includes a city road section, an out of the town road section, and a motorway section.


Figure 3-5: RDE route Lelystad

## 3.4 Test cycles

In this study, tests were conducted with the following test cycles:

- NEDC test starting with a cold engine, see section 2.3
- NEDC test starting with a warm engine, see section 2.3
- EUDC test starting with a warm engine, see section 2.5
- Constant speeds (80, 100, 120, and 130 km/h).
- UDC test starting with a cold engine, see section 2.7
- UDC test starting with a warm engine, see section 2.7
- RDE test, see section 3.3.3.

Table 3-2 provides an overview of the parameters of the test cycles used.

Table 3-2: Overview of test cycles

| Test | Distance [km] | Duration [s] | Average Speed [km/h] |
|---|---|---|---|
| NEDC | 11.0 | 1180 | 33.6 |
| 3*EUDC | 20.8 | 1200 | 62.4 |
| 4*UDC | 16.3 | 3120 | 18.7 |
| ECE | 1.0 | 195 | 18.7 |
| RDE Lelystad | 83.0 | 5617* | 55.9* |

* Estimated. The duration and speed of an RDE test depends on the current traffic conditions.

In order to carry out the tests on the test track in Lelystad, the RDW has installed a "driver aid" in the test vehicle. The driver aid display instructs the driver on both the speed profile and the switching scheme of the manual gearbox that need to be followed during the test.

### 3.5 Applied driving resistance curves on the chassis dynamometer

In this emission study, tests were conducted on the chassis dynamometer with five different settings (RL1 to RL5). The parameters of the five applied driving resistance curves are represented in Table 3-3.

Table 3-3: Parameters of the five applied driving resistance curves on the dynamometer

| Source | Inertia | F0 | F1 | F2 |
|---|---|---|---|---|
| | [kg] | [N] | [N/km] | [N/km$^2$] |
| OEM (RL1) | 1360 | 66.4 | 0.63 | 0.0358 |
| TCL (RL 2) | 1422 | 99.1 | 1.03 | 0.0350 |
| TCL (RL 3) | 1422 | 150.0 | 1.03 | 0.0350 |
| TCL (RL 4) | 1422 | 220.0 | 1.03 | 0.0350 |
| TCL (RL 5) | 1414 | 340.0 | -0.79 | 0.0553 |

### 3.6 Fuels

The diesel reference fuel CEC-RF-Euro 6 B7 was used in the chassis dynamometer programme, the certificates of which are included in Appendix A.

The emissions tests on the test track in Lelystad were performed with diesel commercial fuel with EN590 specification.

### 3.7 Emission research methodology

The $NO_x$ emission behaviour of the engine and the LNT of the Suzuki Vitara Euro 6b diesel have been investigated in detail and the following test methodologies have been chosen:

- Conducting the defined test cycles.
- Unambiguous structure of the UDC emission test: Because a 4*UDC test consists of 16 ECE cycles and the emissions are determined per ECE cycle, good insight can be obtained into the emission behaviour over time because the test results of the ECE cycles can be compared.
- Furthermore, the emissions before and after LNT were measured in tests, which provides insight into the emission behaviour of the engine and the LNT.
- Measure and report preconditioning tests of the 4*UDC emission tests as an emission test.
- Conducting identical emission tests on the test track and on the chassis dynamometer.

# 4 Results for engine calibration 1

The results of the emissions study are presented thematically in this chapter with the aim of increasing the readability of this report. This means that the results of the tests that were conducted at different times, are compared to each other. In some cases the results of previously conducted exploratory RDW emission studies are also included. This section will focus on the $NO_x$ emissions of the Suzuki Vitara with engine calibration 1.

## 4.1 Study emissions on a test track and on public roads

### *4.1.1 Measured emissions in practice with engine calibration 1*

This section discusses partial objective 4 from section 1.2.

*Background:*
In the exploratory RDW study of 2017, the $NO_x$ emissions of a first Suzuki Vitara were measured in various tests on the test track. These took place at ambient temperatures of 20 to 26 °C. The measured $NO_x$ emissions ranged from 126 to 517 mg/km, see Figure 4-1.
Three RDE tests were also carried out at that time, which provide an overview of daily average emissions in practice. $NO_x$ emissions of 423 to 517 mg/km were measured, (see section 1.1).

*Execution:*
During the study presented in this report, a number of tests that had previously been carried out by RDW on a first Suzuki Vitara in the exploratory emission study, were repeated for verification. For these tests, carried out in 2018, a second Suzuki Vitara Euro 6 diesel (with chassis number TSML YD81S00124642) was used, with engine calibration 1. In the tests carried out by the RDW on the first vehicle in 2016, which was reported by RDW on in 2017, the ambient temperature was 14-21 °C. For the tests carried out on the second vehicle in 2018, the ambient temperature was 2-11 °C.

*Result:*
The measured $NO_x$ emissions of the two Suzuki Vitaras are shown in Figure 4-1: in the left half of the figure are the results of the measurements in 2016, in the right half the results of the measurements on the second vehicle in 2018. The various test cycles are shown on the x-axis of this figure with the corresponding average ambient temperature at which they were carried out.

The exploratory emission tests with the second vehicle led to measured $NO_x$ emissions that varied from 321 to 905 mg/km.

In the two RDE tests performed with the second vehicle, $NO_x$ emissions of respectively 831 and 905 mg/km were measured. With a test at a constant speed of 130 km/h, the measured $NO_x$ emission is 1354 mg/km.

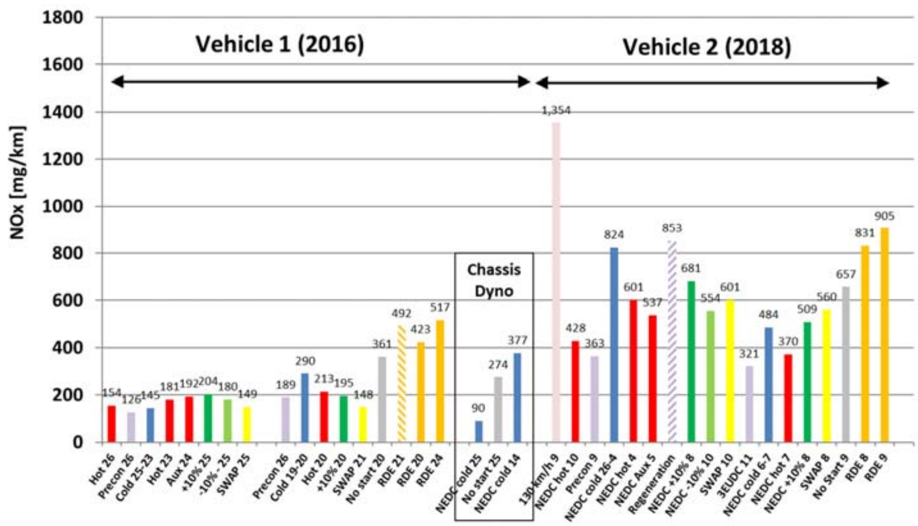


Figure 4-1: Measured $NO_x$ emissions from the first exploratory test track measurements of the two investigated Suzuki Vitaras Euro 1 diesel with engine calibration 1 The first vehicle was tested by RDW in 2016 at ambient temperatures of 20-26 °C on the test track and on the chassis dynamometer. The second vehicle was tested on the test track in 2018, at ambient temperatures of 4-11 °C.

*Partial conclusion 1:*
The Suzuki Vitara Euro 6b diesel, tested in the 2017 RDW study, and the second Suzuki Vitara Euro 6b diesel, tested in this study, both equipped with engine calibration 1, highly exceed the NOx limit value of 80 mg/km in emissions tests on the test track (up to more than 10 times). It also appears that the NOx emission at an ambient temperature of 4-11 °C is twice as high as in the same tests carried out at an ambient temperature of 20-26 °C.

### 4.1.2 *Effects of ambient temperature on emissions*

This section deals with partial objectives 9 of section 1.2, and the following research question in particular: To what extent does the ambient temperature influence the emission behaviour of the test vehicle?

*Background:*
In Europe, external temperatures can vary considerably during the calendar year. Since the external temperature is measured by the vehicle, the question is: to what extent does this affect the engine adjustment?

*Execution:*
To answer this question, NEDC tests with a cold start were performed on different days at different ambient temperatures on the test track. Prior to an NEDC test, an (adjusted) preconditioning test (3*EUDC) was carried out in all cases and in most cases the vehicle was conditioned indoors with a temperature of 25 °C.

*Result:*
The emission results of the NEDC tests that were conducted with different conditioning and external temperatures are represented in Table 4.1 and Figure 4-2. The duration of the three LNT regenerations during the preconditioning tests are stated as well. The $NO_x$ emission at ambient temperatures of 18 to 28°C is 73 up to 283 mg/km and appears to be related to the external temperature. The corresponding $CO_2$ emission is 139 to 143 g/km. In one test carried out at an ambient temperature of 6 °C, the $NO_x$ emission is 897 mg/km and the $CO_2$ emission is 169 g/km. Only in tests at an ambient temperature above 20 °C and a full third LNT regeneration of 9 seconds, and an adjusted preconditioning cycle, the NEDC $NO_x$ emission is 73-82 mg/km and is in line with the limit value of 80 mg/km.

Table 4-1: NEDC test results on the test track with engine calibration 1 at different ambient temperatures

| Date | Ambient temperature [°C]* | Duration of 3 LNT regenerations in precon. [s] | $CO_2$ [g/km] | $NO_x$ [mg/km] before LNT - after LNT *** |
|---|---|---|---|---|
| 29-3-2018 | 5 - 6 | 8+14+9 | 169.3 | -- - 897 |
| 9-4-2018 | 25 - 18 | 10+12+11 | 142.6 | -- - 283 |
| 7-5-2018 | 26 - 26 | 6+11+0 | 138.5 | 241 - 193 |
| 8-5-2018 | 27 - 29 | 14+12+5 | 137.8 | 245 - 157 |
| 14-5-2018 | 26 - 28 | 10+11+0 | 140.3 | 270 - 191 |
| 30-5-2018 | 25 - 27 | 12+11+9** | 140.4 | 189 - 82 |
| 31-5-2018 | 26 - 27 | 11+6+9** | 139.2 | 199 - 73 |

* The first stated temperature is in the conditioning room and the test starts at this temperature. The second value is the average external temperature on the test track. ** The preconditioning cycle was terminated in the third EUDC cycle at 100 km/h immediately after the LNT regeneration.
*** SEMS measurement corrected in relation to LNT regeneration.

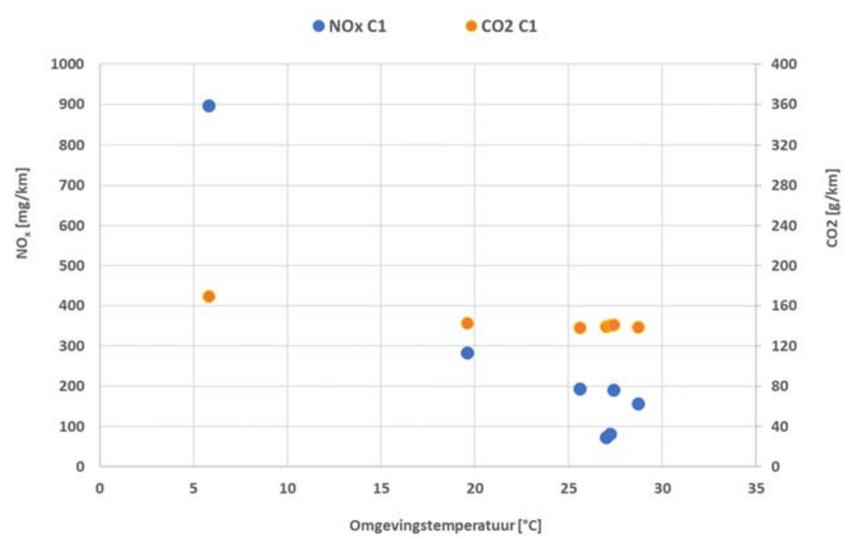


Figure 4-2: Corrected $NO_x$ and $CO_2$ emissions of NEDC tests with a cold start, measured on the test track with engine calibration 1 at different ambient temperatures.

*Partial conclusion 2:*
The results of NEDC tests with a cold start of the Suzuki Vitara Euro 6b diesel with engine calibration 1 that were carried out on the test track, show that the $NO_x$ emission is strongly dependent on the ambient temperatures and the preconditioning test that was conducted. With an ambient temperature above 20 °C and a standard preconditioning cycle (3*EUDC), a $NO_x$ emission of 157-191 mg/km is measured in an NEDC on the test track. The only circumstances under which the NOx limit value of 80 mg/km is not exceeded in an NEDC test on the test track, is with an ambient temperature above 20 °C and an adjusted preconditioning cycle.

### *4.1.3 Influences of the preconditioning test on the $NO_x$ emission in the emission test with engine calibration 1*

This section discusses partial objective 11 from section 1.2.

Given the spread of $NO_x$ emissions with roughly a factor of three in NEDC tests, see Figure 4-2, further research has been done into the condition of a LNT (the extent to which the $NO_x$ trap is filled) and the regeneration frequency.

*Background:*
A Lean $NO_x$ Trap (LNT) is capable of storing a certain amount of $NO_x$. Over time (for example a couple of minutes), the LNT is regenerated for a couple of seconds. A very rich air-fuel mixture is given to the LNT during regeneration. The goal is then to convert the stored $NO_x$ into other components ($H_2O$, $CO_2$, $N_2$ and $O_2$). After the regeneration, the LNT is "empty" and is able to store $NO_x$ again.

*Result:*
A 3*EUDC preconditioning test is shown in Figure 4-3, in which the LNT is regenerated three times at speeds of 80-100 km/h. This happens at a more or less defined time moment in the EUDC test cycle. With every LNT regeneration (which takes place roughly every 400 s), an $O_2$ concentration of 0 vol% is briefly measured after the LNT. A full LNT regeneration is shown in more detail in Figure 4-4.
The LNT is normally regenerated for about 10 seconds and the oxygen concentration in the exhaust gas is nil. During the LNT regeneration, the $NO_x$ concentration measured by the sensor appears to be very high after the LNT for 3-4 seconds. The measured high $NO_x$ concentration at the time of LNT regenerations is further investigated in chapter 5.

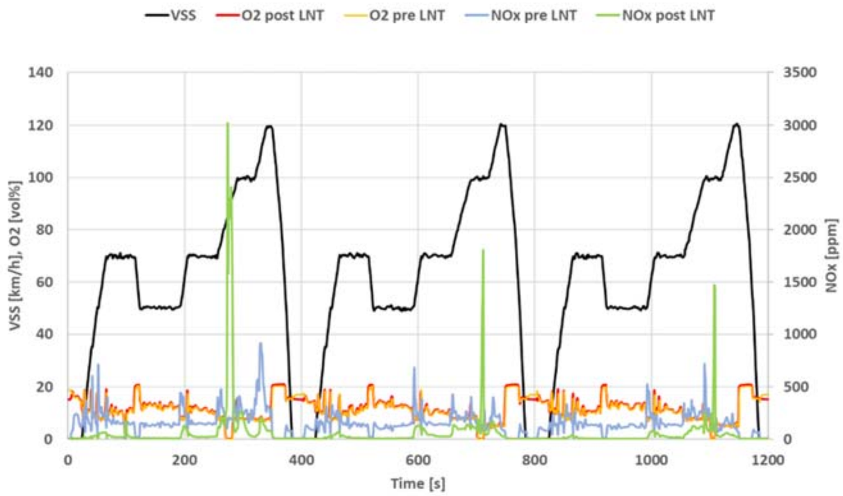


Figure 4-3: 3*EUDC test with engine calibration 1 and warm start, conducted on 18-04-2018 on the test track, at an ambient temperature of 24 °C. The LNT is regenerated three times for 10-12 seconds.

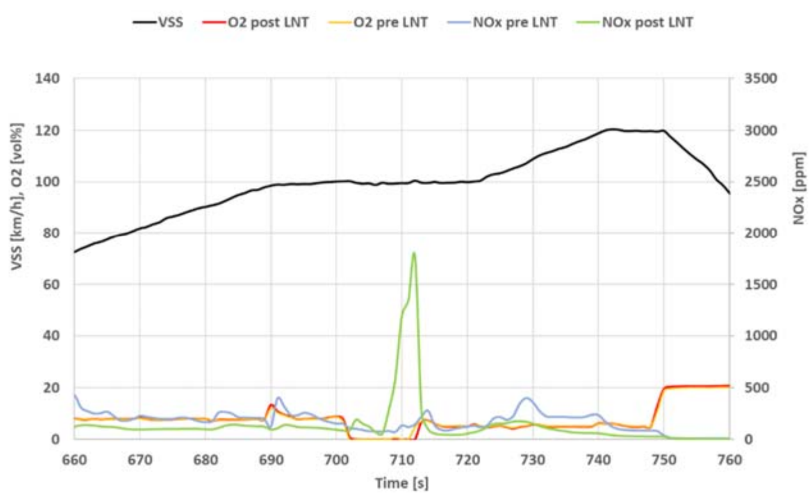


Figure 4-4: LNT regeneration of a 3*EUDC test with engine calibration 1 and warm start, conducted on 18-04-2018 on the test track, at an ambient temperature of 24 °C. The LNT is regenerated for about 10 seconds and the oxygen concentration in the exhaust gas is nil. During the LNT regeneration, the sensor briefly measured a very high $NO_x$ concentration.

Furthermore, the preconditioning of the LNT in a 3*EUDC test appears to not always be reproducible. Results of a preconditioning test are shown in Figure 4-5, in which the LNT regenerations are very short (3 seconds) or do not take place at all. This means that the quality of the LNT regenerations in a preconditioning test determine the degree of filling of the LNT catalyst at the start of the NEDC test and can influence the $NO_x$ emissions in the NEDC test.

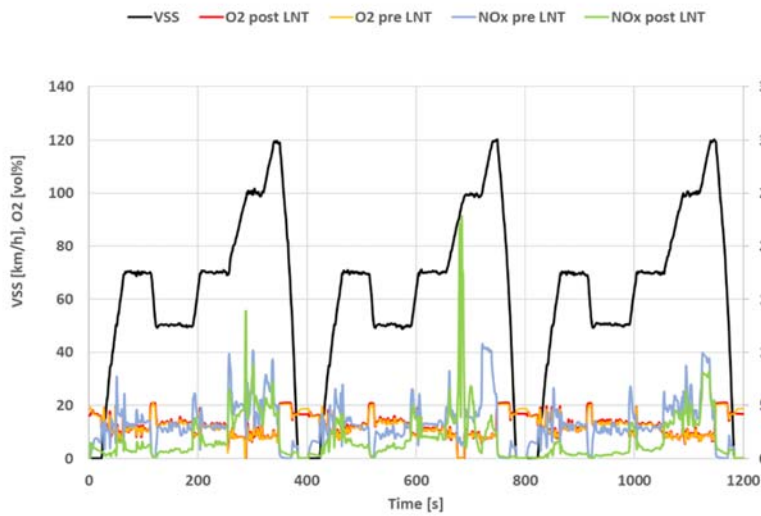


Figure 4-5: 3*EUDC test with engine calibration 1 and warm start, conducted on 24-04-2018 on the test track, at an ambient temperature of 15 °C. The LNT is first regenerated for 3 seconds and then 13 seconds, but in the last ECE cycle the LNT is not regenerated.

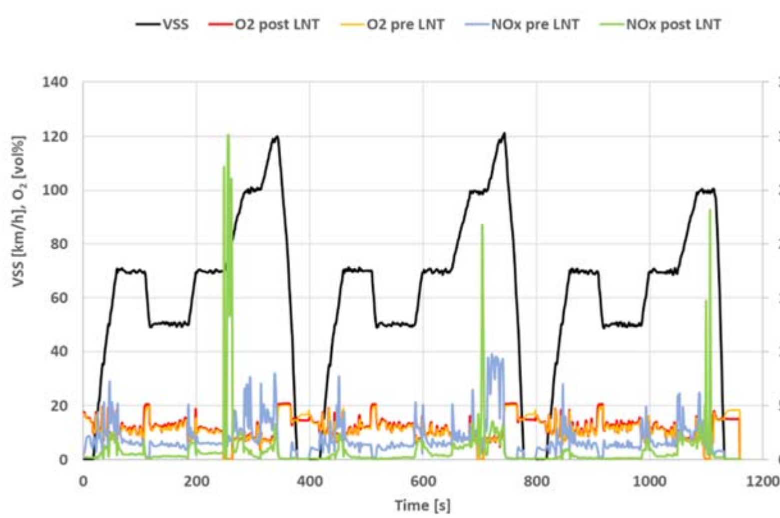


Figure 4-6: 3*EUDC test with engine calibration 1 and warm start, conducted on 29-05-2018 on the test track, at an ambient temperature of 28 °C. The LNT is regenerated three times for 10-13 seconds. The last EUDC cycle ended after the 100 km/h part of the LNT regeneration.

The measurement data from the 3*EUDC preconditioning tests show that the duration and time of the LNT regenerations in a preconditioning test determine the degree of filling of the LNT at the end of this preconditioning test, and therefore the degree of filling at the start of an emission test. It is shown in Table 4.1 that the lowest $NO_x$ emission in an NEDC test with a cold start can be achieved at an ambient temperature of 26 °C and three LNT regenerations in a slightly adjusted preconditioning test that was stopped at 100 km/h immediately after the third LNT regeneration, see Figure 4-6.

The number and duration of the LNT regenerations in a preconditioning test that takes place before the official emission test (NEDC) determines the available $NO_x$ storage capacity of the LNT at the start of an NEDC test.

*Partial conclusion 3:*
In the EUDC preconditioning tests of the Suzuki Vitara Euro 6b diesel with engine calibration 1, the LNT is regenerated, by default, three times at speeds of 80 - 100 km/h. As a result, the NOx storage capacity of the LNT is maximised at the start of an emission test. During the emission test, the NOx can be buffered and, when driving at a speed of 100 km/h, partly converted into harmless components. Incomplete LNT regenerations in the preconditioning test lead to an increased $NO_x$ emission in the subsequent emission test.

### 4.1.4 *Effects on emissions when starting with a cold and warm engine with engine calibration 1.*

This section discusses sub-objectives 5 and 9 of section 1.2, and the following research questions in particular: To what extent does the thermal condition or coolant temperature when the engine is started, affect the emission behaviour of the vehicle?

*Background:*
The effect of an engine's starting thermal condition on vehicle emissions can be mapped by starting identical tests with different coolant temperatures, a so-called "cold" and "warm" engine or cold and warm start. Tests with a cold start, begin with a coolant temperature of 25 °C or the current ambient temperature and tests with a warm start begin with a coolant temperature of 80-85 °C.
The behaviour of the EGR system has been further investigated by measuring the position signal of the high-pressure EGR valve. This position signal is a changing direct voltage and is expressed in millivolts (mV). The high-pressure EGR valve is closed with a low DC voltage and is open with a high DC voltage.

*Execution:*
In this test programme, two NEDC tests with cold and warm starts were carried out one after the other. A standard preconditioning cycle (3*EUDC) was conducted for the cold test. The tests with a warm start were carried out immediately after the NEDC test with a cold start.

*Result:*
The $NO_x$ emissions from NEDC tests with cold and warm starts are shown in Table 4-2. With engine calibration 1 and ambient temperatures of 6 °C, the $NO_x$ emissions are 937 and 547 mg/km in tests with cold and warm starts. With ambient temperatures between 27 and 29 °C, the $NO_x$ emission in the NEDC test with a cold start decrease significantly (up to 259 mg/km on the test track). The $NO_x$ emissions in an NEDC test with a warm start are 329 mg/km.

Table 4-2: $NO_x$ and $CO_2$ emissions of NEDC tests with cold and warm starts on the test track with engine calibration 1.

| Date | T environment [°C] | $CO_2$ [g/km] | $NO_x$ [mg/km] | $CO_2$ [g/km] | $NO_x$ [mg/km] | Location |
|---|---|---|---|---|---|---|
| | Cold and warm start | Cold start | | Warm start | | |
| 29-3-2018 | 6 and 6 | 169.3 | 897 | 140.6 | 533 | Test track |
| 14-5-2018 | 27 and 29 | 141.1 | 191 | 139.7 | 266 | Test track |

In a first assessment of the results of the NEDC emission tests with a cold and warm start (Table 4.2), it is noticeable that an NEDC test with a warm start and an ambient temperature of 6 °C leads to lower $NO_x$ emissions (533 mg/km) compared to the NEDC test with a cold start (897 mg/km). However, there is an increase in $NO_x$ emissions (from 191 to 266 mg/km) at an ambient temperature of 27 to 29 °C. In addition to the effect of ambient temperature on $NO_x$ emissions, there might be other factors that influence the $NO_x$ emission behaviour.

The cause of the differences in $NO_x$ emissions in the NEDC tests with a cold start have been investigated further. The graphs of NEDC tests are shown in Figure 4-7 to Figure 4-10 with the NEDC speed profile (VSS), the temperature in the engine inlet (IAT) and the coolant temperature (ECT), the ambient temperature (Tambient), the position signal of the high-pressure EGR valve, and the $NO_x$ emissions.
In both tests the high-pressure EGR system is almost only active at speeds up to 50 km/h.

In the NEDC test with a cold start, conducted at an ambient temperature of 6 °C, with a $NO_x$ emission of 897 mg/km, the high-pressure EGR valve is only opened sporadically, see Figure 4-7. In the NEDC test with a cold start, conducted at an ambient temperature of 27-28 °C, the high-pressure EGR valve is open relatively more often, and the $NO_x$ emission is 191 mg/km, see Figure 4-8.

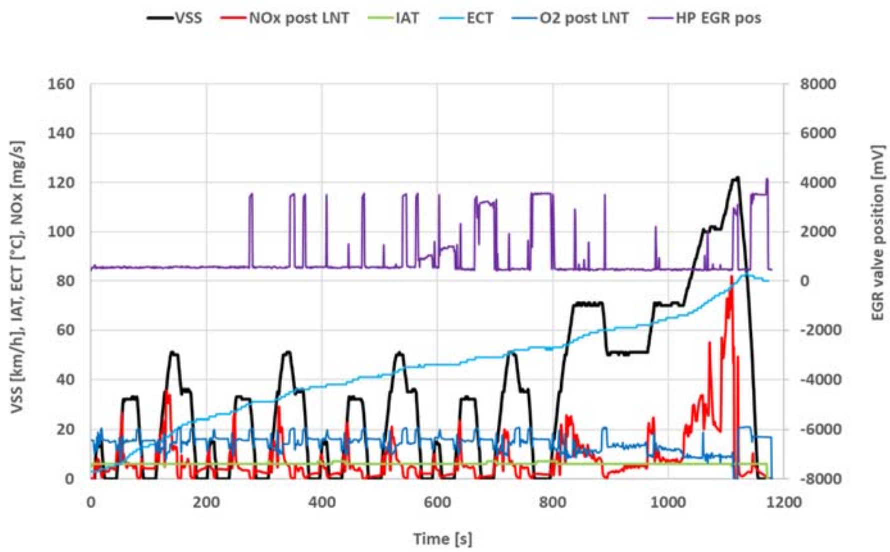


Figure 4-7: NEDC test of 29-03-2018, with engine calibration 1 and a cold start, conducted on the test track at an ambient temperature of 6 °C. The $NO_x$ emission is 897 mg/km. A regeneration of 8 seconds takes place at 120 km/h. A preconditioning test with 3 LNT regenerations (10-12 seconds) was conducted prior to this NEDC test on 28-03-2018.

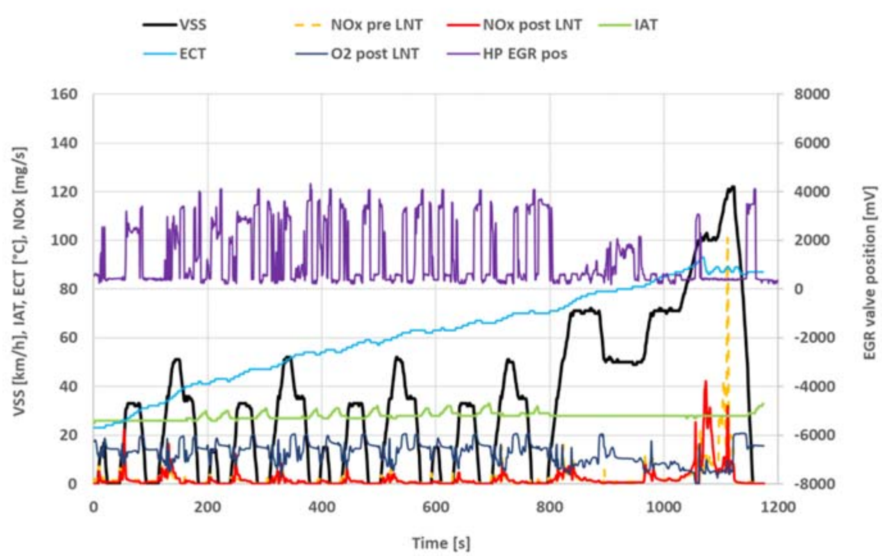


Figure 4-8: NEDC test of 14-05-2018, with engine calibration 1 and a cold start, conducted on the test track at an ambient temperature of 27-28 °C. The $NO_x$ emission is 191 mg/km. A LNT regeneration of 8 seconds takes place at 95 km/h. A preconditioning test with 3 LNT regenerations (12-12-1 seconds) was conducted prior to this NEDC test on 11-03-2018.

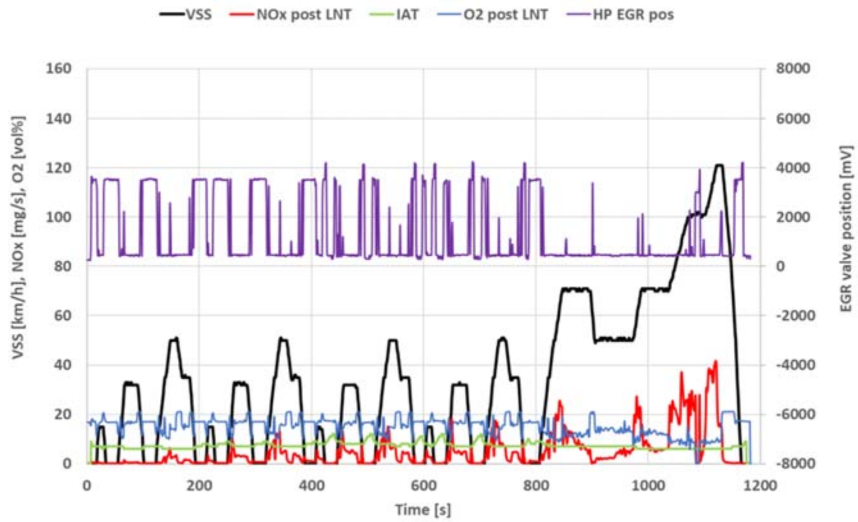


Figure 4-9: NEDC test of 29-03-2018, with engine calibration 1 and a cold start, conducted on the test track at an ambient temperature of 6 °C. The $NO_x$ emission is 533 mg/km. A preconditioning test with 1 LNT regeneration (8 seconds) was conducted prior to this NEDC test on 29-03-2018.

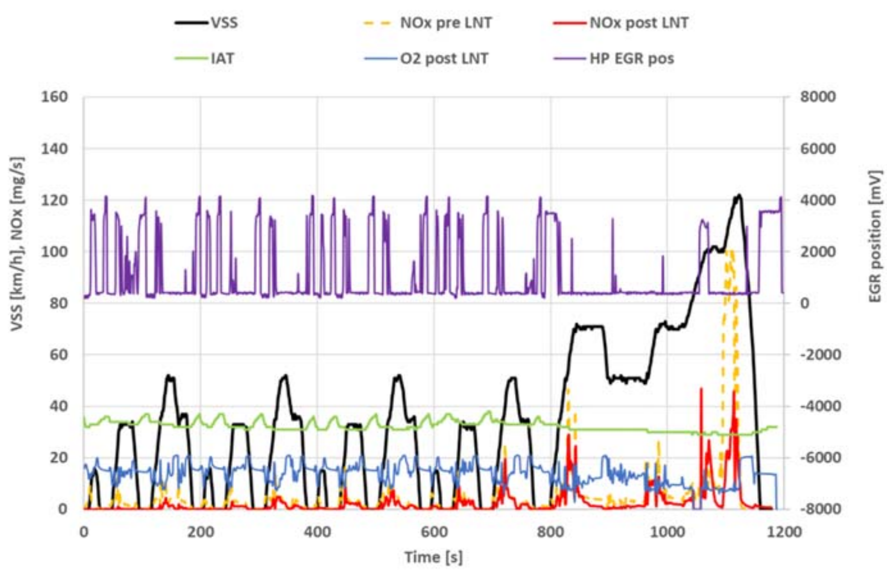


Figure 4-10: NEDC test of 14-05-2018, with engine calibration 1 and a warm start, conducted on the test track at an ambient temperature of 26-28 °C. The $NO_x$ emission is 266 mg/km. A LNT regeneration of 14 seconds takes place at approximately 90 km/h. A preconditioning test with 1 LNT regeneration (7 seconds) was conducted prior to this NEDC test on 14-05-2018.

In the NEDC test with a warm start, at an ambient temperature of 6 °C, the $NO_x$ emission is 533 mg/km, see Figure 4-9. With an ambient temperature of 27-28 °C, the $NO_x$ emission in the NEDC test with a warm start is 266 mg/km, see Figure 4-10 and Figure 4-11. A similar LNT regeneration at 100 km/h was conducted in both preconditioning tests (NEDC with a cold start).
The high-pressure EGR system appears to be similarly controlled in both NEDC tests with a warm start and at different ambient temperatures, but for a longer period of time during the test at an ambient temperature of 6 °C in the first 400 seconds of the emission test. Nevertheless, the $NO_x$ emission of 547 mg/km is higher than in the test with a higher ambient temperature. Information about the control of the low-pressure EGR system is missing here, this is necessary for a better interpretation of this $NO_x$ emission behaviour.

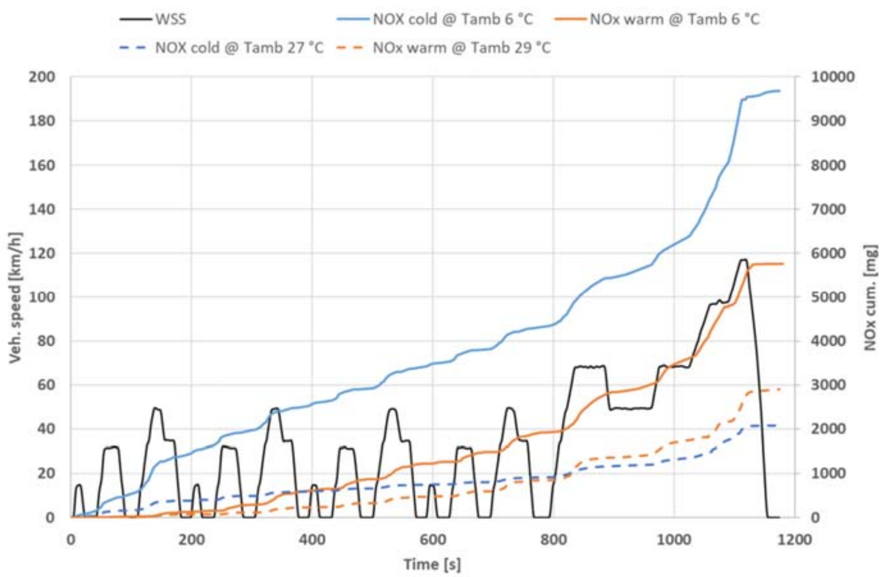


Figure 4-11: Cumulative $NO_x$ emissions from engine calibration 1 in NEDC tests with a cold and warm starts at different ambient temperatures.

*Partial conclusion 4:*
The thermal condition of the engine with engine calibration 1 has a different effect on $NO_x$ emissions at different ambient temperatures. With an ambient temperature of 6 °C the $NO_x$ emission decreases in an NEDC test with a warm start compared to an NEDC test with a cold start, while at a temperature of 26 °C the $NO_x$ emission increases. The ambient temperature seems to have a bigger influence on the $NO_x$ emissions than the thermal condition of the engine.

### 4.1.5 *Emission behaviour curve after a cold start of the engine with engine calibration 1.*

This section discusses partial objectives 5, 6 and 10 of section 1.2, and the following research question in particular: To what extent does the emission behaviour of the vehicle change after the engine has started?

*Background:*
It is generally known that an engine warms up after a cold start and that the emission behaviour of the vehicle changes during this warm-up phase. As part of Dieselgate, questions arose that relate to actively switching systems on or off over

time, distance travelled or accumulated parameters after the engine has been started. In principle, these questions are not connected to the warming up of an engine, but may also play a role at the same time. Special attention has been paid to the behaviour of the EGR system and for this, just like in section 4.1.4, the position signal of the high-pressure EGR valve has been measured.

*Execution:*
The warm-up behaviour of an engine has been investigated with a UDC test cycle which again consists of several ECE cycles. UDC tests, such as those described in section 2.7, were used in this study amongst others. An UDC test consists of four ECE cycles. The ECE test cycle lasts for 195 seconds and is repeated 16 times. This test is further referred to as 4*UDC test and lasts for 3120 seconds.

On the test track in Lelystad, five 4*UDC tests with a cold start and six 4*UDC tests with a warm start were carried out with the vehicle with the original engine calibration. The $NO_x$ emission in mg was calculated for each ECE cycle and is presented as bar graphs in Figure 4-12 to Figure 4-22. Test results of 4*UDC tests with a cold start are shown in Figure 4-12 to Figure 4-16 and tests with a warm start in Figure 4-17 to Figure 4-22.

To verify the emission tests on the test track, 4*UDC tests with a cold start were conducted on the chassis dynamometer with the vehicle with the original engine calibration. The results are shown in Figure 4-23 to Figure 4-24.

*Result:*
The measurement results of a 4*UDC test that was conducted at an ambient temperature of 22 °C are shown in Figure 4-12. The $NO_x$ emission per ECE cycle is initially almost 300 mg and drops to 170-180 mg in the following six ECE cycles, but then rises abruptly in the eighth ECE cycle to approximately 350 mg and then to more than 450 mg. The high-pressure EGR valve opens in the first two ECE cycles and takes a more or less constant position from the third ECE cycle (voltages around 200-250 mV). The position is constant from the seventh ECE cycle (approximately 175 mV), but the $NO_x$ emission then rises from 180 to 350-470 mg per ECE cycle.

Figure 4-13 shows the results of a 4*UDC test with a cold start, conducted at an ambient temperature of 18 °C. The $NO_x$ emission per ECE cycle varies between approximately 300 to 800 mg and is not stable. In the second part of this test (from the tenth ECE cycle), the $NO_x$ emission is substantially higher than in the first part. Since the $NO_x$ emission before the LNT was also measured and it has a similar variation to the $NO_x$ emission after the LNT, the $NO_x$ variation can be attributed to an engine adjustment (variable EGR system setting or change in fuel injection). Despite the preconditioning test in which the LNT has been regenerated, the LNT does not buffer any $NO_x$. This is evident from the fact that the $NO_x$ emissions before and after LNT are virtually the same. This phenomenon cannot be explained.

Figure 4-14 shows the results of a 4*UDC test with a cold start conducted at an ambient temperature of 30-32 °C. The $NO_x$ emissions per ECE cycle are approximately the same as in the test in Figure 4-12, but the $NO_x$ emissions increase sharply from the tenth ECE cycle to ultimately more than 400 mg per ECE cycle.

This jump in $NO_x$ emissions can be attributed to the engine adjustment (changed EGR system setting or fuel injection) because the $NO_x$ emission before the LNT rises from 250 to 450 mg per ECE cycle. Furthermore, the NOx buffer of the LNT is slowly filled, this is evident from the measured decreasing difference in $NO_x$ emissions before and after the LNT. This $NO_x$ difference is 170 mg in the first ECE cycle and 50 mg in the last cycle.

Figure 4-15 shows the results of a 4*UDC test with a cold start conducted at an ambient temperature of 13 °C. The $NO_x$ emission per ECE cycle varies between approximately 500 and 750 mg and this gradually increases during the test. No clear jump in emissions is observed in this test. The NOx buffering of the LNT is very low, only in the first ECE cycle is the buffering greater than in the other 15 cycles.  This can be explained by the lack of LNT regenerations in the second and third EUDC of the preconditioning test.

Figure 4-16 shows the results of a 4*UDC test with a cold start, conducted at an ambient temperature of 20 °C. The $NO_x$ emissions per ECE cycle are approximately the same as the tests in Figure 4-12 and Figure 4-14. In this test a clear $NO_x$ emission jump can be observed in the tenth ECE cycle. This jump in $NO_x$ emissions can be attributed to the engine adjustment (changed EGR system setting or fuel injection) because the $NO_x$ emission before the LNT rises from 300 to 450 mg per ECE cycle. The LNT trap is filled during the course of this test because the difference in $NO_x$ emissions before and after LNT decreases during the course of the test, from approximately 150 to 50 mg per ECE cycle. The permanent difference between the measurements before and after the LNT may not be due to the operation of the LNT, but due to the conditions for the LNT, where the pressure and temperature are substantially higher.  Certainly in Figure 4-15, with a small but constant difference without variations, in the order of 6%, gives cause for further investigation of the measuring principle. This study has been reported in section 5.3.4.

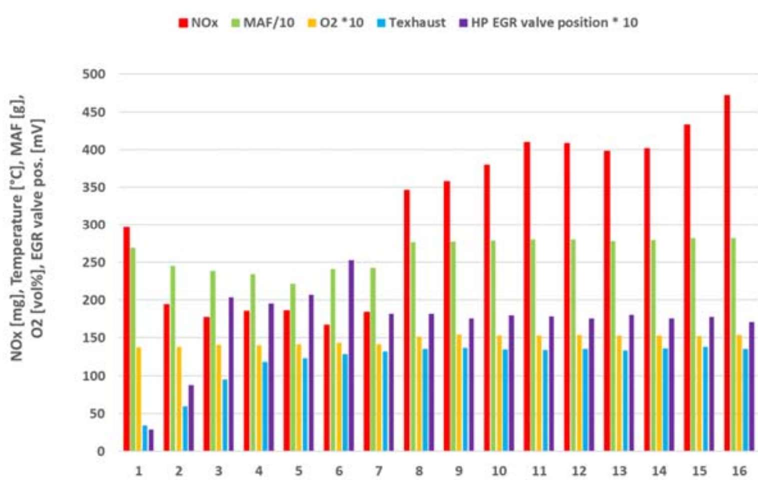


Figure 4-12: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a cold start, performed on 10-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 22°C. Preconditioning 3*EUDC with a warm start, conducted on 09-04-2018, with three LNT regenerations of 13, 13 and 5 seconds.

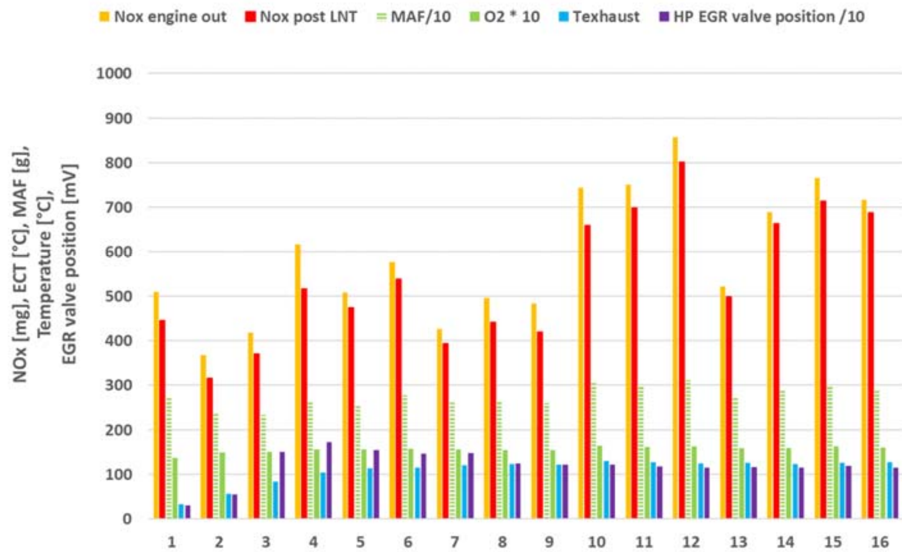


Figure 4-13: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a cold start, performed on 16-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 18°C. Preconditioning 3*EUDC with a warm start, conducted on 11-04-2018, with three LNT regenerations of 2, 15 and 14 seconds.

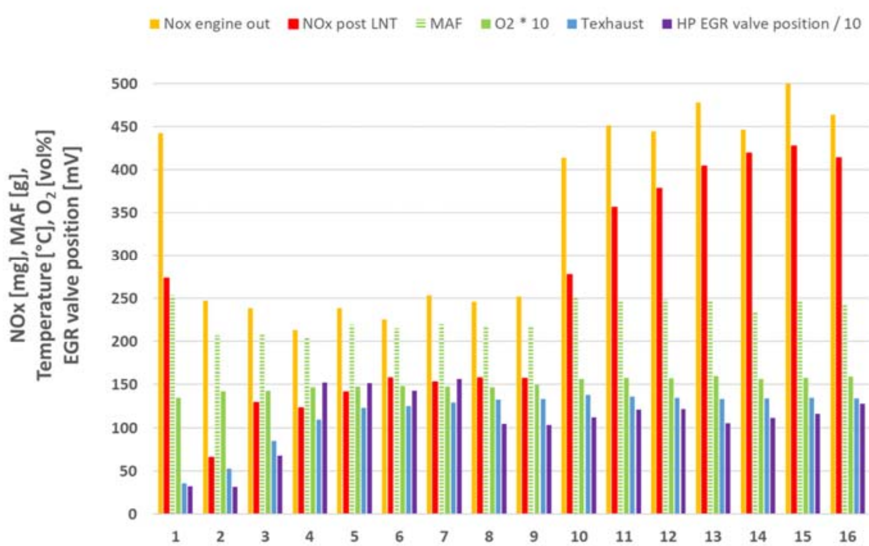


Figure 4-14: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a cold start, performed on 19-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 30-32°C. Preconditioning 3*EUDC with a warm start, conducted on 18-04-2018, with three LNT regenerations of 12, 10 and 7 seconds.

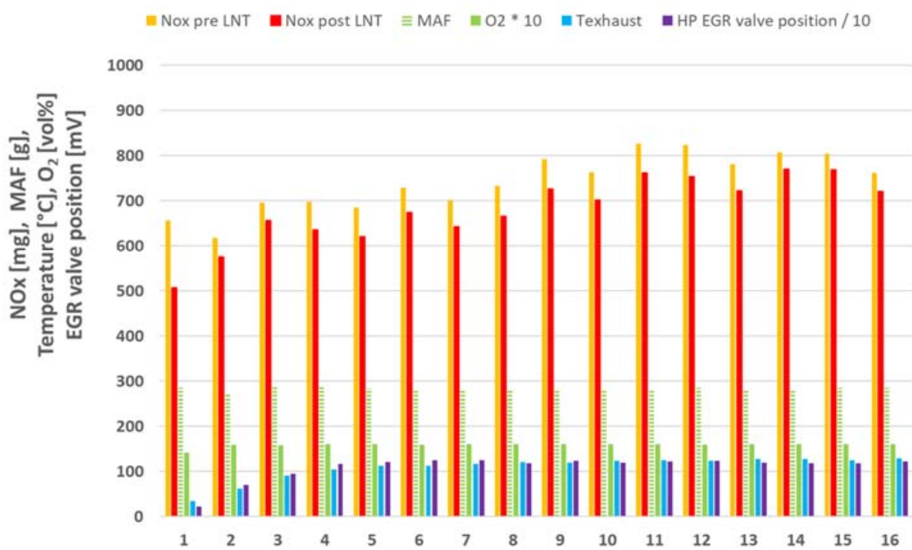


Figure 4-15: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a cold start, performed on 24-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 13°C. Preconditioning 3*EUDC with a warm start, conducted on 19-04-2019, with one LNT regeneration of 10 seconds in the first EUDC.

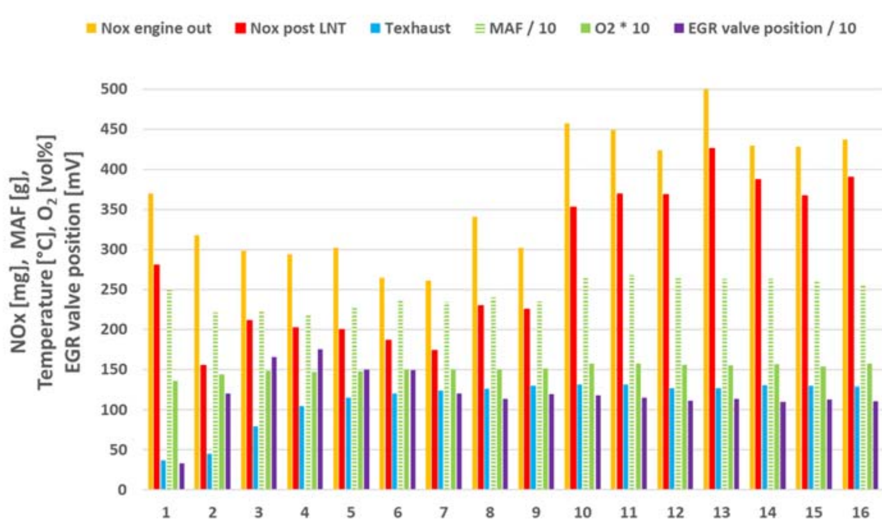


Figure 4-16: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a cold start, performed on 25-05-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 20°C. Preconditioning 3*EUDC with a warm start, conducted on 22-05-2018, with three LNT regenerations of 12, 12 and 8 seconds.

Figure 4-17 shows the results of an incomplete 4*UDC test performed with a warm start at an ambient temperature of 22 °C.

The $NO_x$ emission per ECE cycle varies between approximately 30 to 345 mg and increases in the first four ECE cycles, and then stabilises around 330 mg per ECE cycle.

The measurement results of a 4*UDC test that was conducted at an ambient temperature of 18°C are shown in Figure 4-18. The $NO_x$ emission per ECE cycle of the engine is 540-905 mg. After the LNT, the $NO_x$ emission in the first ECE cycle is 275 mg and this then increases to a level of 530 - 780 mg. This varying emission is mainly caused by the non-constant emission of the engine.
The measured difference in $NO_x$ emissions before and after LNT is 410 mg in the first ECE cycle, and this decreases to almost 0 mg over the course of the test. This shows that the NOx buffer of the LNT is completely filled.

Figure 4-19 shows the results of a 4*UDC test with a warm start conducted at an ambient temperature of 30-32 °C. The $NO_x$ emission per ECE cycle of the engine is 430-520 mg. After the LNT, the $NO_x$ emission in the first ECE cycle is 380 mg, and this then increases to a level of 400 - 485 mg. This varying emission is mainly caused by the non-constant emission of the engine.
The measured difference in $NO_x$ emissions before and after LNT is 40 mg in the first ECE cycle, and this barely decreases in the course of the test. This shows that the NOx buffer of the LNT is almost completely filled at the start of the test, this can be explained by the lack of LNT regenerations in the 4*UDC preconditioning cycle.

The results of a 4*UDC test with a warm start that was conducted at an ambient temperature of 14 °C are shown in Figure 4-20. The $NO_x$ emission per ECE cycle of the engine is 700-840 mg. After the LNT, the $NO_x$ emission in the first ECE cycle is 80 mg, and this then increases to a level of 575 - 750 mg. This increasing emission is mainly caused by the buffer function of the LNT.
The measured difference in $NO_x$ emissions before and after LNT is 740 mg in the first ECE cycle, and this decreases to 60 mg per cycle in the course of the test. This shows that the NOx buffer of the LNT is almost completely filled during this 3120-second emission test.

Figure 4-21 shows the results of an incomplete 4*UDC test performed with a warm start at an ambient temperature of 25°C. The $NO_x$ emission per ECE cycle of the engine is 450-500 mg. After the LNT, the $NO_x$ emission in the first ECE cycle is 75 mg, and this then increases to a level of 370 - 430 mg. This increasing emission is mainly caused by the decline of the buffer function of the LNT over time.
The measured difference in $NO_x$ emissions before and after LNT is 425 mg in the first ECE cycle, and this decreases to 70 mg per cycle in the course of the test. This shows that the NOx buffer of the LNT is almost completely filled during this emission test. The remaining difference may not be the result of the operation of the LNT.

Finally, Figure 4-22 shows the results of an incomplete 4*UDC test performed with a warm start at an ambient temperature of 22 °C. The $NO_x$ emission per ECE cycle of the engine is 350-400 mg. After the LNT, the $NO_x$ emission in the first ECE cycle is 10 mg, and this then increases to a level of 300 - 330 mg. This increasing emission is mainly caused by the decline of the buffer capacity of the LNT.
The measured difference in $NO_x$ emissions before and after LNT is 360 mg in the first ECE cycle, and this decreases to 60 mg per cycle in the course of the test.

This shows that the NOx buffer of the LNT is almost completely filled during this 3120-second emission test.

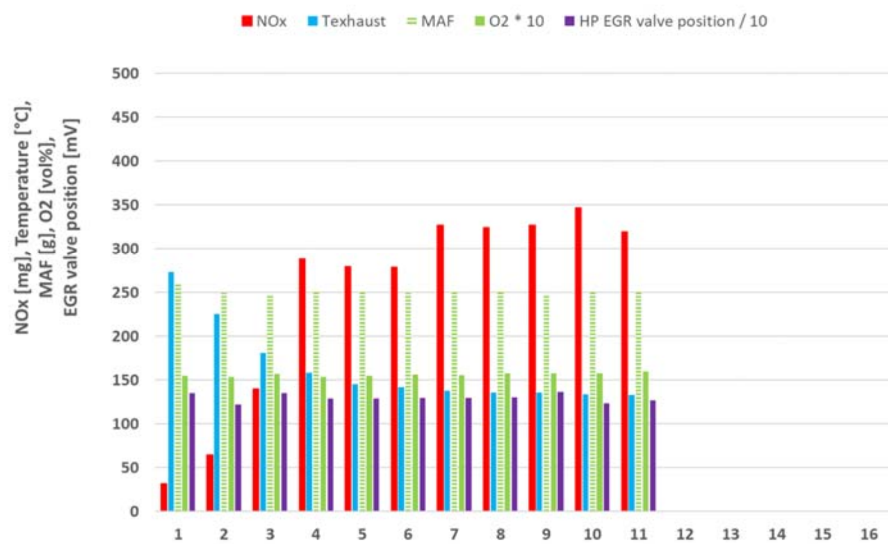


Figure 4-17: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a warm start, performed on 10-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 22 °C. Preconditioning 10 minutes @ 120 km/h with a warm start with various LNT regenerations.

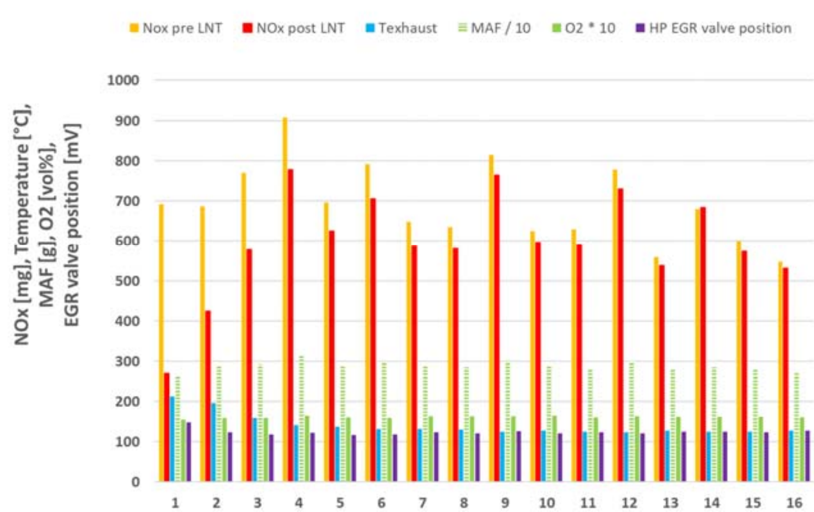


Figure 4-18: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a warm start, performed on 16-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 18 °C. Preconditioning 10 minutes @ 120 km/h with a warm start without LNT regenerations.

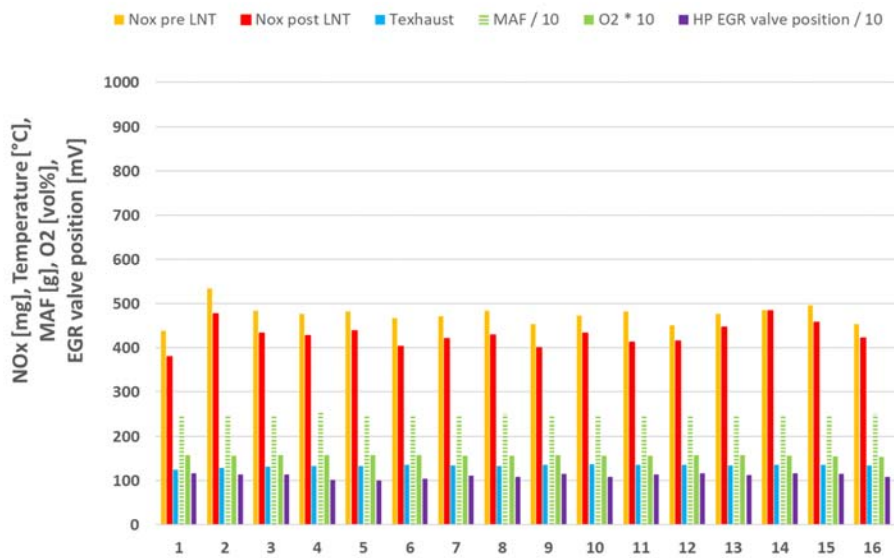


Figure 4-19: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a warm start, performed on 19-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 30-32 °C. Preconditioning 4*UDC with a cold start without LNT regenerations.

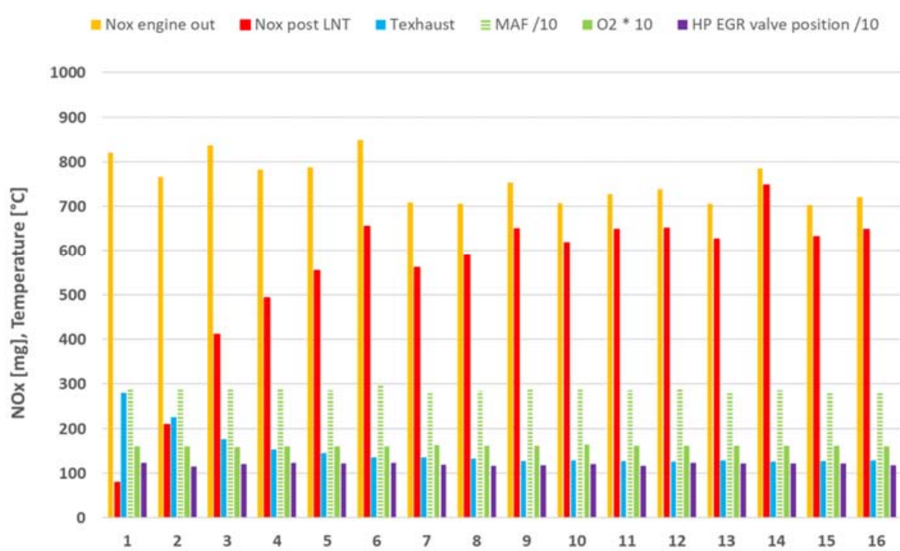


Figure 4-20: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a warm start, performed on 24-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 14 °C. Preconditioning 120 km/h with a warm start with various LNT regenerations.

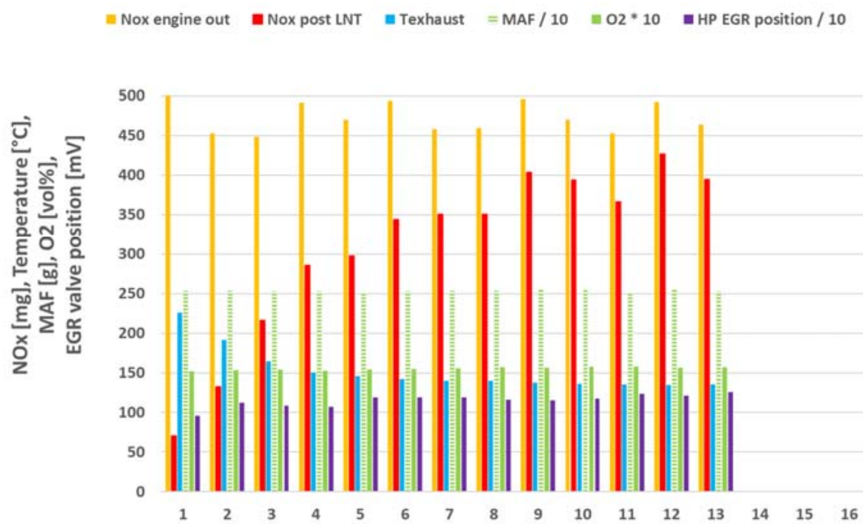


Figure 4-21: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a warm start, performed on 22-05-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 25 °C. Preconditioning 3*EUDC with warm start, with 3 LNT regenerations.

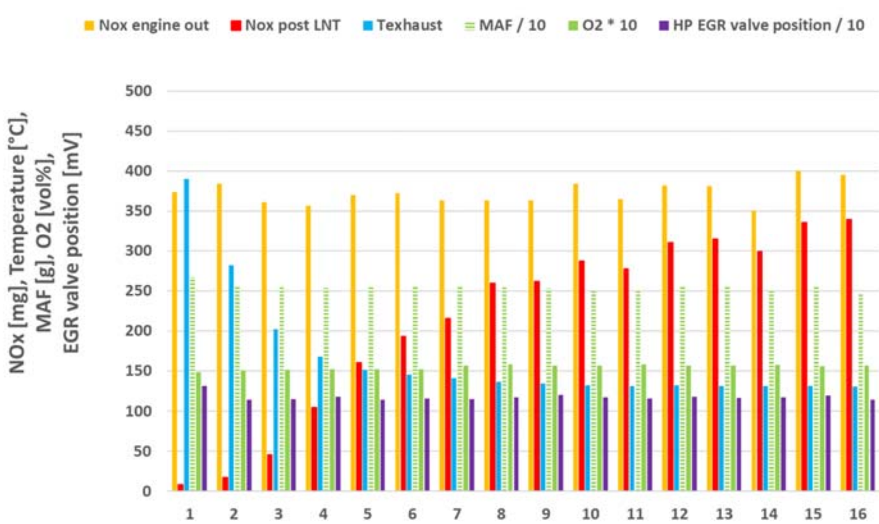


Figure 4-22: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a warm start, performed on 25-05-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 22 °C. Preconditioning 120 km/h with warm start, with 5 LNT regenerations.

To verify the 4*UDC tests on the test track, these tests were also performed on the chassis dynamometer.

Figure 4-23 and Figure 4-24 show the results of 4*UDC tests with a cold start, conducted on the chassis dynamometer, at an ambient temperature of 23°C. After the LNT, the $NO_x$ emission in the ECE cycles 2 to 10 is 50-120 mg, and this then increases abruptly to over 300 mg. Both tests show this abrupt increase in $NO_x$ emissions in the eleventh ECE cycle. In terms of environmental conditions, these dynamometer tests compare quite well with the test conducted on the test track in Figure 4-16. The $NO_x$ emission behaviour in 4*UDC tests with a cold start at an ambient temperature of 22-23°C on the test track and on the chassis dynamometer is almost identical in terms of height and curve.

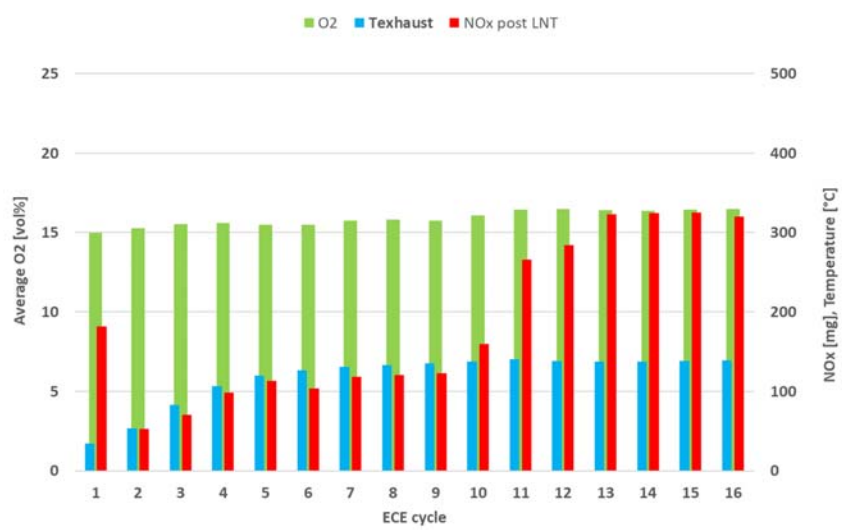


Figure 4-23: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with cold start, performed on 21-08-2018. The test was driven on the chassis dynamometer with road load setting 2 and an ambient temperature of 23 °C. Preconditioning 3*EUDC test on 17-08-2018 with a warm start with 3 LNT regenerations with a duration of 13 seconds.

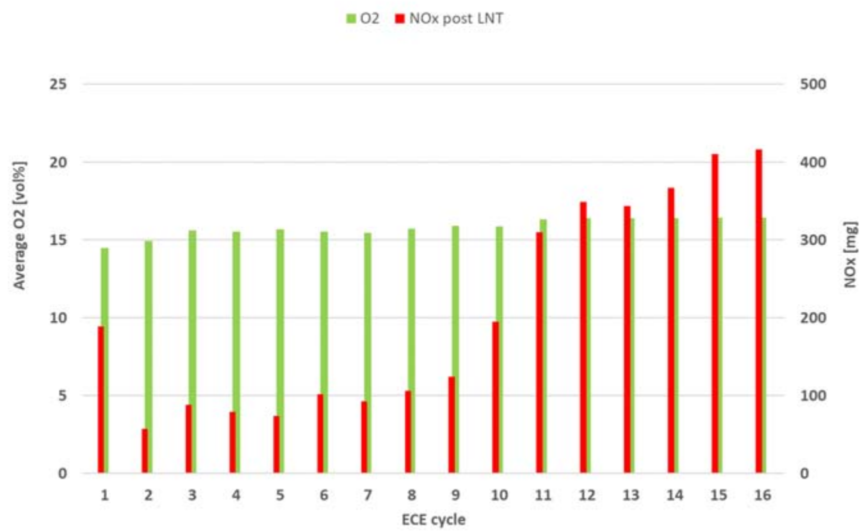


Figure 4-24: $NO_x$ emissions per ECE cycle with engine calibration 1 in a 4*UDC test with a cold start, performed on 03-09-2018. The test was driven on the chassis dynamometer with road load setting 3 and an ambient temperature of 23 °C. Preconditioning 3*EUDC test on 02-09-2018 with a warm start for which no measurement data are available.

*Analysis:*
The test results of the 4*UDC tests performed on the test track and on the chassis dynamometer (see Figure 4-12 to Figure 4-24) lead to the following analysis of the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 1:

*What is the influence of the ambient temperature on the $NO_x$ emissions of the engine?*
Above an ambient temperature of 20 °C, the measured $NO_x$ emission of the engine is initially 250 - 530 mg per ECE cycle, and at ambient temperatures of 13 to 14 °C the $NO_x$ emission of the engine is 620 - 900 mg per ECE cycle. With an ambient temperature of 18 °C, the $NO_x$ emission of the engine varies between 360 and 860 mg per ECE cycle. The $NO_x$ emission of the engine depends on the ambient temperature.

*What is the nature of $NO_x$ emission behaviour over time?*
In 4*UDC tests with a cold start at an ambient temperature above 20 °C there is a sudden increase in $NO_x$ emissions in the eighth, ninth, tenth or eleventh ECE cycle. At ambient temperatures below 20 °C, this jump in $NO_x$ emissions does not occur. This non-constant emission behaviour (the jump in $NO_x$ emission) was not observed in 4*UDC tests with a warm start. Furthermore, this $NO_x$ emission behaviour cannot be explained on the basis of the behaviour of the high-pressure EGR system and cannot be explained on the basis of these measurement data. For the second test vehicle with engine calibration 2, further investigation was done by examining the behaviour of the low-pressure EGR system.

*How does the LNT function in 4*UDC tests and how does it influence $NO_x$ emissions?*
A LNT stores $NO_x$ as long as the buffer capacity is not fully used. Whether there is $NO_x$ buffering, can be determined by measuring the $NO_x$ emissions before and after LNT, and calculating the difference. If there is no difference between the measured $NO_x$ emissions before and after LNT, no $NO_x$ is stored or converted into the LNT. The time for complete filling of the LNT is, among other things, dependent on the operating temperature, the volume of the LNT, and the $NO_x$ production of the engine, in practice this can sometimes take up to 30 minutes.
After buffering has taken place, the LNT can in principle be actively regenerated by adjusting the motor adjustment. A LNT regeneration usually takes 10-15 seconds.

In the 4*UDC tests carried out, NOx buffering almost always appears, but in none of the 4*UDC tests a LNT regeneration was performed. The small remaining effect may be due to inaccuracies in the measurements.
In most preconditioning tests the LNT is regenerated and this means that the $NO_x$ buffer of the LNT is relatively empty at the start of a 4*UDC test and $NO_x$ is stored during the 4*UDC tests. Buffering of $NO_x$ has taken place in many tests because the measured $NO_x$ emission before the LNT is higher than the measured $NO_x$ emission after the LNT. This buffering decreases in the course of the performed emission tests.

In 4*UDC tests, the LNT catalyst involves NOx buffering and the LNT is not regenerated.

*Is there a difference in $NO_x$ emissions in 4*UDC tests with a cold and warm start?*
With ambient temperatures above 20 °C, the $NO_x$ emission per ECE cycle in the first ECE cycles of a 4*UDC test with cold start appears to be substantially lower than in a 4*UDC test with a warm start (220-250 versus 450-500 mg per ECE cycle). When testing with a cold start, the $NO_x$ emission jumps to the level of a test with a warm start over time.

*How do the 4*UDC test results of the chassis dynamometer and test track relate?*
With the same ambient temperatures the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 1 in 4*UDC tests on the test track and on the dynamometer appears to be almost identical. The jump in $NO_x$ emissions occurring during the course of the test and the $NO_x$ emission levels are virtually the same.

*What changes in engine conditions occur during the jump in $NO_x$ emission?*
In Figure 4-14, a few parameters of the 4*UDC test of 19-04-2018 are shown. In the tenth ECE cycle, the air consumption of the engine per ECE cycle (MAF) appears to increase from 220 to 250 g, the high-pressure EGR valve partially closes and the $NO_x$ emission increases substantially. The jump in $NO_x$ emissions in the 4*UDC tests is primarily due to the change in the amount of EGR supplied in the engine.

Partial conclusion 5:
In UDC tests of the Suzuki Vitara Euro 6b diesel with engine calibration 1 and a cold engine start, and at an ambient temperature above 20 °C, it appears that over time the $NO_x$ emissions of the engine abruptly rise from 300 to 450 mg per ECE

cycle. The timing of this sudden increase in $NO_x$ emissions varies in the different tests, but no explanation for this has been found. The increase in $NO_x$ emissions is probably caused by the active control of the EGR system, which regulates the quantity of EGR. This is investigated further with the vehicle with engine calibration 2. These results are reported in chapter 5 of this report. Other engine parameters (such as the fuel injection strategy) may also influence the $NO_x$ emissions.
These have not been examined.
In UDC tests with a warm start at an ambient temperature above 20 °C, the $NO_x$ emissions are consistent at a level between 350-530 mg per ECE cycle and the EGR recirculation appears to be stable.

Partial conclusion 6:
With the same ambient temperatures and the same preconditioning cycles, the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 1 in 4*UDC tests on the test track and on the chassis dynamometer appears to be almost identical. From this it can be concluded that the emission behaviour of the vehicle on the chassis dynamometer and on the test track correspond and reproduce, and that the different types of measuring equipment produce similar results.

### *4.1.6 Emission behaviour at constant speeds with engine calibration 1*

*Background:*
Emissions can be influenced by many (engine) parameters. To gain a better insight into the emission behaviour of the Suzuki Vitara over time, a systematic test methodology is necessary. The systematic approach makes it possible to compare various tests.

*Execution:*
For a further exploration of the emission behaviour over time of the Suzuki Vitara with engine calibration 1, emission tests were carried out at virtually constant speeds.

*Result:*
The results of an initial test at a more or less constant speed of 120 km/h are shown in Figure 4-25. The $NO_x$ emissions vary between 5 and 40 mg/s and have a cyclical course. The LNT is repeatedly regenerated up to t = 470 s. The oxygen concentration in the exhaust gas is generally between 6 and 9 vol% in the periods where no LNT regenerations occur.

The results of a second test at a more or less constant speed of 120 km/h are shown in Figure 4-26. The $NO_x$ emissions increase slowly during the test from 10 to 90 mg/s and have a cyclical nature. Also during this test the $O_2$ concentration in the exhaust gas gradually increases, this indicates a slow decrease of operation of the EGR system. In this test there are no LNT regenerations. The oxygen concentration in the exhaust gas increases during the course of the test and is generally between 7 and 12 vol%.

The results of a test with various constant speeds are shown in Figure 4-27. After a speed is set, the $NO_x$ emission appears to stabilise quickly at a level that is fixed for that speed. In this test of more than 1.5 hours no LNT regenerations take place.

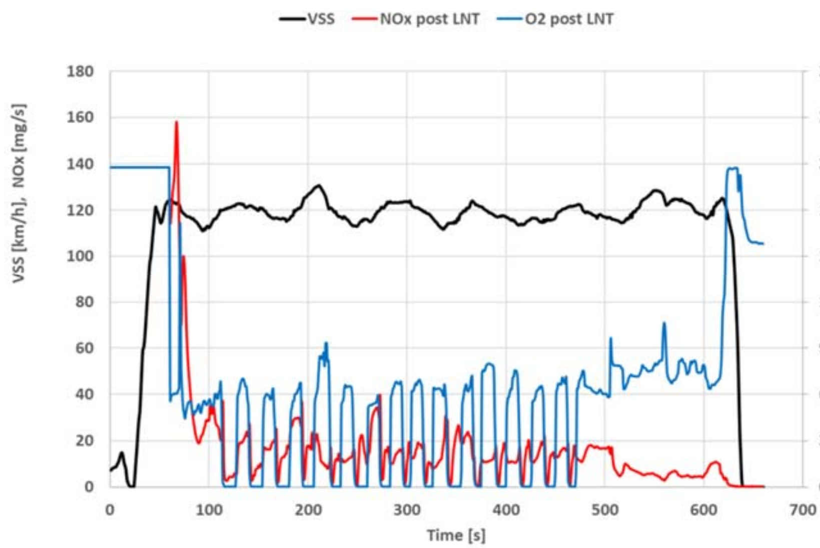


Figure 4-25: $NO_x$ and $O_2$ emissions at 120 km/h with engine calibration 1, performed on the test track on 10-04-2018 at an ambient temperature of 23 °C.

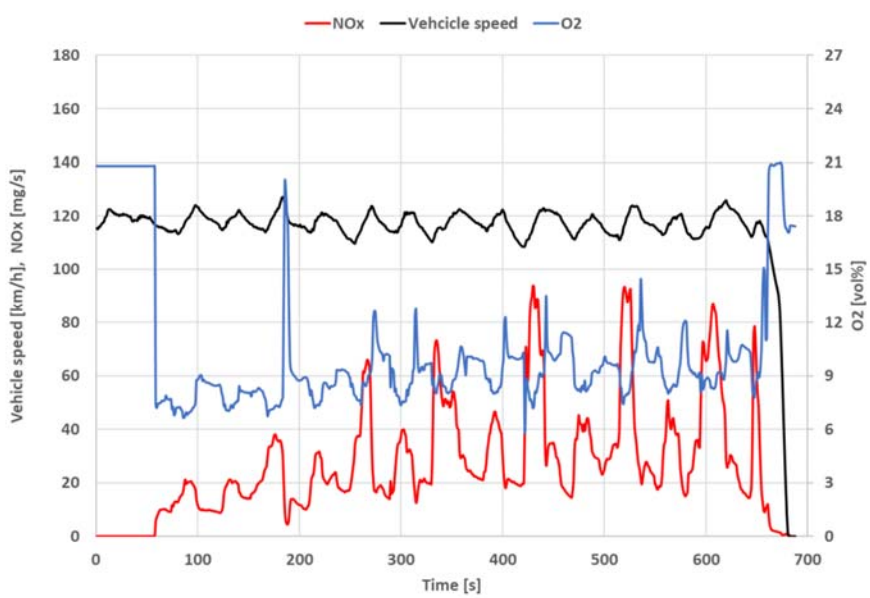


Figure 4-26: $NO_x$ and $O_2$ emissions at 120 km/h with engine calibration 1, performed on the test track on 06-12-2018 at an ambient temperature of 18-20 °C.

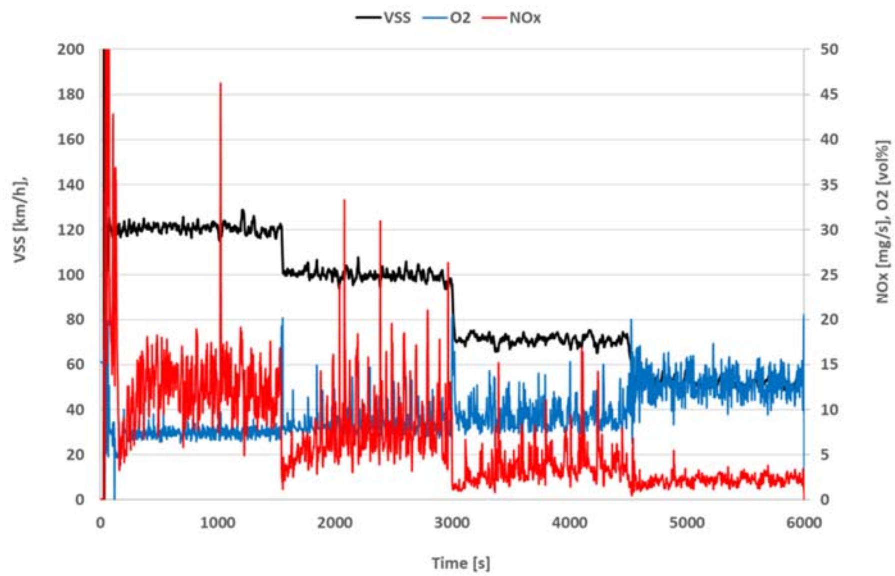


Figure 4-27: $NO_x$ and $O_2$ emissions at 120, 100, 70 and 50 km/h with engine calibration 1, performed on the test track on 31-05-2018 at an ambient temperature of 21-24 °C.

*Analysis:*
Tests conducted at constant speeds with engine calibration 1 involves non-reproducible engine emission behaviour. In a random test at 120 km/h, the LNT is regularly regenerated, while in another similar test, the LNT is not regenerated. In the same tests, the oxygen concentrations in the exhaust gas are also different, this indicates a different control of the EGR systems in the two tests. In another test of more than 1.5 hours at various speeds, the LNT was not regenerated once. No explanation has been found for this described emission behaviour.

*Partial conclusion 7:*
In tests at relatively constant speeds of the Suzuki Vitara with engine calibration 1, the emission behaviour is not reproducible; the $NO_x$ emissions can differ by more than a factor of 2. The measured oxygen concentrations in the exhaust gas vary, this indicates different controlling of the EGR systems. Sometimes there is a rise in $NO_x$ emissions as well. Furthermore, the regeneration behaviour of the LNT in this test cannot be explained.

### *4.1.7 Emission behaviour in RDE tests with engine calibration 1*

This section deals with partial objectives 7 of section 1.2, and the following research question in particular: What is the emission behaviour of the vehicle with engine calibration 1 in practice?

*Background:*
In addition to defined test cycles, Real Driving Emission (RDE) tests were performed in this study.

An RDE test is driven in the city, on the country road and on the motorway, lasts 90-120 minutes, and can differ from test to test because the traffic situations and weather conditions are not constant.

*Execution:*
An RDE route has been developed in the Lelystad area and this has been used to perform RDE tests.

*Result:*
The test results of two RDE tests are shown in Table 4-3.

Table 4-3: Emission results of RDE trips (87.2 km long), with engine calibration 1

| Date | Ambient temperature [°C] | Amount and total duration LNT regenerations in RDE tests. [s] | $CO_2$ [g/km] | $NO_x$ [mg/km] before LNT - after LNT* |
|---|---|---|---|---|
| 28-03-2018 | 13 | 11 - 99 | 137.5 | ----- - 691 |
| 06-06-2018 | 26 | 1 - 13 | 127.0 | 507 - 420 |

*Corrected for LNT regenerations

*Analysis:*
The $NO_x$ emission of the first RDE test carried out at an ambient temperature of 13 °C is 691 mg/km, and LNT regenerations were performed in this test for 99 seconds. In the RDE test at 26 °C, the $NO_x$ emission was 420 mg/km and LNT regenerations were carried out for 13 seconds. Since the $NO_x$ emission for the LNT is 507 mg/km, the $NO_x$ reduction that the LNT has achieved can be determined, this is 87 mg/km. Despite the longer total duration of the LNT regenerations in the RDE test at an ambient temperature of 13 °C, the $NO_x$ emission is substantially higher in this test than the $NO_x$ emission of the RDE test at an ambient temperature of 26 °C.

*Partial conclusion 8:*
In RDE tests with engine calibration 1, the $NO_x$ emission is dependent on the ambient temperature. Substantially higher $NO_x$ emissions were measured at an ambient temperature of 13 °C, than at an ambient temperature of 26 °C (691 versus 420 mg/km).

## 4.2 Verification chassis dynamometer emissions with engine calibration 1

The majority of this study was conducted on the test track of the RDW. These test results have been verified by repeating certain tests on the chassis dynamometer. The emissions in a type-approval test were also verified with measurements on the chassis dynamometer.

### *4.2.1 Verification emissions in an NEDC type-approval test*

This section deals with sub-objectives 1 of section 1.2, and the following research question in particular: To what extent does the tested vehicle meet the Euro 6 limit values?

*Background:*
A vehicle manufacturer must perform In Service Conformity (ISC) test programmes with a limited number of vehicles of a certain model by conducting NEDC type-approval tests. ISC programmes are intended to check whether vehicles meet the applicable emission requirements. Vehicles under five years old or with a maximum mileage of 100,000 km must meet the ISC requirements. The tested Suzuki Vitara Euro 6 diesel was named on 8 July 2015 and was tested on the chassis dynamometer in August 2018 at a mileage of 95,068 km.

*Execution:*
The vehicle has been tested on the chassis dynamometer in various test cycles, including the NEDC test cycle. The tests were performed with reference fuel (see Appendix A) and with various driving resistance curves. Prior to the NEDC tests, preconditioning tests were conducted on the chassis dynamometer (3*EUDC), after which the vehicle was conditioned for more than 6 hours in a room with a temperature of 23°C. The temperature of the chassis dynamometer room was 23°C during the tests.

*Result and analysis:*
Table 4-4 shows the Euro 6 limit values, the results of the NEDC type-approval test for this vehicle model (OEM Type approval) and the results of an NEDC test achieved through measurements on the chassis dynamometer in this study.
With the OEM road load (RL1) the NEDC $NO_x$ emission measured in this study is 64.9 - 83.1 mg/km, this is on average lower than the limit value of 80 mg/km but higher than the measured value of 37.7 mg/km in the type approval. The measured CO, THC + $NO_x$, PM, and PN emissions are lower than the Euro 6 limit values.
In addition, the $CO_2$ emissions of 1114.9 – 117.2 g/km is 8-11% higher than the value of 106 g/km measured by the manufacturer. This indicates a relatively higher engine load in the NEDC test of this study, which also causes the $NO_x$ emissions to be relatively higher than the measured values in the type-approval.

Table 4-4: Limit values and measured values in NEDC emission tests on the dynamometer, with driving resistance curve RL1 and a cold start with engine calibration 1.

| | $CO_2$ | CO | $NO_x$ | THC+$NO_x$ | PM | PN |
|---|---|---|---|---|---|---|
| | [g/km] | [mg/km] | [mg/km] | [mg/km] | [mg/km] | [#/km] |
| Euro 6 limit value | - | 500 | 80 | 170 | 4.5 | $6.0 * 10^{11}$ |
| NEDC RL 1* | - | 131.2 | 37.7 | 77.1 | 0.95 | $1.4 * 10^{11}$ |
| NEDC RL 1* | 124.2 | 238.5 | 82.9 | 137.9 | 0.15 | $4.9 * 10^{10}$ |
| NEDC RL 1 | 114.9 | 236.9 | 64.9 | 118.1 | 0.12 | $4.7 * 10^{10}$ |
| NEDC RL 1 | 117.2 | 207.5 | 83.1 | 129.0 | 0.27 | $5.1 * 10^{10}$ |
| NEDC RL 1 | 115.5 | 165.0 | 76.3 | 110.7 | - | $3.4 * 10^{10}$ |

*OEM Type approval **Start-stop not active

*Partial conclusion 9:*
In an NEDC test with engine calibration 1, which is carried out according to the type-approval test requirements on the chassis dynamometer, the $CO_2$ emissions are 114.9 – 117.2 g/km, which is 8 - 11% higher than the value specified by the manufacturer. The measured $NO_x$ emission is 64.9 - 83.1 and is on average 7% below the Euro 6 limit value. This test vehicle with engine calibration 1 meets the Euro 6 $NO_x$ limit values.

### 4.2.2 *Effects of the different driving resistance curves on the emissions*

This section deals with partial objectives 3 of section 1.2, and the following research question in particular: What is the effect of different driving resistance curves on exhaust emissions?

*Background:*
In a chassis dynamometer test, the total driving resistance and weight of a vehicle is simulated by the chassis dynamometer. In order to simulate this, the driving resistance curve of the test vehicle is first determined on the road and then these values are set on the chassis dynamometer.
It is generally known that driving resistance curves determined in accordance with the test procedure in the type-approval results in low values.
The driving resistance curves of the test vehicle are shown in section 5.1. There still appears to be a very substantial difference between the manufacturer's driving resistance curve and the established driving resistance curve on the RDW test track. Since this test programme has been carried out on both the chassis dynamometer and on the road, it is important to have a good overview of the differences in test results.

*Execution:*
The test vehicle was tested on the chassis dynamometer with the manufacturer's driving resistance curve (RL 1) and with three other driving resistance curves (RL2, RL3 and RL4).

*Result:*
The results of three NEDC tests with four different driving resistance curves on the dynamometer (RL 1, 2, 3, 4) are shown in Table 4-5. With an increase in driving resistance (RL 1 to RL 4), $CO_2$ emissions increase from 114.9 - 117.2 g/km to 151.9 g/km. The $NO_x$ emission varies between 64.9 and 167.6 mg/km and does not appear to be related to driving resistance.

Table 4-5: Measurements in NEDC emission tests with engine calibration 1 with different chassis dynamometer settings.

| | $CO_2$ | CO | $NO_x$ | THC+$NO_x$ | PM | PN |
|---|---|---|---|---|---|---|
| | [g/km] | [mg/km] | [mg/km] | [mg/km] | [mg/km] | [#/km] |
| Euro 6 limit value | - | 500 | 80 | 170 | 4.5 | $6.0 * 10^{11}$ |
| NEDC RL 1* | - | 131.2 | 37.7 | 77.1 | 0.95 | $1.4 * 10^{11}$ |
| NEDC RL 1* | 124.2 | 238.5 | 82.9 | 137.9 | 0.15 | $4.9 * 10^{10}$ |
| NEDC RL 1 | 114.9 | 236.9 | 64.9 | 118.1 | 0.12 | $4.7 * 10^{10}$ |
| NEDC RL 1 | 117.2 | 207.5 | 83.1 | 129.0 | 0.27 | $5.1 * 10^{10}$ |
| NEDC RL 1 | 115.5 | 165.0 | 76.3 | 110.7 | - | $3.4 * 10^{10}$ |
| NEDC RL 2 | 125.4 | 229.5 | 124.8 | 169.9 | 0.35 | $3.6 * 10^{10}$ |
| NEDC RL 2 | 122.2 | 176.7 | 80.5 | 125.0 | 0.18 | $6.3 * 10^{10}$ |
| NEDC RL 3 | 131.1 | 230.6 | 79.7 | 116.2 | - | $7.6 * 10^{10}$ |
| NEDC RL 4 | 151.9 | 318.0 | 167.6 | 216.9 | 0.20 | $1.2 * 10^{11}$ |

*OEM Type approval **Start-stop not active

*Partial conclusion 10:*
The results of NEDC tests on the chassis dynamometer with engine calibration 1 and different driving resistance curves, show that $CO_2$ emissions increase as the

driving resistance increases. An increase in the driving resistance results in an increase in the engine load, which, in this testing programme, leads to an increase in $CO_2$ emissions from 115 to 152 g/km (+ 32%). The $NO_x$ emission varies between 65 and 168 mg/km and has no direct relationship with the increasing driving resistance.

### 4.2.3 *Comparison of SEMS emission results with chassis dynamometer emission results*

This section deals with partial objectives 7 of section 1.2, and the following research question in particular: What is the quality of the SEMS in comparison with the measurement results of the chassis dynamometer?

*Background:*
The measuring systems of the chassis dynamometer differ from the mobile measuring system, SEMS. The legally prescribed method on the chassis dynamometer is conducted with a dilution tunnel with a constant flow rate and sampling with a continuous flow volume. This exhaust gas is collected in bags and subsequently analysed in exhaust gas analysers.
The SEMS is equipped with a $NO_x$-$O_2$ sensor in the exhaust and uses sensors that were fitted into the vehicle through the On Board Diagnostics (OBD) system. Both measuring systems have been used in this study.

*Execution:*
In a couple of chassis dynamometer tests a validation of the SEMS was conducted with the measuring equipment of the chassis dynamometer. Both measuring systems were operating simultaneously.

*Result:*
The $CO_2$ emissions of five different NEDC emission tests are shown in Figure 4-28. The measured SEMS $CO_2$ emissions are 118 – 134 g/km and are 0.6 to 4.4% higher than those measured with the legally prescribed chassis dynamometer method.
Figure 4-29 shows the corresponding $NO_x$ emissions. The measured SEMS $NO_x$ emissions are 63 - 182 mg/km after correction for the LNT regenerations, and deviate -2.3 to + 2.6% from the results that were measured with the legally prescribed chassis dynamometer method.

*Analysis:*
All measured SEMS $CO_2$ emissions are higher than the emissions from the chassis dynamometer and this deviation is fairly consistent. This indicates a slight systematic deviation from SEMS.

*Partial conclusion 11:*
The $CO_2$ and $NO_x$ emissions of the Suzuki Vitara with engine calibration 1, measured by the SEMS mobile measurement system, deviate slightly from the test results determined according to the legal measuring method on the chassis dynamometer. These deviations are 0.6 - 4.4% for $CO_2$ and -2.3 – 2.6% for $NO_x$. For the partial conclusions that relate to the $NO_x$ emissions in this study, the above-mentioned differences in measurement results from the SEMS system and the legal method on the chassis dynamometer do not have any consequences, since all these deviations are small.

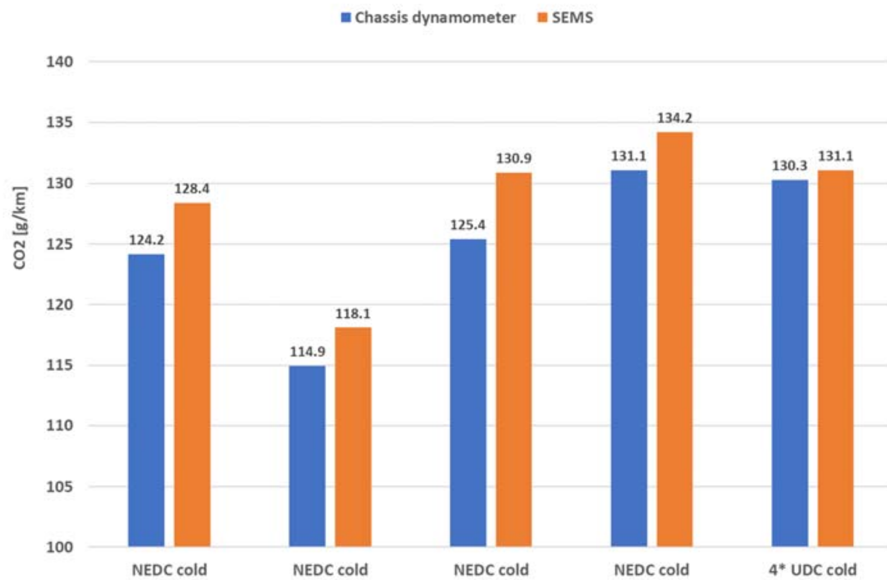


Figure 4-28: $CO_2$ emissions with engine calibration 1 from different chassis dynamometer tests measured with the chassis dynamometer equipment and with the SEMS.

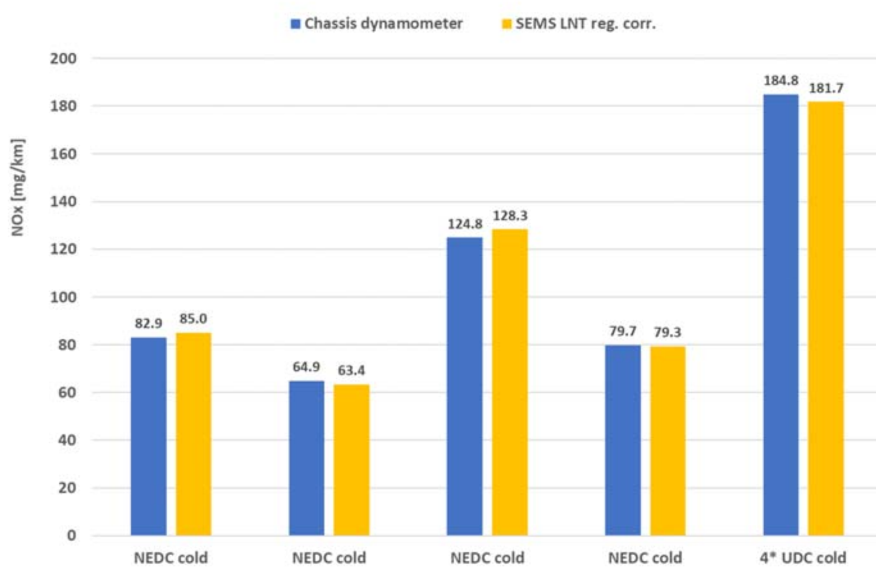


Figure 4-29: $NO_x$ emissions with engine calibration 1 from five chassis dynamometer tests measured with the dynamometer equipment and with the SEMS.

### *4.2.4 Effects LNT regenerations on the measured $NO_x$ emissions*

*Background:*
In section 4.1.3, during all 3*EUDC tests, at the time of the LNT regenerations, $NO_x$ peak emissions were measured by the $NO_x$-$O_2$ sensor of SEMS.
This phenomenon also occurs during the LNT regeneration in the NEDC test, see Figure 4-30. Research has been conducted into this phenomenon. It should be noted here that LNT regenerations represent only a very small part of the total operating time. However, the measured $NO_x$ peak emissions are very large and this means that the effect on the end results of a test can be substantial.

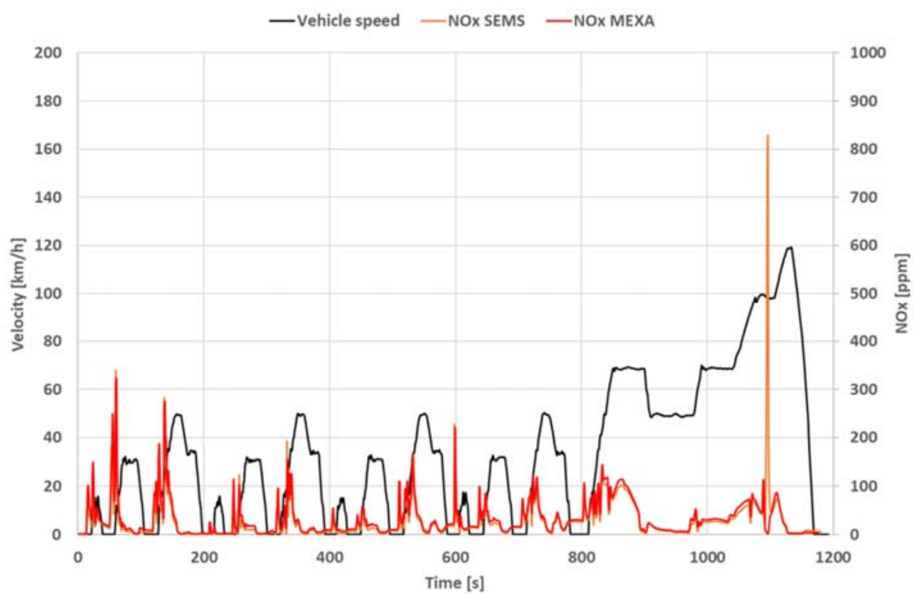


Figure 4-30: $NO_x$ emissions with engine calibration 1 of an NEDC test conducted on 15-08-2018 on the chassis dynamometer measured with the chassis dynamometer equipment (MEXA) and with SEMS.

*Execution:*
In an NEDC test performed on the chassis dynamometer, the emissions were measured both by the measuring equipment of the dynamometer (MEXA) and by SEMS. These test results were compared.

*Result and analysis:*
The $NO_x$ and $O_2$ concentrations at the time of a LNT regeneration, measured by the test equipment of the chassis dynamometer and SEMS, are shown in Figure 4-31. During a LNT regeneration, the oxygen concentration in the exhaust gas appears to be 0.00 vol%, the SEMS $NO_x$-$O_2$ sensor even measures a negative oxygen concentration. Now, during LNT regenerations, the $NO_x$ concentration measured by SEMS appears to have a peak value of more than 800 ppm, while the measured $NO_x$ concentration by the dynamometer analyser is 0 ppm.
The product specifications of the $NO_x$-$O_2$ sensor describe the operational conditions.

One of these conditions is that exhaust gas must contain at least a small amount of oxygen. Since the exhaust gas does not contain oxygen during a LNT regeneration, the measured values must be considered as "not valid" at those times. It now appears in Figure 4-31 that the $NO_x$ concentrations measured by the dynamometer (MEXA) at the time of a LNT regeneration are 0 ppm. Therefore, in this research project the $NO_x$ concentrations for LNT regenerations (measured $O_2$ <= 0.00 vol%) are set at 0 ppm.

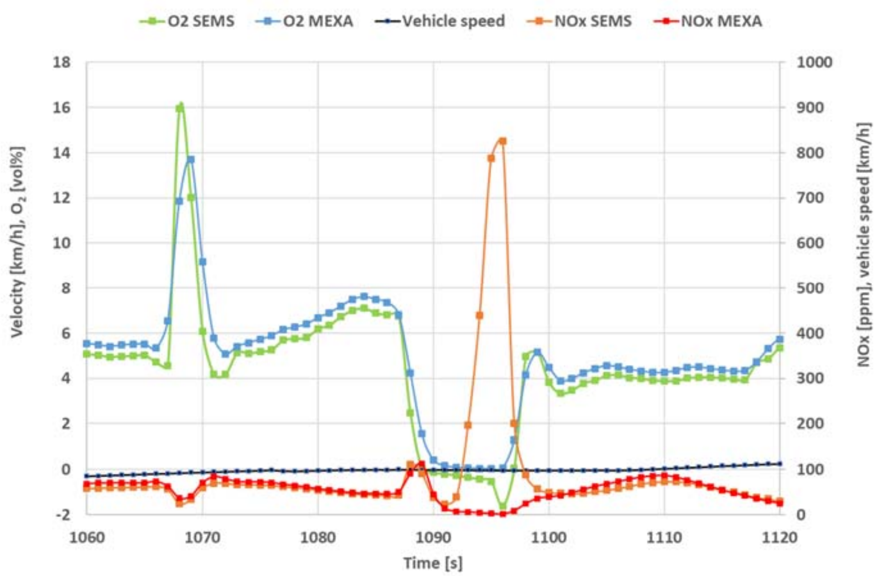


Figure 4-31: $NO_x$ emissions with engine calibration 1 of an NEDC test conducted on 15-08-2018 on the chassis dynamometer measured with the dynamometer equipment (MEXA) and with SEMS.

*Partial conclusion:*

$NO_x$ peak emissions were measured by the SEMS measurement system during LNT regenerations. Research has shown that during a LNT regeneration the exhaust gas does not contain oxygen. This oxygen-free exhaust gas does not appear to fall within the specification of the operating conditions of the $NO_x$-$O_2$ sensor, and the results are different. All measured values are therefore corrected on the basis of measured values provided by the $NO_x$ analyser of the chassis dynamometer under those conditions (oxygen-free exhaust gas).

# 5 Results for engine calibration 2

The results of the emissions study are presented thematically in this chapter with the aim of increasing the readability of this report. This means that the results of the tests that were conducted at different times, are compared to each other.
In some cases the results of previously conducted exploratory RDW emission studies are also included. This chapter describes the research performed on a Suzuki Vitara with engine calibration 2 ("update").

## 5.1 Determination of the driving resistance of the test vehicle on the test track

In this section, partial objective 2 of section 1.2 is discussed.

*Background:*
The emission tests that were conducted on the test track, were partially repeated on the chassis dynamometer. When testing on the chassis dynamometer, the driving resistance curve of the test vehicle needs to be set. If the driving resistance curve determined on the test track is set on the chassis dynamometer, the test conditions on the chassis dynamometer are able to approximate the situation on the test track. See also section 2.4 for more background information on the determination of the driving resistance curve.

The driving resistance curve has also been determined by the manufacturer prior to the type-approval test, this is indicated in Figure 5-2 and Table 5-1 by “OEM” or “RL 1”.

*Execution:*
In this study, the driving resistance curve of the test vehicle was determined in accordance with the legal procedure. This test is first carried out on the straight sections of the test track and is indicated by "TCL" in the results, see Figure 5-2. At the end of the test programme, the driving resistance curve of the test vehicle over the entire test track is determined (including the bends), see Figure 5-1.
The test track in Lelystad consists of two straight sections and two turns, see section 3.3.2. Sixteen road load tests were performed with six different starting points on the test track. This approach enables a good distribution of the different speeds across the track sections.

*Result:*
The TLC driving resistance curve is higher than the OEM curve, especially at lower speeds. Possible causes of this increased driving resistance are:
- A road surface with more driving resistance;
- A high vehicle weight;
- Less trace of the wheels in the bends,
- More friction in the powertrain of the test vehicle than in the vehicle used for the type-approval;
- Tires with a higher rolling resistance.

The results of these driving resistance curves (in red and green) are shown in Figure 5-2 and Table 5-1.

Through turns, the average driving resistance on the test track in Lelystad increases over the speed interval of 10-130 km/h by approximately 300-400 N. This means the driving resistance doubles at lower speeds.

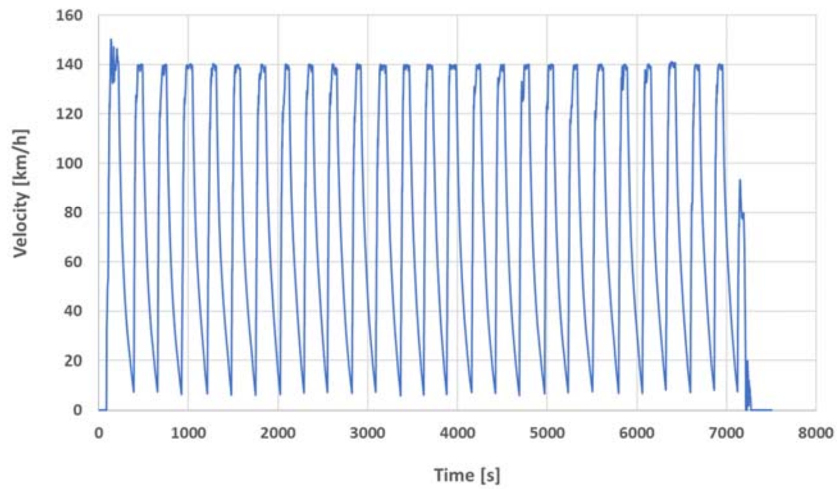


Figure 5-1: Road load testing of the Suzuki Vitara on the test track in Lelystad with six different starting points on the test track

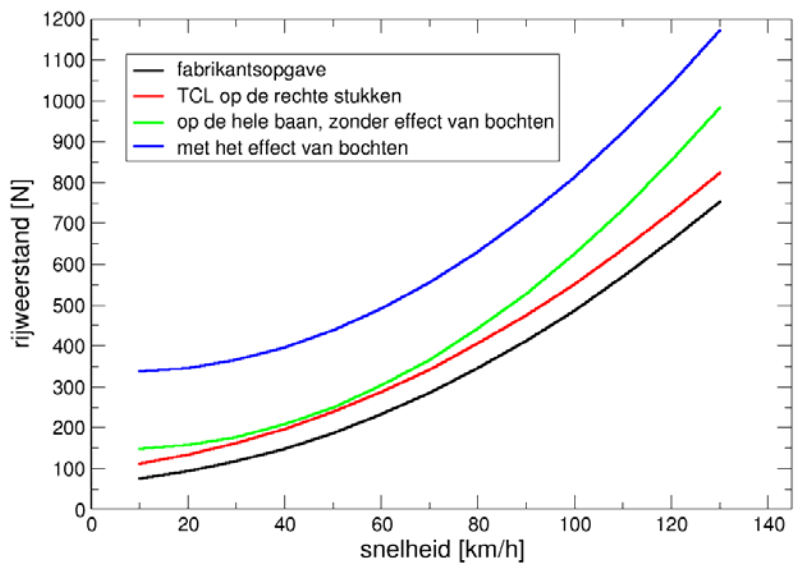


Figure 5-2: Driving resistance curves of the Suzuki Vitara under different conditions: black: according to the vehicle manufacturer, red: test track RDW Lelystad straight parts only, green: test track RDW without effect of turns, blue: test track of RDW including turns.

Table 5-1: Coefficients of the driving resistance curves of the Suzuki Vitara

| Source | Inertia | F0 | F1 | F2 |
|---|---|---|---|---|
| | [kg] | [N] | [N/km] | [N/km$^2$] |
| OEM (RL1) black | 1360 | 66.4 | 0.63 | 0.0358 |
| TCL (RL 2) red | 1422 | 99.1 | 1.03 | 0.0350 |
| TCL (RL 3) | 1422 | 150.0 | 1.03 | 0.0350 |
| TCL (RL 4) | 1422 | 220.0 | 1.03 | 0.0350 |
| TCL (RL 5) blue | 1414 | 340.0 | -0.79 | 0.0553 |

*Partial conclusion 12:*
The driving resistance curve of the test vehicle on the test track in Lelystad is roughly 1.5 to 5.2 times higher than the driving resistance curve determined by the manufacturer. The absolute difference in driving resistance force is 300 - 400 N over the speed range of 10-130 km/h. This difference is largely caused by the turns in the test track.

## 5.2 Study of on-road emissions on a test track and on public roads

This section will focus on the $NO_x$ emissions of the Suzuki Vitara with engine calibration 2.

The $NO_x$ emissions from this engine are regulated by four technologies or subsystems, as described in section 4.1.

### *5.2.1 Effects of ambient temperature on emissions*

This section deals with partial objective 9 of section 1.2, and the following research question in particular: To what extent does the ambient temperature influence the emission behaviour of the test vehicle?

*Background:*
In Europe, external temperatures can vary considerably during the calendar year. Since the external temperature is measured by the vehicle, the question is: to what extent does this affect the engine adjustment?

*Execution:*
To answer this question, NEDC tests with a cold start were performed on different days at different ambient temperatures. Prior to an NEDC test, an (adjusted) preconditioning test (3*EUDC) was carried out in all cases and in most cases the vehicle was conditioned indoors with a temperature of 25°C.

*Result:*
The emission results of the NEDC tests with engine calibration 2, that were conducted with different conditioning and external temperatures, are represented in Table 5-2 and Figure 5-3. The duration of the three LNT regenerations during the preconditioning tests are also mentioned.
The $NO_x$ emission at ambient temperatures of 13 to 23°C and previously performed with a standard preconditioning test (3*EUDC) is 200 to 293 mg/km, and appears to be related to the external temperature. The corresponding $CO_2$ emissions are the same in the three tests performed and are 149 g/km.

Table 5-2: NEDC test results on the test track with engine calibration 2 at different ambient temperatures.

| Date | Ambient temperature [°C]* | Duration of 3 LNT regenerations in precon. [s] | $CO_2$ [g/km] | $NO_x$ [mg/km] Pre LNT – Post LNT** |
|---|---|---|---|---|
| 6-11-2018 | 25 - 13 | 14 - 12 - 14 | 148.8 | 432 - 293 |
| 7-11-2018 | 25 - 17 | 0 - 4 - 12 | 148.9 | 284 – 266 |
| 18-4-2019 | 25 - 23 | 15 -10 - 11 | 149.1 | 325 – 200 |

* The first stated temperature is in the conditioning room and the test starts at this temperature. The second value is the average external temperature on the test track.
** SEMS measurement corrected in relation to LNT regeneration.

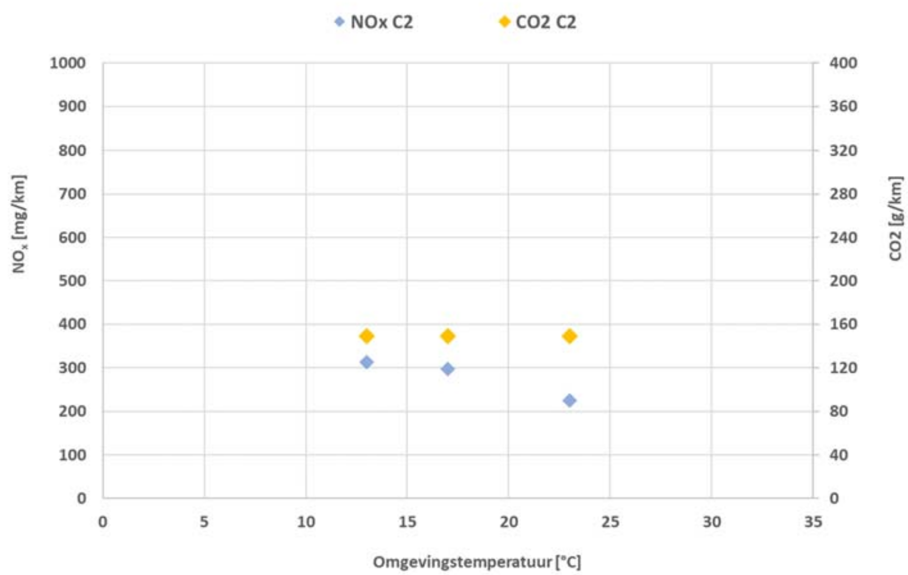


Figure 5-3: Corrected $NO_x$ and $CO_2$ emissions of NEDC tests with a cold start, measured on the test track with engine calibration 2 at different ambient temperatures

*Partial conclusion 13:*
The results of NEDC tests with a cold start of the Suzuki Vitara Euro 6b diesel with engine calibration 2 that were carried out on the test track at ambient temperatures of 13 - 23 °C, show that the $NO_x$ emission increases if the ambient temperatures drop. Furthermore, the number and duration of the LNT regenerations in the preconditioning test influences the $NO_x$ emissions in the NEDC test. With an ambient temperature above 20 °C and a standard preconditioning cycle (3*EUDC), a $NO_x$ emission of 200 mg/km is measured in an NEDC on the test track.

### 5.2.2 *Influences of the preconditioning test on the $NO_x$ emission in the emission test with engine calibration 2*

This section discusses partial objective 11 from section 1.2.

Given the spread of $NO_x$ emissions within NEDC tests, further research has been done into the condition of an LNT (the extent to which the $NO_x$ trap is filled) and the regeneration frequency.

*Background:*
A Lean $NO_x$ Trap (LNT) is capable of storing a certain amount of $NO_x$ during a couple of minutes. After a while the LNT is regenerated for a few seconds. The LNT is given a very rich air-fuel mixture during regeneration. The goal is then to convert the stored $NO_x$ into harmless components ($H_2O$, $CO_2$, $N_2$ and $O_2$). After the regeneration, the LNT is "empty" and is able to store $NO_x$ again.

*Result:*
A 3*EUDC preconditioning test is shown in Figure 5-4, in which the LNT is regenerated three times at speeds of 80-100 km/h. This happens at a more or less defined time in the EUDC test cycle. With every LNT regeneration (which takes place roughly every 400 s), an $O_2$ concentration of 0 vol% is briefly measured after the LNT. These LNT regenerations have the same pattern as the vehicle with engine calibration 1, see section 4.1.3.
A preconditioning cycle is shown in Figure 5-5, with two LNT regenerations that took place in the second and third EUDC.

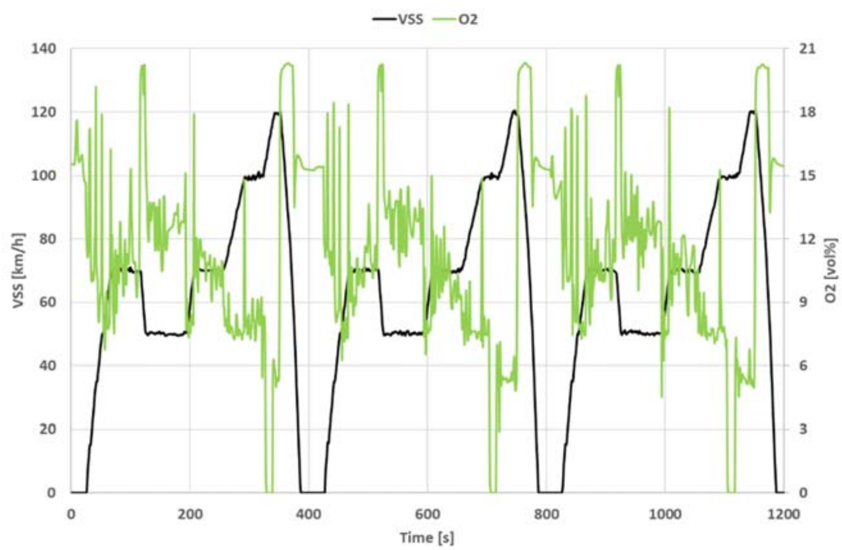


Figure 5-4: 3*EUDC test with engine calibration 2 and warm start, conducted on 24-10-2018 on the test track, at an ambient temperature of 17 °C. The LNT is regenerated three times for 11-13 seconds.

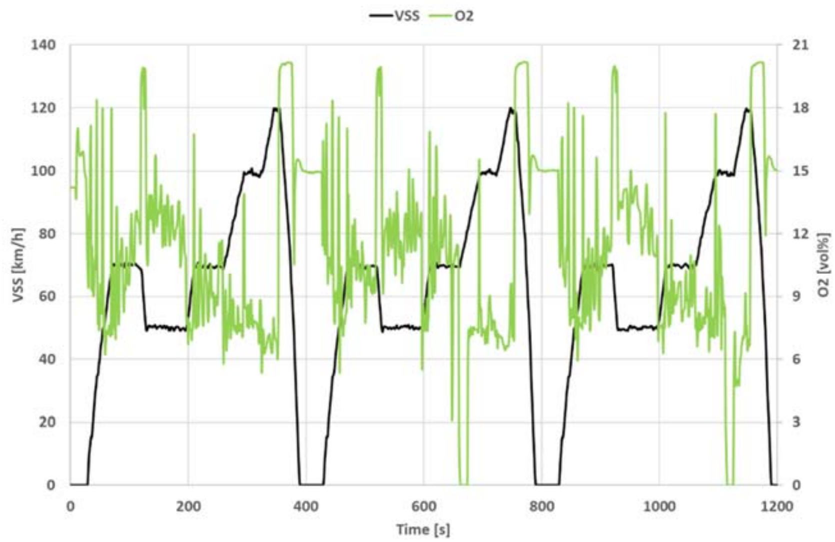


Figure 5-5: 3*EUDC test with engine calibration 2 and warm start, conducted on 18-09-2018 on the test track, at an ambient temperature of 26 °C. The LNT is regenerated twice for 12-14 seconds.

*Analysis:*
As with engine calibration 1, engine calibration 2 regenerates the LNT at certain points in the 3*EUDC preconditioning cycle. For unknown reasons, these LNT regenerations do not always take place in the 3*EUDC test cycles. This means that the condition of the LNT (the $NO_x$ filling degree of the $NO_x$ buffer) can be different at the start of an emission test.

*Partial conclusion 14:*
In 3*EUDC preconditioning tests with engine calibration 2, the LNT is regenerated three times. For unknown reasons, these LNT regenerations sometimes do not (fully) take place. This same regeneration behaviour has been observed with engine calibration 1, see 4.1.3. This means that the $NO_x$ buffer capacity varies at the start of an emission test and this influences the $NO_x$ emissions from the emission test.

### 5.2.3 *Effects on emissions when starting with a cold and warm engine with engine calibration 2.*

This section discusses sub-objectives 5 and 9 of section 1.2, and the following research questions in particular: To what extent does the thermal condition or coolant temperature when the engine is started affect the emission behaviour of the vehicle?

*Background:*
The effect of an engine's starting thermal condition on vehicle emissions can be mapped by starting identical tests with different coolant temperatures, a "cold" or "warm" engine, or cold and warm starts. Tests with a cold start, begin with a coolant temperature of 25 °C or the current ambient temperature and tests with a warm start begin with a coolant temperature of 80-85 °C.

*Execution:*
In this test programme, NEDC tests with cold and warm starts were carried out one after the other, on the test track. A standard preconditioning cycle (3*EUDC) was performed for the cold test and started in a preconditioning room with a temperature of 25 °C. The tests with a warm start were carried out immediately after the NEDC test with a cold start.

*Result:*
The emission results of NEDC tests with cold and warm starts on the test track with engine calibration 2 are shown in Table 5-3 and Figure 5-6.

Table 5-3: $NO_x$ and $CO_2$ emissions of NEDC tests with cold and warm starts on the test track with engine calibration 2

| Date | T environment [°C] | $CO_2$ [g/km] | $NO_x$ [mg/km] | $CO_2$ [g/km] | $NO_x$ [mg/km] | Location |
|---|---|---|---|---|---|---|
| | Cold and warm start | Cold start | | Warm start | | |
| 6-11-2018 | 13 and 13 | 150.2 | 312 | 142.4 | 210 | Test track |

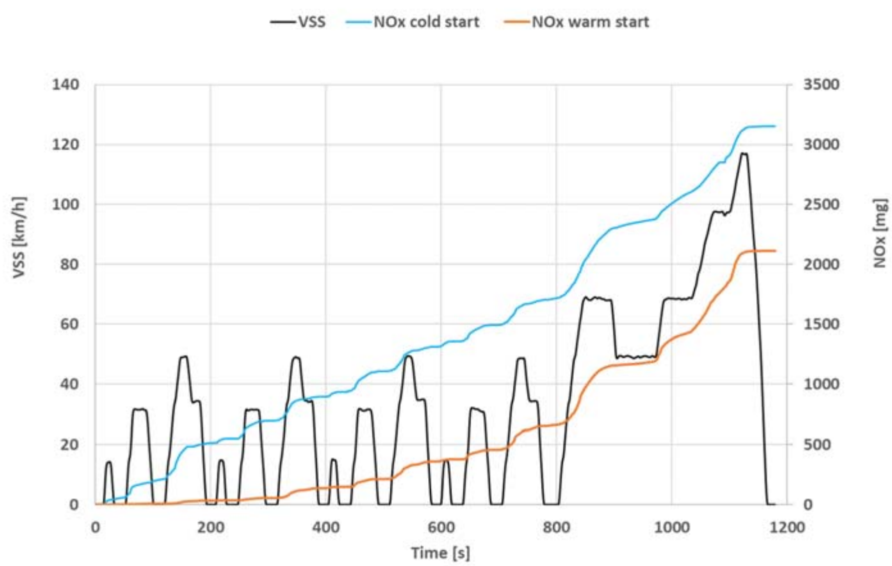


Figure 5-6: Cumulative $NO_x$ emissions from NEDC tests with a cold and warm start performed on 6-11-2018, at an ambient temperature of 13 °C on the test track with engine calibration 2. The cold one was started in a conditioning room with a temperature of 25 °C.

Analysis:
The NEDC $NO_x$ emissions with a cold start of engine calibration 2 are 312 mg/km at an ambient temperature of 13 °C, and are substantially higher than the $NO_x$ emissions of 200 mg/km of an NEDC test with a warm start. This difference mainly arises in the first 500 s of the NEDC test.

*Partial conclusion 15:*
The NEDC $NO_x$ emissions with a cold start of engine calibration 2 are substantially higher than the $NO_x$ emissions of an NEDC test with a warm start. This difference mainly arises in the first 500 s of the NEDC test.

### *5.2.4 Emission behaviour curve after a start of the engine with engine calibration 2.*
This section discusses partial objectives 5, 6 and 10 of section 1.2, and the following research question in particular: To what extent does the emission behaviour of the vehicle change after the engine has started?

*Background:*
It is generally known that an engine warms up after a cold start and that the emission behaviour of the vehicle changes during this warm-up phase. As part of Dieselgate, questions arose that relate to actively switching systems on or off over time, distance travelled or accumulated parameters after the engine has been started. In principle, these questions are not connected to the warming up of an engine, but may also play a role at the same time. Special attention has been paid to the behaviour of the EGR system and for this, the position signal of the low-pressure EGR valve has been measured.

*Execution:*
The warm-up behaviour of an engine with engine calibration 2 has been investigated with a UDC test cycle which again consists of several ECE cycles. UDC tests, such as those described in section 2.7, were used in this study amongst others. An UDC test consists of multiple ECE cycles. The ECE test cycle lasts for 195 seconds and is repeated 16 till 40 times.

Five UDC tests with a cold start were performed on the test track in Lelystad with engine calibration 2. The $NO_x$ emission in mg was calculated for each ECE cycle and is presented as bar graphs in Figure 5-7 to Figure 5-11.

To verify the emission tests on the test track, 4*UDC tests with a cold start were conducted on the chassis dynamometer with engine calibration 2. The results are shown in Figure 5-12 to Figure 5-13. SEMS emissions were also measured during these tests.

*Result:*
Both in the UDC test in Figure 5-7 and in the test of Figure 5-8 after the first ECE cycle, the $NO_x$ emission after the LNT through ECE cycle 13 is virtually stable. After ECE cycle 14 or 15, the $NO_x$ emission appears to roughly double after the LNT. The measured emissions before the LNT then change to a similar extent, this means that the increase in $NO_x$ emissions is caused by changes in the emission strategy of the engine.
UDC tests were carried out in Figure 5-9 to Figure 5-11. The position signal of the low-pressure EGR valve was also measured in the test of Figure 5-11. In these tests, the $NO_x$ emission rises from approximately ECE cycle 14 to a level that is almost twice as high as the original $NO_x$ level. The tests of Figure 5-10 and Figure 5-11 show that the low-pressure EGR valve is partially closed (from 1100-1200 mV to 800-900 mV) as the $NO_x$ emissions increase.
UDC tests were performed on the chassis dynamometer for verification in Figure 5-12 and Figure 5-13. In these UDC tests, there is an increase in $NO_x$ emissions of

more than a factor of three over time (after ECE cycle 12 or 13). In these tests the $NO_x$ emissions were measured by both the measuring equipment of the chassis dynamometer and by SEMS. These results are almost identical; the maximum measured differences of the $NO_x$ emissions are 5%.

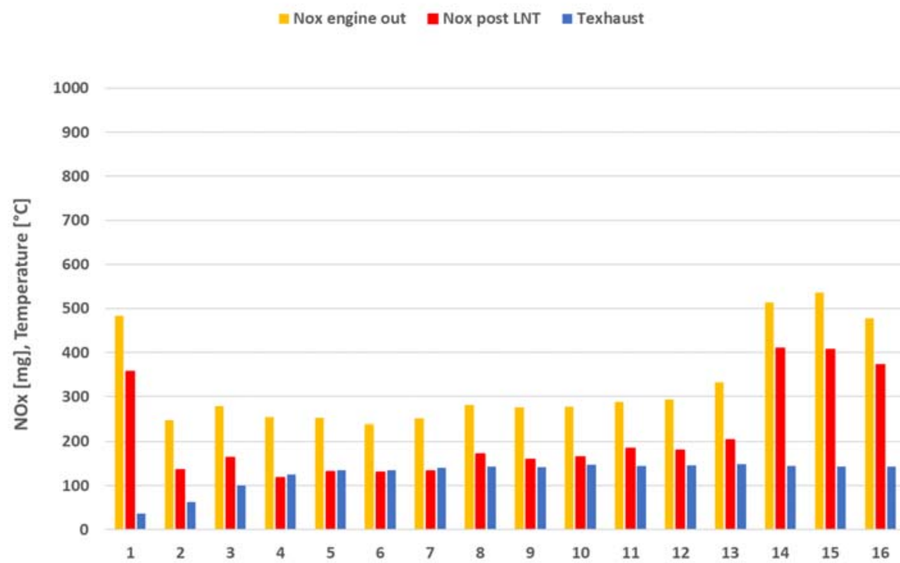


Figure 5-7: $NO_x$ emissions per ECE cycle with engine calibration 2 in a 4*UDC test with a cold start, start-stop not active, performed on 19-09-2018. The test was started in a conditioning room of 26 °C and was conducted on the test track of the RDW at an ambient temperature of 26 °C. Preconditioning 3*EUDC with a warm start, conducted on 18-09-2018, with three LNT regenerations of 14 seconds in the second EUDC cycle.

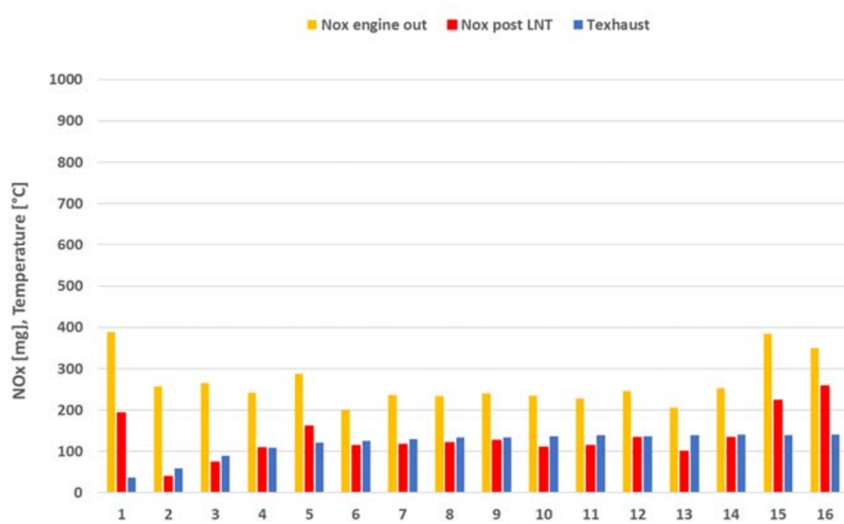


Figure 5-8: $NO_x$ emissions per ECE cycle with engine calibration 2 in a 4*UDC test with a cold start, start-stop active, performed on 24-10-2018. The test was started in a conditioning room of 26 °C and was conducted on the test track of the RDW at an ambient temperature of 18 °C. Preconditioning 3*EUDC test conducted on 18-10-2018, with a warm start for which no measurement data are available.

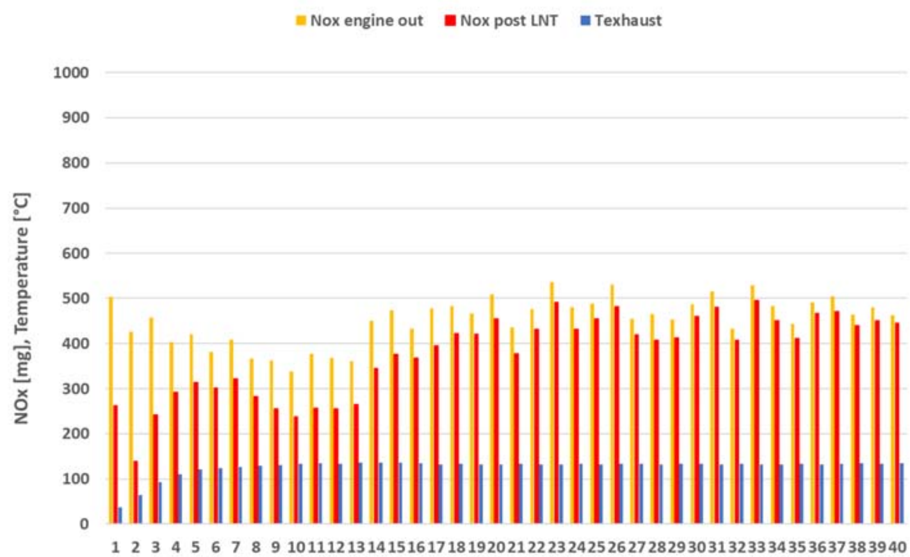


Figure 5-9: $NO_x$ emissions per ECE cycle with engine calibration 2 in a 10*UDC test with a cold start, start-stop active, performed on 8-11-2018. The test was started in a conditioning room of 26 °C and was conducted on the test track of the RDW at an ambient temperature of 13 °C. Preconditioning 3*EUDC with a warm start, conducted on 7-11-2018, with 2 LNT regenerations in the second and third EUDC cycles.

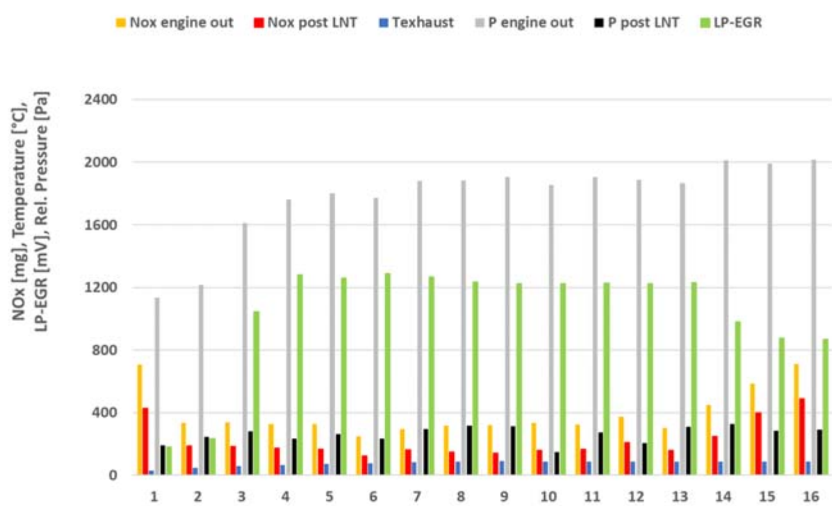


Figure 5-10: $NO_x$ emissions per ECE cycle with engine calibration 2 in a 10*UDC test with a cold start, start-stop active, performed on 23-04-2019. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW at an ambient temperature of 23 °C. Preconditioning 3*EUDC with a warm start, conducted on 18-04-2018, with 2 LNT regenerations in the second and third EUDC cycles.

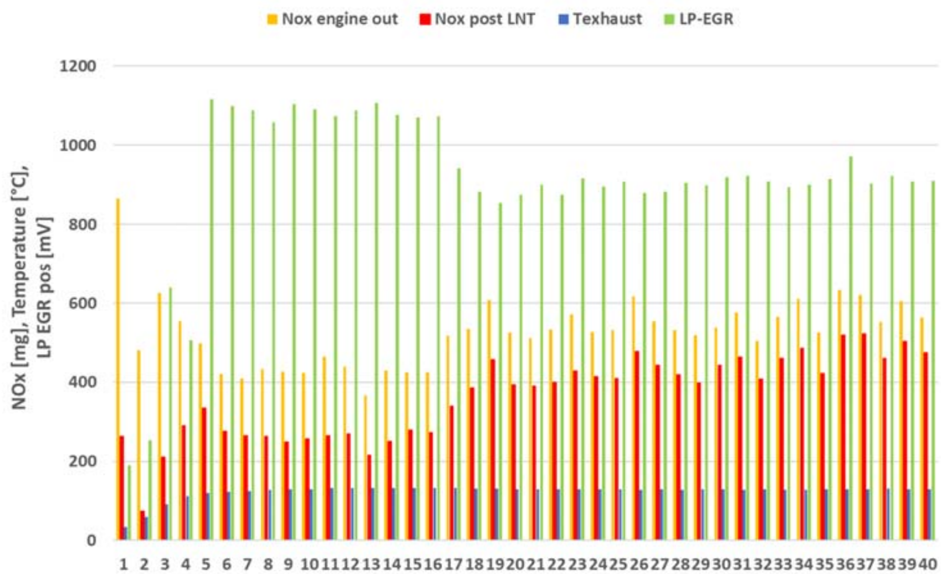


Figure 5-11: $NO_x$ emissions per ECE cycle with engine calibration 2 in a 10*UDC test with a cold start, start-stop active, performed on 07-05-2019. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW at an ambient temperature of 13 °C. Preconditioning 3*EUDC with a warm start, conducted on 02-05-2018 with 3 LNT regenerations.

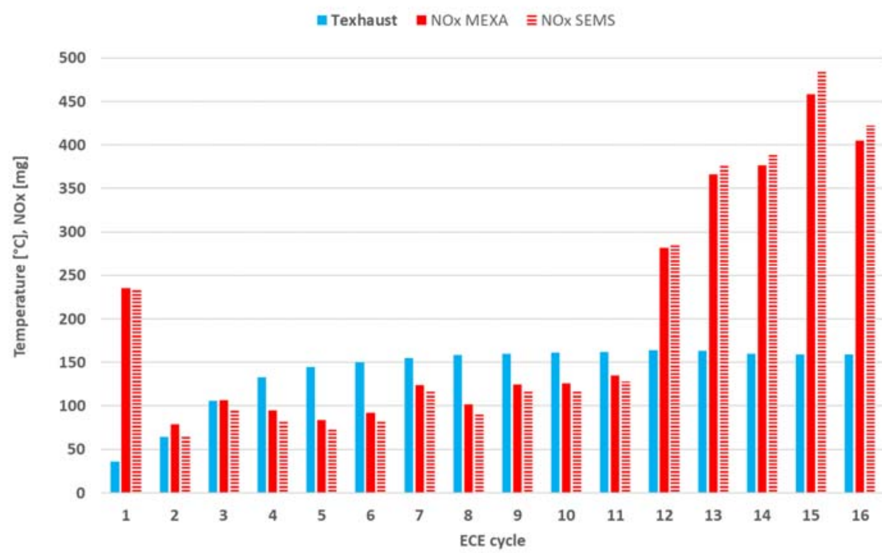


Figure 5-12: $NO_x$ measured with a chassis dynamometer analyser (MEXA) and with SEMS per ECE cycle with engine calibration 2 in a 4*UDC test with a cold start, start-stop active, performed on 11-12-2018. The test was conducted on the chassis dynamometer at an ambient temperature of 23 °C. Preconditioning 3*EUDC with a warm start, conducted on 10-12-2018, with 3 LNT regenerations in the second and third EUDC cycles.

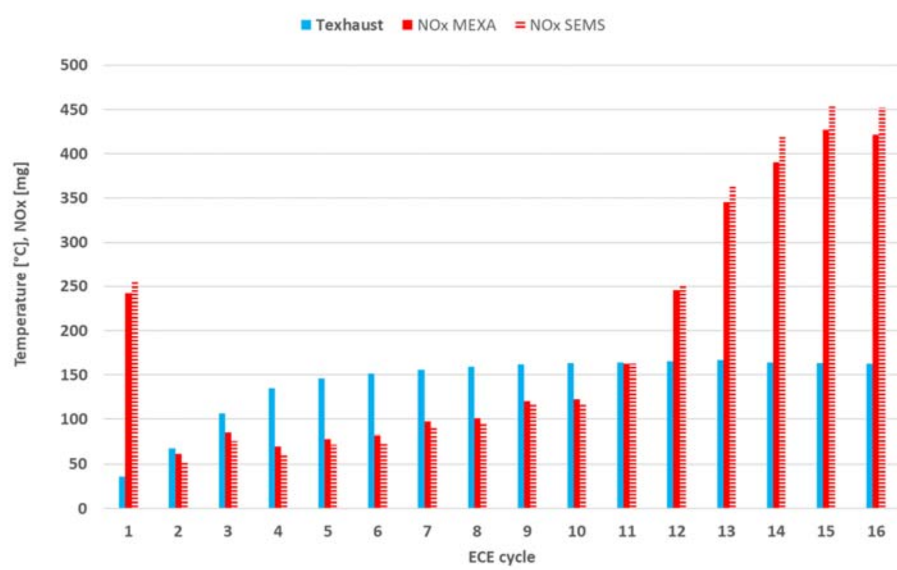


Figure 5-13: $NO_x$ measured with a chassis dynamometer analyser (MEXA) and with SEMS per ECE cycle with engine calibration 2 in a 4*UDC test with a cold start, start-stop active, performed on 12-12-2018. The test was conducted on the chassis dynamometer at an ambient temperature of 23 °C. Preconditioning 3*EUDC with a warm start, conducted on 11-12-2018, with 2 LNT regenerations in the second and third EUDC cycles.

*Analysis:*
In UDC tests with a cold start and engine calibration 2 performed at an ambient temperature above 20 °C, there is an increase in $NO_x$ emissions by a factor of three (from around 150 to 450 mg per ECE cycle) over time. This increase in $NO_x$ emissions usually takes place in or after the 14th ECE cycle. Simultaneously with the increase in $NO_x$ emissions, it has been established that the low-pressure EGR valve is partially closed.

*Partial conclusion 16:*
In UDC tests on the test track and the dynamometer of the Suzuki Vitara Euro 6b diesel with engine calibration 2 and a cold engine start, and at an ambient temperature above 20 °C, it appears that over time the $NO_x$ emissions of the vehicle abruptly rise from approximately 150 to 450 mg per ECE cycle. The time of this sudden rise in $NO_x$ emissions lies within the twelfth to fourteenth ECE cycle of a UDC test. The increase in $NO_x$ emissions is (partly) caused by the adjusted method of controlling the EGR system, which regulations the quantity of EGR. Other engine parameters (such as the fuel injection strategy) may also influence the $NO_x$ emissions. These have not been examined.

Partial conclusion 17:
With the same ambient temperatures and the same preconditioning cycles, the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 2 in 4*UDC tests on the test track and on the chassis dynamometer appears to be almost identical. From this it can be concluded that the emission behaviour of the vehicle on the test track can be reproduced on the chassis dynamometer, that the emission behaviour on the dynamometer and on the test track are almost identical, and that the different types of measuring equipment produce similar results.

### *5.2.5 Emission behaviour at constant speeds on the test track*

This section discusses partial objectives 5 and 10 of section 1.2, and the following research question in particular: To what extent does the emission behaviour of the vehicle change when driving at constant speeds?

*Background:*
Emissions can be influenced by many (engine) parameters. To gain a better insight into the emission behaviour of the Suzuki Vitara over time, a systematic test methodology is necessary. The systematic approach makes it possible to compare various tests.

*Execution:*
For a further exploration of the emission behaviour over time of the Suzuki Vitara with engine calibration 2, emission tests were carried out at virtually constant speeds.

*Result:*
The results of a test at a more or less constant speed of 115 km/h are shown in Figure 5-14. What is striking is the cyclical nature of the emissions. This cycle time corresponds to the lap time on the test track in the test. It also appears that the $NO_x$ emissions are not constant and are between 5 and 60 mg/s in this test.

This is caused by the very dynamic control of the low-pressure EGR system as well as the LNT regeneration and buffering of $NO_x$. It is also striking that the low-pressure EGR system suddenly appears to be closed at t = 1100 s, from this time on regeneration of the diesel particulate filter is carried out. This is terminated around t = 1550 s.
In Figure 5-15, a test has been done at a constant speed of 110 km/h with a cold engine start. Around t = 500 s, 12 km has been covered, the low-pressure EGR valve is partially closed and in the subsequent 1400 s the LNT is regenerated 3 times.
In Figure 5-16 emission measurements are carried out at various constant speeds, this test takes more than 1.5 hours. The diesel particulate filter is regenerated from t = 1200 s to t = 1600 s. In the subsequent 4400 s, the LNT is not regenerated once.
In Figure 5-17emission measurements are done at 130 km/h. At t = 400 s the oxygen concentration and the $NO_x$ emission for LNT in the exhaust gas increases rather suddenly, this indicates a reduced administration of EGR. 11 km has been driven from the start of the test. The LNT is regenerated three times from t = 400 s to t = 1200 s. No LNT regenerations occurred in the next 800 s.

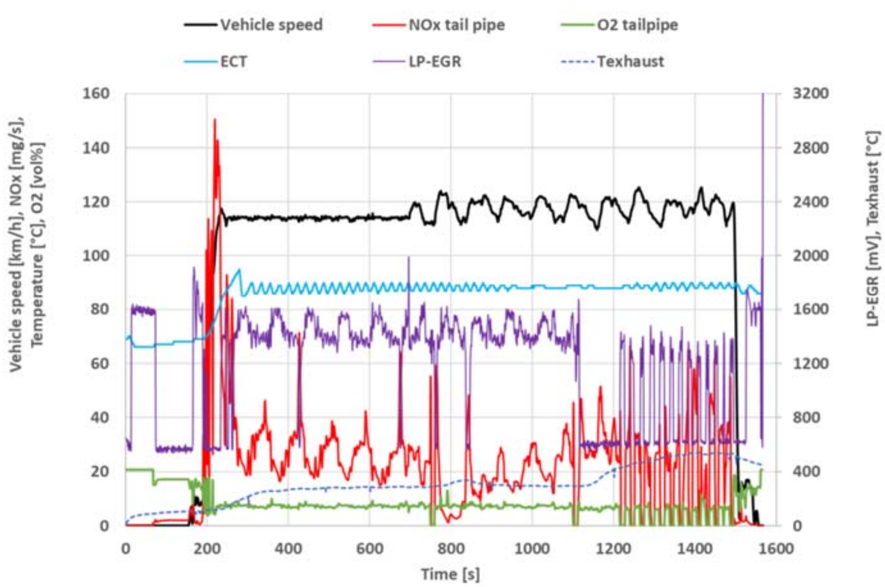


Figure 5-14: $NO_x$ and $O_2$ emissions measured at a constant speed of 115 - 120 km/h (warm start) with SEMS with engine calibration 2, performed on 16-04-2019. The test was conducted on the test track at an ambient temperature of 21 °C. The position signal of the low-pressure EGR valve is also shown. From t = 1100 - 1550 s the diesel particulate filter is regenerated.

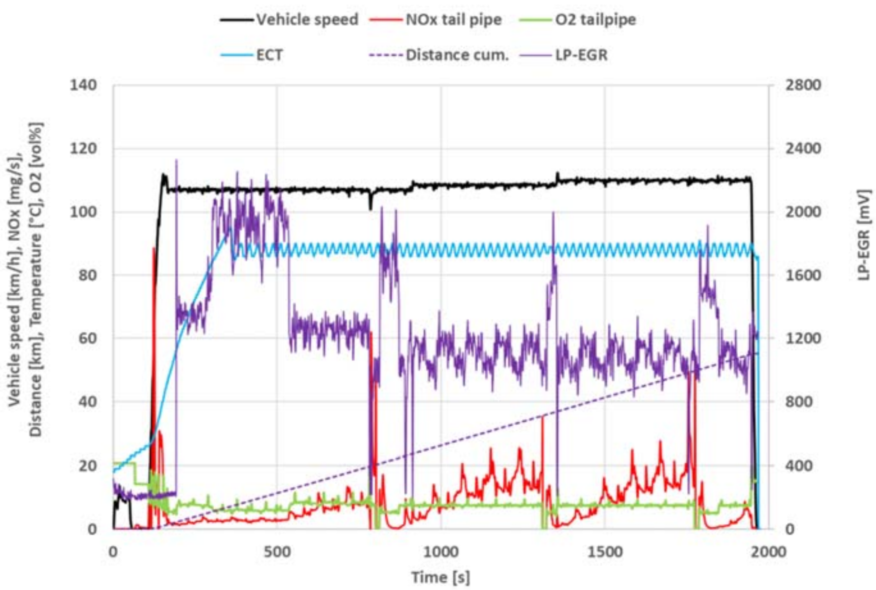


Figure 5-15: $NO_x$ and $O_2$ emissions measured with engine calibration 2 at a constant speed of 110 km/h (cold start) with SEMS, conducted on 17-04-2019. The test was conducted on the test track at an ambient temperature of 20 °C. The position signal of the low-pressure EGR valve is also shown.

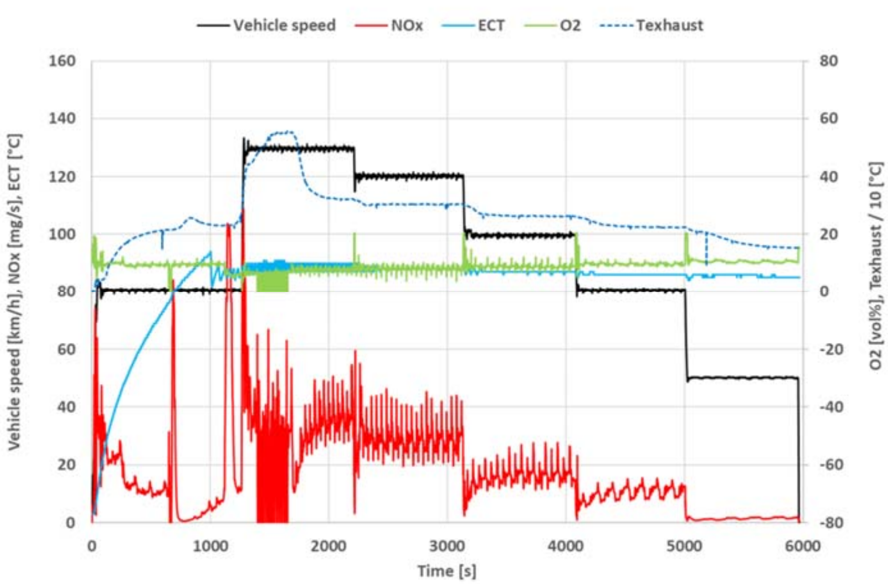


Figure 5-16: $NO_x$ and $O_2$ emissions measured with engine calibration 2, at a constant speed of 80, 130, 120, 100, 80 - 50 km/h (cold start) with SEMS with engine calibration 2, performed on 16-11-2018. The test was conducted on the test track at an ambient temperature of 6-10 °C. The diesel particulate filter is regenerated at 130 km/h.

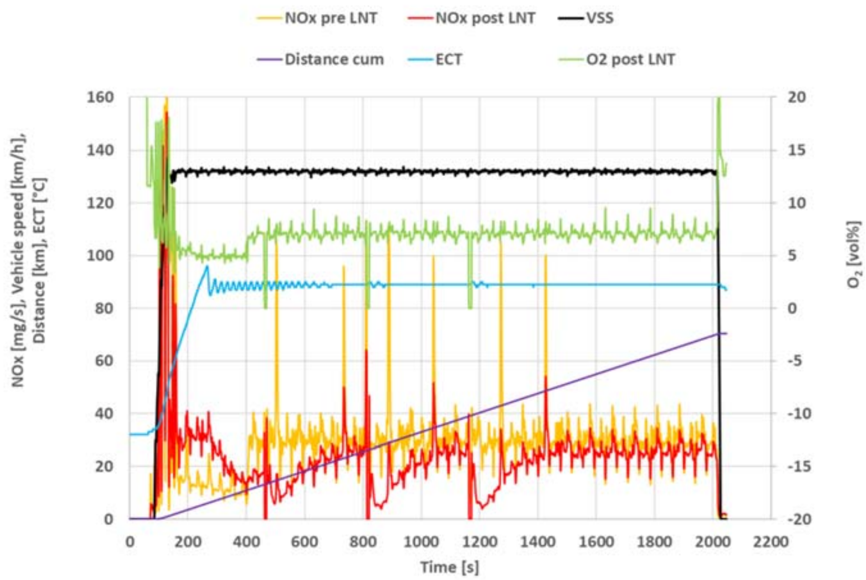


Figure 5-17: $NO_x$ and $O_2$ emissions measured with engine calibration 2 at a constant speed of 130 km/h after a cold start with SEMS, conducted on 31-08-2018. The test was conducted on the test track at an ambient temperature of 20-23 °C.

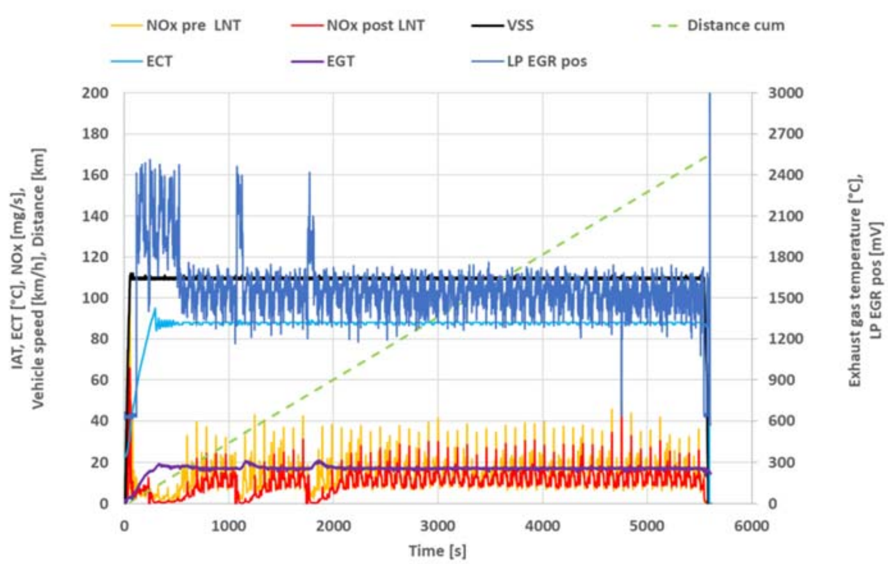


Figure 5-18: $NO_x$ and $O_2$ emissions measured at a constant speed of 110 km/h with SEMS and a vehicle with engine calibration 2, performed on 18-07-2019. The test was conducted on the test track at an ambient temperature of 26 °C. Preconditioning test 20 minutes @ 130 km/h.

*Analysis:*

There is strongly varying $NO_x$ emission behaviour of the engine in tests at constant speeds with engine calibration 2. In a random test at constant speed and with a cold start, the LNT is periodically regenerated for 1200 s after the start of a test.

After that, no more LNT regenerations take place. The actuator of the low-pressure EGR system also appears to be partially closed after a distance of 12-15 km, in which case less EGR is given to the engine.

To clarify the emission behaviour of the Suzuki Vitara with engine calibration 2, the $NO_x$ emissions from Figure 5-18 from the test at a constant speed of 110 km/h were stylised in Figure 5-19 by displaying the average $NO_x$ emissions before and after LNT over seven consecutive time periods (see Table 5-4). In the first 115 seconds the engine coolant heats up from 23 to 58 °C and then the valve of the low-pressure EGR system is opened, the $NO_x$ emissions decrease from 796 to 230 mg/km at that time. A moment later at t = 241 s the regeneration of the LNT takes place and then up to t = 510 s the average $NO_x$ emission is 43 mg/km. A distance of approximately 13.7 km has now been covered. At t = 510 s the low-pressure EGR valve is partially closed and thanks to the two LNT regenerations at t = 1060 and 1738 s the average $NO_x$ emission up to t = 2274 s is 272 - 293 mg/km. From t = 2275 to 5595 no LNT regenerations are performed and the average $NO_x$ emission is 446 mg/km.

Table 5-4: Average $NO_x$ emissions of 7 periods, measured at a constant speed of 110 km/h with SEMS and a vehicle with engine calibration 2, performed on 18-07-2019. The test was conducted on the test track at an ambient temperature of 26 °C.

| T1 | T2 | $NO_x$ 1 | $NO_x$ 2 | Distance | EGR pos ave | $NO_x$ 1 | $NO_x$ 2 |
|---|---|---|---|---|---|---|---|
| [s] | [s] | [mg] | [mg] | [km] | [mV] | [mg/km] | [mg/km] |
| 0 | 115 | 2994 | 1996 | 2.51 | 636 | 1193 | 796 |
| 116 | 240 | 693 | 814 | 3.54 | 2024 | 196 | 230 |
| 241 | 510 | 917 | 328 | 7.65 | 2047 | 120 | 43 |
| 511 | 1106 | 7347 | 4939 | 16.88 | 1595 | 435 | 293 |
| 1107 | 1802 | 8530 | 5354 | 19.71 | 1583 | 433 | 272 |
| 1803 | 2274 | 6354 | 3650 | 13.36 | 1541 | 475 | 273 |
| 2275 | 5595 | 46400 | 41615 | 93.25 | 1521 | 498 | 446 |

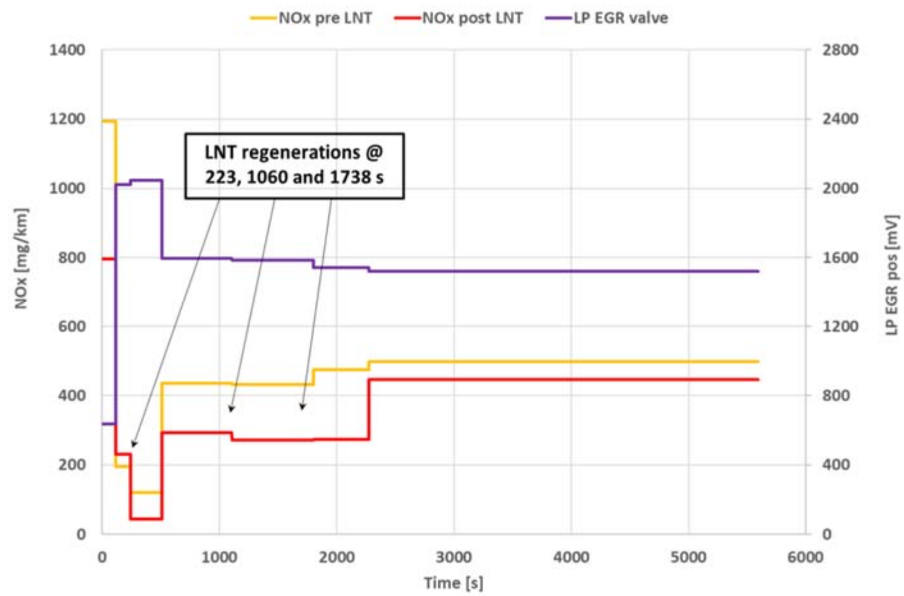


Figure 5-19: Average $NO_x$ emissions, measured at a constant speed of 110 km/h with SEMS and a vehicle with a cold engine start and engine calibration 2, performed on 18-07-2019. The test was conducted on the test track at an ambient temperature of 26°C. Preconditioning test 20 minutes @ 130 km/h.

*Partial conclusion 18:*
In tests with a cold start and constant speeds of 110 and 130 km/h there is a strongly varying $NO_x$ emission. After the cold start, the $NO_x$ emission is around 800 mg/km. This drops after 2 minutes by activating the low-pressure EGR system to 230 mg/km and then drops to 43 mg/km after the fourth minute due to a LNT regeneration. After the eighth minute the low-pressure EGR system partially closes and the average $NO_x$ emission rises to 272 - 293 mg/km and then rises to 446 mg/km when the LNT regenerations are no longer conducted from the 28th minute onwards. It is unclear why the LNT regenerations no longer take place then. This was not examined further.

### *5.2.6 Emission behaviour in RDE tests with engine calibration 2*

This section discusses partial objectives 7 of section 1.2, and the following research question in particular: What is the emission behaviour of the vehicle with engine calibration 2 in practice?

*Background:*
In this study, the emission behaviour of the Suzuki Vitara was systematically investigated in defined tests. In addition to defined test cycles, Real Driving Emission (RDE) tests were performed. An RDE test is conducted on public roads (city, country road and on motorway), lasts 90-120 minutes, and can differ from test to test because the traffic situations and weather conditions are not constant.

*Execution:*
An RDE route has been developed in the Lelystad area and this has been used to perform RDE tests.

*Result:*
The test results of four RDE tests are shown in Table 5.5.

Table 5-5: Emission results of RDE trips (87 km long), with engine calibration 2

| Date | Ambient temperature [°C] | Amount and total duration of LNT regenerations in RDE tests. [s] | $CO_2$ [g/km] | $NO_x$ [mg/km] before LNT - after LNT* |
|---|---|---|---|---|
| 01-11-2018 | 15.6 | 4 - 19 | 137.1 | ----- - 619 |
| 21-05-2019 | 15.4 | 10 - 41 | 129.3 | 617 - 399 |
| 28-05-2019 | 17.5 | 4 - 21 | 128.5 | 622 - 461 |
| 29-05-2019 | 18.7 | 9 - 63 | 135.5** | 662 - 494 |

*Corrected for LNT regenerations,
**With diesel particulate filter regeneration of 600 s.

*Analysis:*
Four RDE tests carried out on a fixed route near Lelystad with a relatively constant ambient temperature of 15 - 19 °C provide the following picture: The $CO_2$ emissions of the first and last RDE test are 136-137 g/km and are higher than the $CO_2$ emissions of 129 g/km in the second and third test. This can be explained as follows: In the first test of 01-11-2018, the motorway was used for a longer period of time at a speed of 130 km/h, in the other tests the maximum speed was 125-126 km/h. In the last RDE test, the diesel particulate filter has been regenerated and this causes additional $CO_2$ emission.
In these four RDE tests, the measured $NO_x$ emissions are 399 to 619 mg/km.
In these tests, the maximum speed driven on the motorway and the total duration of LNT regenerations per test appear to be determining factors for the total $NO_x$ emissions per RDE test. Therefore, the measured spread in $NO_x$ emissions of 399 - 619 mg/km can be interpreted as a normal phenomenon in RDE tests that is associated with the emission behaviour of this vehicle.

*Partial conclusion 19:*
In four RDE tests with engine calibration 2 and with average ambient temperatures of 15 to 19 °C, the measured $CO_2$ emissions are 129 - 137 g/km and the $NO_x$ emissions are 399 to 619 mg/km. This spread of emissions is normal and fits the nature of RDE tests that may have a certain variation in execution.

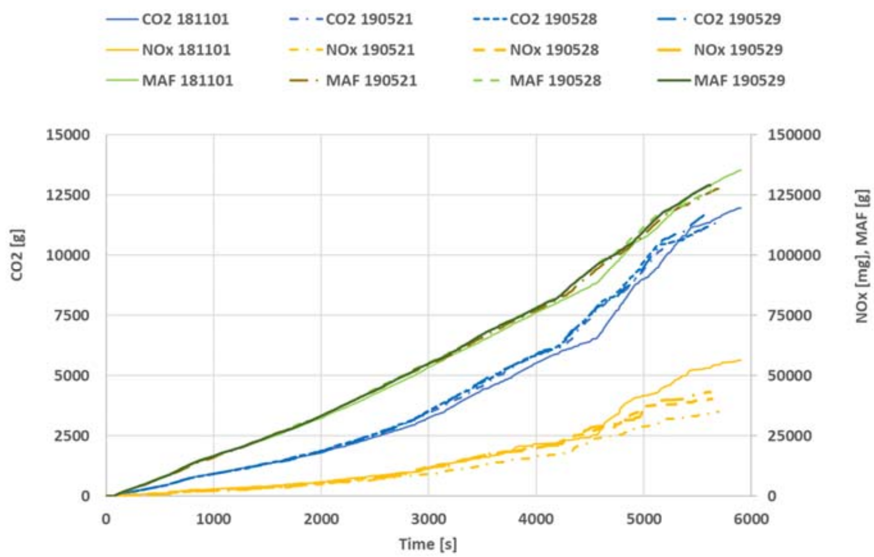


Figure 5-20: Cumulative $CO_2$ and $NO_x$ emissions measured in RDE tests with engine calibration 2.

## 5.3 Verification of the chassis dynamometer emission test results of the vehicle with engine calibration 2

This section deals with partial objectives 1 of section 1.2, and the following research question in particular: To what extent does the tested vehicle meet the Euro 6 limit values?

### 5.3.1 *Verification of emissions in an NEDC type-approval test*

This section deals with partial objectives 1 of section 1.2, and the following research question in particular: To what extent does the tested vehicle meet the Euro 6 limit values?

*Background:*
A vehicle manufacturer must perform In-Service Conformity (ISC) test programmes with a limited number of vehicles of a certain model by conducting NEDC type-approval tests. ISC programmes are intended to check whether vehicles meet the applicable emission requirements. Vehicles under five years old or with a maximum mileage of 100,000 km must meet the ISC requirements. The tested Suzuki Vitara Euro 6b diesel was named on 9 January 2016 and was tested on the chassis dynamometer in December 2018 at a mileage of 40,500 km.

*Execution:*
The vehicle with engine calibration 2 was tested on the chassis dynamometer in the NEDC test cycle. The tests were performed with reference fuel (see Appendix A). Prior to the NEDC tests, preconditioning tests were conducted on the chassis dynamometer (3*EUDC), after which the vehicle was conditioned for more than 6 hours in a room with a temperature of 23°C. The temperature of the chassis dynamometer room was 23°C during the tests.

*Result and analysis:*
Table 5-6 shows the Euro 6 limit values, the results of the NEDC type-approval test for this vehicle model (OEM Type approval) and the results of an NEDC test. With the OEM road load (RL1) the NEDC $NO_x$ emission measured is 63.5 mg/km, this is 21 % lower than the limit value but higher than the measured value of 37.7 mg/km in the type approval. In addition, the $CO_2$ emissions of 118.5 g/km is 12% higher than the value of 106 g/km measured by the manufacturer. Furthermore, this increased $CO_2$ emission of 118.5 g/km has been measured with any production vehicle and it is conceivable that this vehicle has a relatively high resistance in the total power train. The measured $CO_2$ emission of 118.5 g/km indicates a relatively higher engine load in the NEDC test of this study. This is probably also the cause of the relatively high $NO_x$ emissions that are higher than the measured values in the type approval.

Table 5-6: Limit values and measured values in NEDC cold start emissions tests with engine calibration 2.

| | $CO_2$ | CO | $NO_x$ | THC+NOx | PM | PN |
|---|---|---|---|---|---|---|
| | [g/km] | [mg/km] | [mg/km] | [mg/km] | [mg/km] | [#/km] |
| Euro 6 limit value | - | 500 | 80 | 170 | 4.5 | $6.0 * 10^{11}$ |
| NEDC RL 1* | - | 131.2 | 37.7 | 77.1 | 0.95 | $1.4 * 10^{11}$ |
| NEDC RL 1 | 118.5 | 362.1 | 63.5 | 119.6 | 0.17 | $3.0 * 10^{10}$ |

*OEM type approval

*Partial conclusion 20:*
In an NEDC test with engine calibration 2, which is carried out according to the type-approval test requirements on the chassis dynamometer, the $CO_2$ emissions are 118.5 g/km, which is 12% higher than the type-approval value specified by the manufacturer. The measured $NO_x$ emission is 63.5 mg/km, this is 21% below the Euro 6 limit value. This test vehicle with engine calibration 2 meets the Euro 6 $NO_x$ limit values.

### 5.3.2 *Effects of the different driving resistance curves on the emissions*

This section deals with sub-objectives 3 of section 1.2, and the following research question in particular: What is the effect of different driving resistance curves on exhaust emissions?

*Background:*
In a chassis dynamometer test, the total driving resistance and weight of a vehicle is simulated by the chassis dynamometer. In order to simulate this, the driving resistance curve of the test vehicle is first determined on the road and then these values are set on the chassis dynamometer.
It is generally known that driving resistance curves determined in accordance with the test procedure in the type-approval results in low values.
The driving resistance curves of the test vehicle are shown in section 3.5. There appears to be a very substantial difference between the manufacturer's driving resistance curve and the established driving resistance curve on the RDW test track. Since this test programme has been carried out on both the dynamometer and on the road, it is important to have a good overview of the possible differences in test results.

*Execution:*
The test vehicle was tested on the chassis dynamometer with the manufacturer's driving resistance curve (RL 1) as well as with a driving resistance curve (RL 5) determined on the test track in Lelystad.

*Result and analysis:*
The results of NEDC tests with different driving resistance curves, conducted on the chassis dynamometer, are shown in Table 5-7. With an increase in driving resistance (RL 1 to RL 5), $CO_2$ emissions increase from 118.5 to 175-178 g/km. At the same time, the $NO_x$ emissions also increase from 63.5 to 120-141 mg/km.

Table 5-7: Measurements in NEDC emission tests with engine calibration 2 with different chassis dynamometer settings.

| | $CO_2$ | CO | $NO_x$ | THC+NOx | PM | PN |
|---|---|---|---|---|---|---|
| | [g/km] | [mg/km] | [mg/km] | [mg/km] | [mg/km] | [#/km] |
| Euro 6 limit value | - | 500 | 80 | 170 | 4.5 | $6.0 * 10^{11}$ |
| NEDC RL 1 | 118.5 | 362.1 | 63.5 | 119.6 | 0.17 | $3.0 * 10^{10}$ |
| NEDC RL 5 | 174.9 | 325.0 | 141.1 | 169.6 | 0.20 | $5.1 * 10^{10}$ |
| NEDC RL 5 | 178.1 | 478.0 | 119.9 | 171.5 | 0.03 | $4.7 * 10^{10}$ |

*OEM type-approval

*Partial conclusion 21:*
The results of NEDC tests on the chassis dynamometer with engine calibration 2 and different driving resistance curves, show that $CO_2$ emissions increase as the driving resistance increases. An increase in the driving resistance (RL1 to RL5) results in an increase in the engine load, which leads to an increase in $CO_2$ emissions from 119 to 175-178 g/km (+ 48%). At the same time, the $NO_x$ emissions also increase from 64 to 120-141 mg/km (+ 87% to + 120%).

### 5.3.3 *Comparison of SEMS emission results with dynamometer emission results*

This section deals with sub-objectives 7 of section 1.2, and the following research question in particular: What is the quality of the SEMS in comparison with the measurement results of the chassis dynamometer?

*Background:*
The measuring systems of the chassis dynamometer differ from the mobile measuring system SEMS. The legally prescribed method on the dynamometer is conducted with a dilution tunnel with a constant flow rate and sampling with a continuous flow volume. This exhaust gas is collected in bags and subsequently analysed in exhaust gas analysers.
The SEMS is equipped with a $NO_x$-$O_2$ sensor in the exhaust and uses sensors that were fitted into the vehicle through the On Board Diagnostics (OBD) system. Both measuring systems have been used in this study.

*Execution:*
In a couple of dynamometer tests a validation of the SEMS was conducted with the measuring equipment of the dynamometer. Both measuring systems were operating simultaneously.

*Result:*
The cumulative $CO_2$ and $NO_x$ emissions from various emission tests measured with the dynamometer measuring equipment and SEMS are shown in Table 5-8, Figure 5-21 and Figure 5-22. The $CO_2$ emissions measured with SEMS are 6.6% to 9.0% higher than the $CO_2$ emissions measured on the chassis dynamometer. For $NO_x$, SEMS measures emissions that are 1.8% lower to 2.2% higher than measured with the chassis dynamometer.

Table 5-8: $CO_2$ and $NO_x$ emissions with engine calibration 2 of NEDC and UDC tests conducted on the dynamometer measured with the chassis dynamometer equipment and with SEMS.

| | Chassis dynamometer | SEMS | Chassis dynamometer | SEMS |
|---|---|---|---|---|
| | $CO_2$ | $CO_2$ | $NO_x$ | $NO_x$ |
| | [g/km] | [g/km] | [mg/km] | [mg/km] |
| NEDC cold | 118.5 | 126.3 | 63.5 | 62.4 |
| 4*UDC | 172.8 | 187.1 | 196.1 | 200.5 |
| 4*UDC | 169.5 | 184.8 | 187.2 | 190.5 |

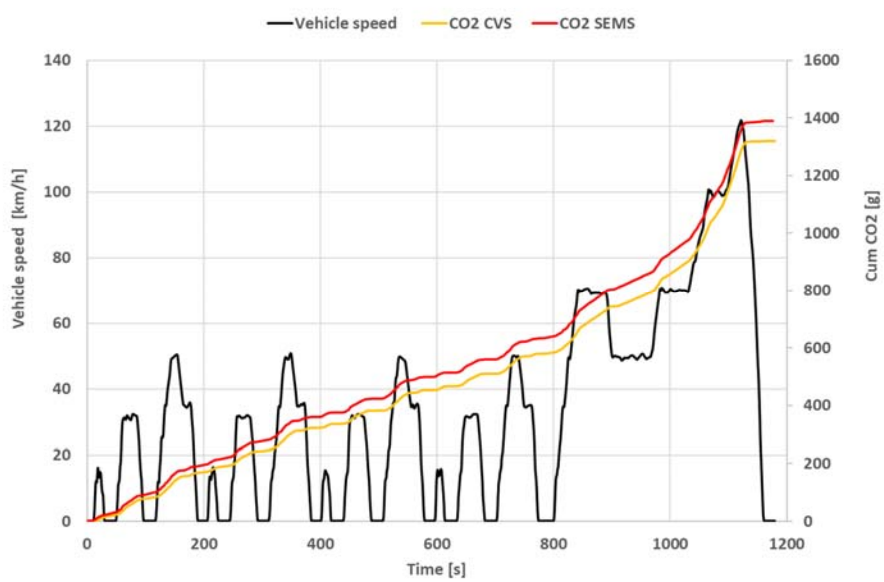


Figure 5-21: Cumulative $CO_2$ emissions with engine calibration 2 of an NEDC test conducted on 10-12-2018 on the chassis dynamometer, measured with the chassis dynamometer equipment and with SEMS.

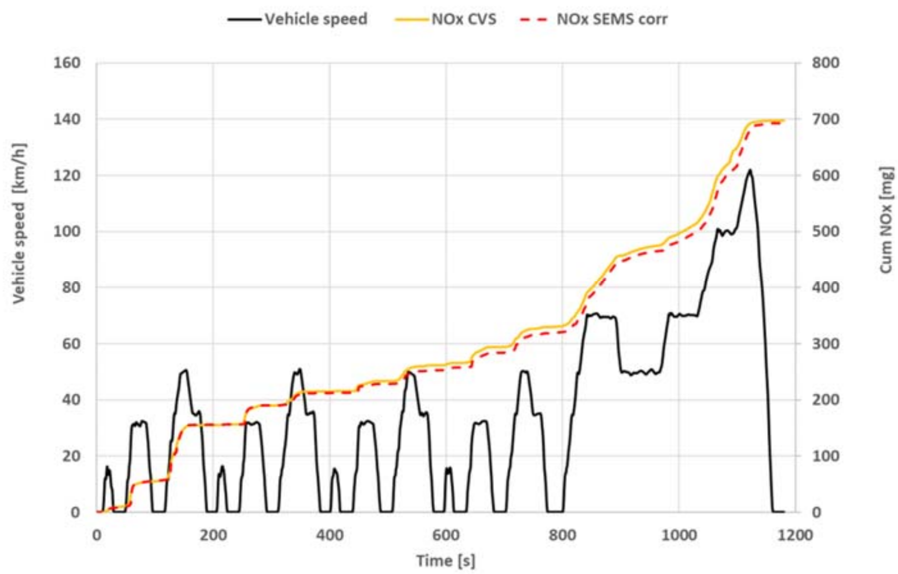


Figure 5-22: Cumulative $NO_x$ emissions with engine calibration 2 of an NEDC test conducted on 10-12-2018 on the chassis dynamometer measured with the dynamometer equipment and with SEMS.

*Partial conclusion 22:*
The $CO_2$ and $NO_x$ emissions of the Suzuki Vitara with engine calibration 2, measured by the SEMS mobile measurement system, deviate slightly from the test results determined according to the legal measuring method on the chassis dynamometer. These deviations are 6.6 to 9.0% for $CO_2$ and -2.3 to 2.6% for $NO_x$. For the partial conclusions that relate to the $NO_x$ emissions in this study, the above-mentioned differences in measurement results from the SEMS system and the legal method on the chassis dynamometer do not have any consequences, since all these deviations are small.

### 5.3.4 *Effects of exhaust gas pressure on measured $NO_x$ emissions*

*Background:*
The $NO_x$-$O_2$ sensors used in SEMS are mounted in the exhaust. A certain overpressure is present in the exhaust depending on the operating condition of the engine. The location of the $NO_x$-$O_2$ sensor also determines the exhaust back pressure that this sensor experiences. The question of what influence the occurring overpressure at the location of a $NO_x$-$O_2$ sensor has on the measured $NO_x$ concentration has been investigated further. The reason for this research is the structural difference between the $NO_x$ measurement before the LNT and after LNT. The difference does not seem to be dependent on the circumstances and does not vary with the degree of buffering. The difference temporarily increases after regeneration. The conditions before and after the LNT, pressure, temperature, and composition of the exhaust gas, etc. can influence the sensor. The pressure is one of these factors that is known to have an influence. Because the first sensor is before the LNT and the diesel particulate filter, the pressure can be substantially higher than the outside pressure.

*Execution:*
The Suzuki Vitara with engine calibration 2 is equipped with two pressure sensors that have measured the pressures near the two mounted $NO_x$-$O_2$ sensors (before and after the LNT). A number of tests were then carried out on the test track and both the occurrence of $NO_x$ concentrations and the pressures were measured. The pressure dependence of the $NO_x$-$O_2$ sensor was also determined in a separate measurement setup. This is done by giving the sensor a specific calibration gas and subsequently varying the pressure in the measuring chamber of the $NO_x$-$O_2$ sensor.

*Result:*
The measured pressures before and after LNT of a NEDC test are shown in Figure 5-23. Before the LNT the measured overpressures are 0 - 13 kPa and after the LNT these overpressures are 0 - 4 kPa. The pressure is higher, especially at high power and with higher exhaust gas flow. These are also the circumstances in which more $NO_x$ is produced.
In Figure 5-24 the pressure measurement is compared to the mass flow.
The mass flow seems to show more of the dynamics than the slower pressure sensors. In Figure 5-25 the influence is shown of the overpressure on the measured $NO_x$ concentration of a certain calibration gas.

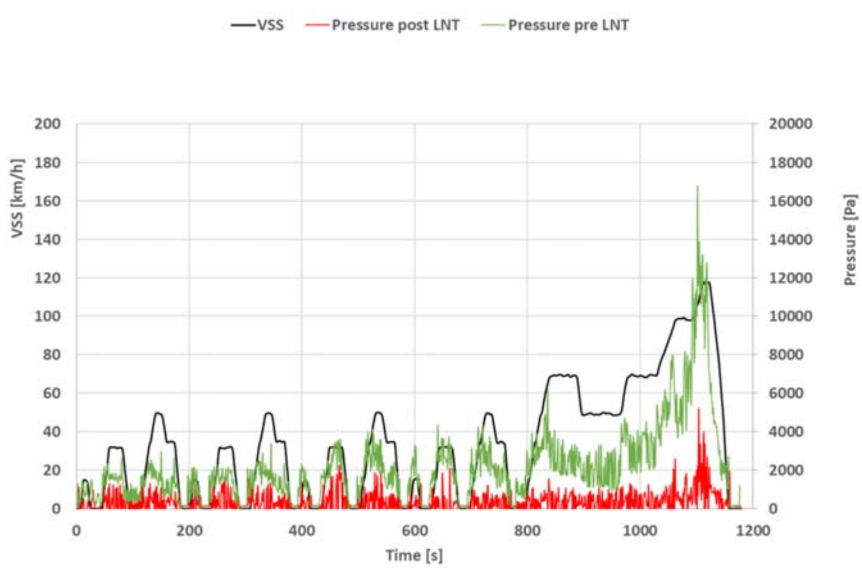


Figure 5-23: Measured relative pressures before and after diesel particulate filter/LNT with engine calibration 2 of an NEDC test performed on 18-04-2019 on the test track.

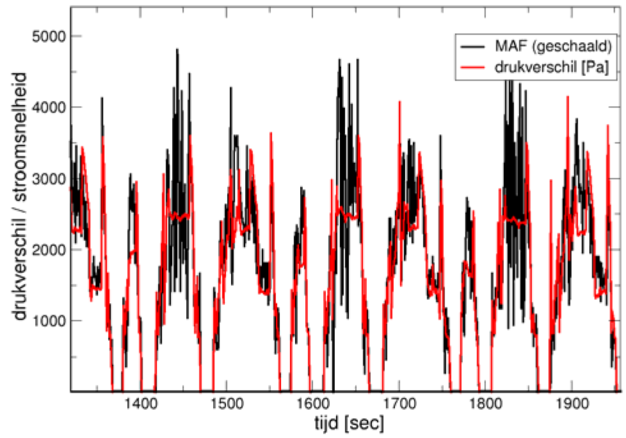


Figure 5-24: The measured pressure difference is correlated to the mass of the exhaust gas stream. This results in the pressures following the outlet flow, but that the faster variations are not all picked up.

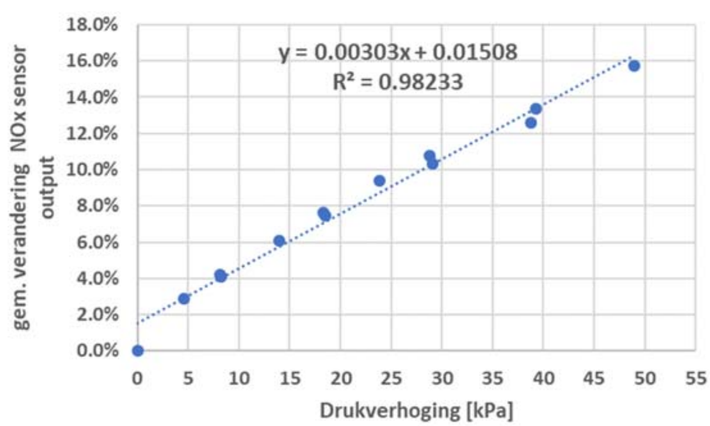


Figure 5-25: Influence of a stationary pressure on the $NO_x$ measurement value of the applied $NO_x$-$O_2$ sensor of the SEMS measurement system

*Analysis:*
The measured overpressures at the $NO_x$-$O_2$ sensor after the LNT are usually 0 - 2 kPa, only at speeds above 100 km/h this overpressure is at most 4 kPa. With these measured overpressures, the maximum deviation of the measured $NO_x$ concentration of the $NO_x$-$O_2$ sensor is 2.7%, with an uncertainty of the same order, due to the uncertainty in the current pressure measurement.
The measured overpressures at the $NO_x$-$O_2$ sensor after the LNT are usually 0 - 6 kPa, only at speeds above 100 km/h this overpressure is at most 14 kPa. With these measured overpressures, the deviation from the measured $NO_x$ concentration of the $NO_x$-$O_2$ sensor is a maximum of 5.8%.

*Partial conclusion 23:*
The measured overpressure to which the $NO_x$-$O_2$ sensor, which is mounted after the LNT, is exposed in this test program is small (maximum 4 kPa) and the corresponding correction of the measured NOx concentration is 1.5 - 2.7%, based on the pressure measurements.
The occuring pressures at the two $NO_x$-$O_2$ sensors do explain part of the remaining constant differences in $NO_x$ emissions as measured before and after the LNT.
The pressure sensor may not be able to fully follow the peak values.
The measurements after the LNT are at lower overpressures and were validated against the laboratory results. The measurement before the LNT should be considered as more of an indication, with greater measurement inaccuracy, due to the measurement conditions before the LNT.

# 6 Comparing the emissions of engine calibrations 1 and 2

*What are the similarities and differences in emission behaviour of vehicles with engine calibration 1 and 2?*

In chapter 4 and chapter 5 the results of various emission tests of the Suzuki Vitara with engine calibration 1 and engine calibration 2 are shown. Comparison of the test results of the two engine calibrations yields the following:

- In NEDC tests on the chassis dynamometer, the $NO_x$ limit value of 80 mg/km is met for both engine calibrations and 1 regeneration of the LNT takes place. In the case of an increased driving resistance curve, a similar increase in $NO_x$ emissions is measured for both engine calibrations.
- In NEDC tests on the test track at an ambient temperature above 20°C, the $NO_x$ limit value of 80 mg/km is not met for both engine calibrations. The $NO_x$ emission is then approximately 150 - 200 mg/km for both engine calibrations.
- In NEDC tests on the test track, the $NO_x$ emission for both engine calibrations is dependent on the ambient temperatures and the $NO_x$ emission increases below 20 °C, see Figure 6-1.

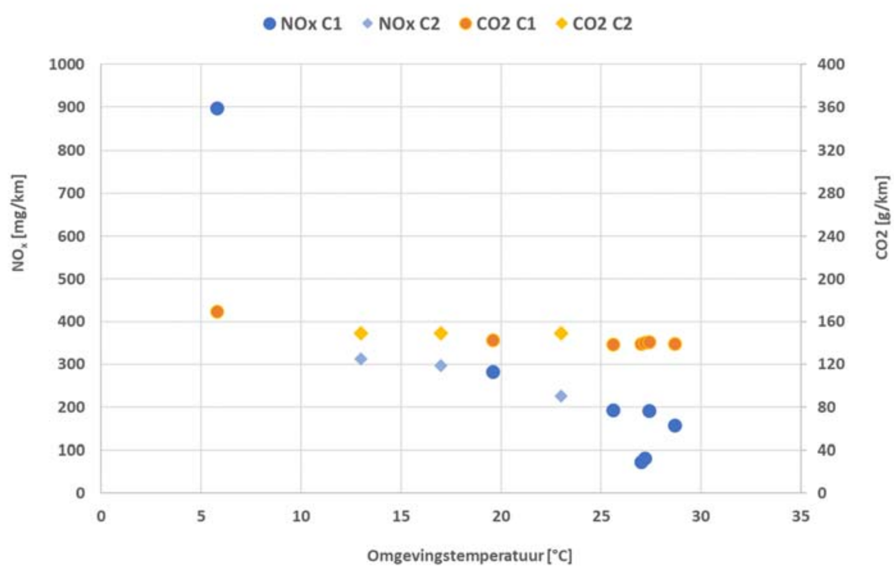


Figure 6-1: Corrected $NO_x$ and $CO_2$ emissions of NEDC tests with a cold start, measured on the test track with engine calibration 1 and 2 at different ambient temperatures.

- In preconditioning tests (3*EUDC), the LNT is regenerated at the same time for both engine calibrations in many cases.
- For both engine calibrations, a preconditioning test with regenerations of the LNT influences the $NO_x$ emission of the subsequent emission test.

- In UDC tests at an ambient temperature higher than 20°C, the $NO_x$ emission of both engine calibrations is approximately 400 mg per ECE cycle over time.
- In UDC tests with a cold start and ambient temperatures higher than 20°C, the $NO_x$ emission of both engine calibrations is higher than 400 mg per ECE cycle.
- In UDC tests with a cold start and ambient temperatures higher than 20°C, the $NO_x$ emission of increases abruptly with a factor two or three per ECE cycle over time (after 12 km). With engine calibration 1 this phenomenon occurs about 1750 s after the cold start and with engine calibration 2 after 3120 s. For engine calibration 2, it has been determined that the low-pressure EGR valve is then partially closed. Considering the increasing air consumption of the engine with engine calibration 1 and the constant operation of the high-pressure EGR system, it is also suspected here that the low-pressure EGR system is partially closed.
- In UDC testing, the LNT is not regenerated in both engine calibrations.
- In almost all tests at constant speed with engine calibration 1, the LNT is not regenerated. With engine calibration 2, the LNT in tests with constant speed is only regenerated during the first 1800 s after the cold start.
- In RDE tests performed at ambient temperatures between 13 and 26°C with both engine calibrations, the $NO_x$ emissions are dependent on the ambient temperature. Above 20°C the RDE $NO_x$ emission is approximately 400 mg/km and at an ambient temperature of 13 °C the $NO_x$ emission is 700 mg/km. For both engine calibrations, the number and the total duration of the LNT regenerations increases as the ambient temperature drops.

Partial conclusion 24:
The $NO_x$ emissions of the Suzuki Vitara Euro 6b diesel with engine calibrations 1 and 2 are similar in many tests and circumstances. This has been determined on both the chassis dynamometer and the test track. Engine calibration 2 appears to regenerate the LNT more frequently at constant speeds only during the first 1800 s after the cold start and changes the control strategy of the low-pressure EGR system at a later time than with engine calibration 1.

# 7 Discussion

*Are emissions tests of the Suzuki Vitara Euro 6 diesel on the chassis dynamometer and on the test track comparable?*
Emission tests on a dynamometer are well defined because the European emissions legislation for road vehicles accurately describes these tests.

This is particularly applicable to the following components:
- Prescribed test equipment
- Simulation of the driving resistance curve and vehicle weight
- Vehicle preconditioning
- The ambient temperature and humidity in the test laboratory
- The lack of external influences (wind, precipitation, slopes in the road)
- High-quality test equipment that is calibrated for each test.

On the test track of RDW in Lelystad, testing according to the legally prescribed requirements is not possible. Environmental conditions are different and the test procedures (such as preconditioning) are performed slightly differently on certain points than they are on the chassis dynamometer. Furthermore, the test track consists of two straight road sections and two bends, which leads to significant differences in the effective driving resistance curve compared to the chassis dynamometer. In addition, the environmental conditions such as the external temperature and the wind force and wind direction are different each day. The SEMS emission measurement system used is based on sensors and has different properties than the chassis dynamometer measuring equipment.
The measured differences in $CO_2$ emissions from similar tests at the same ambient temperatures on the chassis dynamometer and on test track can be explained because the test vehicle undergoes a higher driving resistance on the test track than it does on the chassis dynamometer. On the test track, the $NO_x$ emissions appear to be equal to the measured emissions from similar tests on the chassis dynamometer.

*What are the considerations for applying Exhaust Gas Recirculation (EGR)?*
The Suzuki Vitara is equipped with two EGR systems, a high-pressure, and a low-pressure system. The high-pressure EGR system allows a certain amount of unfiltered exhaust gas to flow back into the engine under certain conditions, the low-pressure EGR system returns filtered exhaust gas, after the diesel particulate filter, to the engine. This Exhaust Gas Recirculation, or EGR, is primarily used to reduce $NO_x$ emissions. The supply of cooled exhaust gas to the intake air of the engine reduces the amount of oxygen available in the engine, and reduces the combustion temperature. This results in a reduction in $NO_x$ emissions.

*What are the considerations for applying a Lean $NO_x$ Trap (LNT)?*
The Suzuki Vitara Euro 6b diesel is equipped with a LNT. This LNT is needed for an additional $NO_x$ reduction, because the two EGR systems that also ensure a certain reduction in $NO_x$ emissions from the engine apparently have insufficient reduction capacity under acceptable engine conditions.
The LNT has a certain storage capacity (also known as a buffer) for $NO_x$ and this is dependent on, among other things, the operating temperature.

During normal operation the LNT will store $NO_x$ until the $NO_x$ buffer is completely filled, this storage period can take up to an hour, but 10 minutes is also very common. The LNT is then regenerated, this usually happens when the $NO_x$ buffer is almost completely filled.

*How does regeneration of a LNT work and which $NO_x$ emission pattern is created?*
During the regeneration of the LNT, the stored $NO_x$, with the help of fuel, is converted into $H_2O$, $CO_2$, $N_2$ and $O_2$, which are harmless components in the context of air quality. For the implementation of the regeneration of a LNT, the setting of the engine is temporarily adjusted. Additional fuel is then injected into the exhaust stroke, among other things. This means that regeneration of a LNT costs extra fuel. After the regeneration, the trap of the LNT is empty and can store $NO_x$ again. The cycle time of a LNT is generally in the order of minutes (see Figure 7-1). Because of this, the current measured emissions in the exhaust can no longer be directly related to the current engine conditions. Figure 7.1 shows, among other things, measured $NO_x$ concentrations during a test on the test track with a constant speed of 130 km/hour.

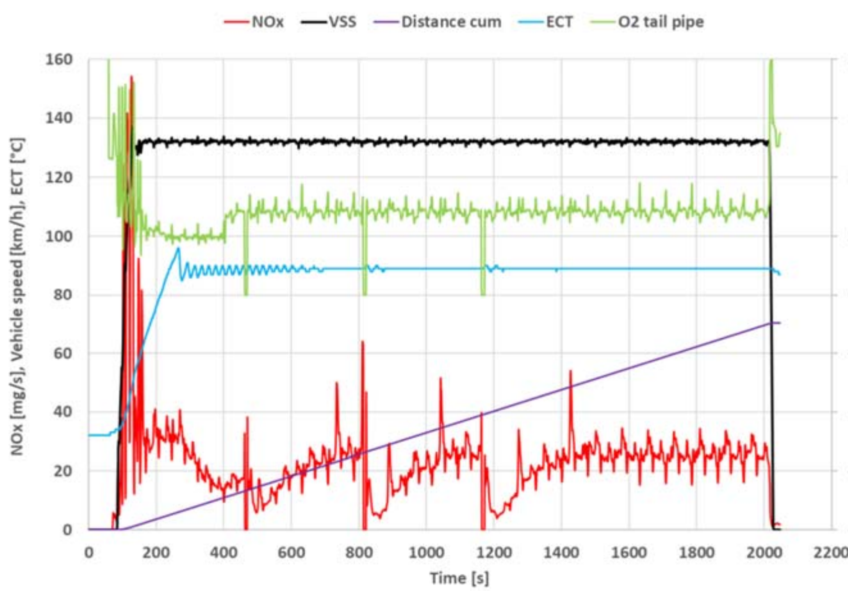


Figure 7-1: $NO_x$ concentrations at a constant speed of 130 km/h. Due to the operation of the LNT, the $NO_x$ emission up to t = 1500 s varies between 5 and 25 mg/s. After that, the LNT is no longer regenerated and the $NO_x$ emission remains stable.

# 8 Conclusions

The Netherlands Vehicle Authority (RDW) commissioned TNO to carry out an emission study of the Suzuki Vitara Euro 6b diesel.
The goal of the study was to map the Suzuki Vitara emission behaviour, measured with 2 different engine calibrations (1 & 2).
To this end, several partial objectives were formulated and emission measurements were carried out on a test track of the RDW, on a chassis dynamometer and on public roads.
When taken together, the results of these measurements provide a good overview of the emission behaviour of the tested vehicles and the differences in emissions before and after the update of the engine calibration software. The conducted tests provide limited insight into the applied EGR and LNT regulation strategies.
The partial conclusions based on the performed measurements have been included below. Some partial conclusions can be characterised as findings.

*Partial conclusion 1:*
The Suzuki Vitara Euro 6b diesel, tested in the 2017 RDW study, and the second Suzuki Vitara Euro 6b diesel, tested in this study, both equipped with engine calibration 1, highly exceed the NOx limit value of 80 mg/km in emissions tests on the test track (up to more than 10 times). It also appears that the NOx emission at an ambient temperature of 4-11 °C is twice as high as in the same tests carried out at an ambient temperature of 20-26 °C.

*Partial conclusion 2:*
The results of NEDC tests with a cold start of the Suzuki Vitara Euro 6b diesel with engine calibration 1 that were carried out on the test track, show that the $NO_x$ emission is strongly dependent on the ambient temperatures and the preconditioning test that was conducted. With an ambient temperature above 20°C and a standard preconditioning cycle (3*EUDC), an $NO_x$ emission of 157-191 mg/km is measured in an NEDC on the test track. The only circumstances under which the NOx limit value of 80 mg/km is not exceeded in an NEDC test on the test track, is with an ambient temperature above 20°C and an adjusted preconditioning cycle.

*Partial conclusion 3:*
In the EUDC preconditioning tests of the Suzuki Vitara Euro 6b diesel with engine calibration 1, the LNT is regenerated, by default, three times at speeds of 80 - 100 km/h. As a result, the NOx storage capacity of the LNT is maximised at the start of an emission test. During the emission test, the $NO_x$ can be buffered and, when driving at a speed of 100 km/h, partly converted into harmless components. Incomplete LNT regenerations in the preconditioning test lead to an increased $NO_x$ emission in the subsequent emission test.

*Partial conclusion 4:*
The thermal condition of the engine with engine calibration 1 has a different effect on $NO_x$ emissions at different ambient temperatures. With an ambient temperature of 6 °C the $NO_x$ emission decreases in an NEDC test with a warm start compared to an NEDC test with a cold start, while at a temperature of 26 °C the $NO_x$ emission

increases. The ambient temperature seems to have a bigger influence on the $NO_x$ emissions than the thermal condition of the engine.

*Partial conclusion 5:*
In UDC tests of the Suzuki Vitara Euro 6b diesel with engine calibration 1 and a cold engine start, and at an ambient temperature above 20 °C, it appears that over time the $NO_x$ emissions of the engine abruptly rise from 300 to 450 mg per ECE cycle. The timing of this sudden increase in $NO_x$ emission varies in the different tests, but no explanation for this has been found. The increase in $NO_x$ emissions is probably caused by the active control of the EGR system, which regulates the quantity of EGR. This is investigated further with the vehicle with engine calibration 2. These results are reported in chapter 5 of this report. Other engine parameters (such as the fuel injection strategy) may also influence the $NO_x$ emissions. These have not been examined.
In UDC tests with a warm start at an ambient temperature above 20 °C, the $NO_x$ emissions are consistent at a level between 350-530 mg per ECE cycle and the EGR recirculation appears to be stable.

*Partial conclusion 6:*
With the same ambient temperatures and the same preconditioning cycles, the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 1 in 4*UDC tests on the test track and on the dynamometer appears to be almost identical. From this it can be concluded that the emission behaviour of the vehicle on the chassis dynamometer and on the test track correspond and reproduce, and that the different types of measuring equipment produce similar results.

*Partial conclusion 7:*
In tests at relatively constant speeds of the Suzuki Vitara with engine calibration 1, the emission behaviour is not reproducible; the $NO_x$ emissions can differ by more than a factor of 2. The measured oxygen concentrations in the exhaust gas vary, this indicates different controlling of the EGR systems. Sometimes there is an increasing trend in $NO_x$ emissions as well. Furthermore, the regeneration behaviour of the LNT in this test cannot be explained.

*Partial conclusion 8:*
In RDE tests with engine calibration 1, the $NO_x$ emission is dependent on the ambient temperature. Substantially higher $NO_x$ emissions were measured at an ambient temperature of 13°C, than at an ambient temperature of 26°C (691 versus 420 mg/km).

*Partial conclusion 9:*
In an NEDC test with engine calibration 1, which is carried out according to the type-approval test requirements on the chassis dynamometer, the $CO_2$ emissions are 114.9 – 117.2 g/km, which is 8 - 11% higher than the value specified by the manufacturer. The measured $NO_x$ emission is 64.9 - 83.1 and is on average 7% below the Euro 6 limit value. This test vehicle with engine calibration 1 meets the Euro 6 $NO_x$ limit values.

*Partial conclusion 10:*
The results of NEDC tests on the chassis dynamometer with engine calibration 1 and different driving resistance curves, show that $CO_2$ emissions increase as

the driving resistance increases. An increase in the driving resistance results in an increase in the engine load, which, in this testing programme, leads to an increase in $CO_2$ emissions from 115 to 152 g/km (+ 32%). The $NO_x$ emission varies between 65 and 168 mg/km and has no direct relationship with increasing driving resistance.

*Partial conclusion 11:*
The $CO_2$ and $NO_x$ emissions of the Suzuki Vitara with engine calibration 1, measured by the SEMS mobile measurement system, deviate slightly from the test results determined according to the legal measuring method on the chassis dynamometer. These deviations are 0.6 - 4.4% for $CO_2$ and -2.3 – 2.6% for $NO_x$. For the partial conclusions that relate to the $NO_x$ emissions in this study, the above-mentioned differences in measurement results from the SEMS system and the legal method on the chassis dynamometer do not have any consequences, since all these deviations are small.

*Partial conclusion 12:*
The driving resistance curve of the test vehicle on the test track in Lelystad is roughly 1.5 to 5,2 times higher than the driving resistance curve determined by the manufacturer. The absolute difference in driving resistance force is 300 - 400 N over the speed range of 10-130 km/h. This difference is largely caused by the turns in the test track.

*Partial conclusion 13:*
The results of NEDC tests with a cold start of the Suzuki Vitara Euro 6b diesel with engine calibration 2 that were carried out on the test track at ambient temperatures of 13 - 23 °C, show that the $NO_x$ emission increases if the ambient temperatures drop. Furthermore, the number and duration of the LNT regenerations in the preconditioning test influences the $NO_x$ emissions in the NEDC test. With an ambient temperature above 20 °C and a standard preconditioning cycle (3*EUDC), a $NO_x$ emission of 200 mg/km is measured in an NEDC on the test track.

*Partial conclusion 14:*
In 3*EUDC preconditioning tests with engine calibration 2, the LNT is regenerated three times. For unknown reasons, these LNT regenerations sometimes do not (fully) take place. This same regeneration behaviour has been observed with engine calibration 1, see paragraph 4.1.3. This means that the $NO_x$ buffer capacity varies at the start of an emission test and this influences the $NO_x$ emissions from the emission test.

*Partial conclusion 15:*
The NEDC $NO_x$ emissions with a cold start of engine calibration 2 are substantially higher than the $NO_x$ emissions of an NEDC test with a warm start. This difference mainly arises in the first 500 s of the NEDC test.

*Partial conclusion 16:*
In UDC tests on the test track and the dynamometer of the Suzuki Vitara Euro 6b diesel with engine calibration 2 and a cold engine start, and at an ambient temperature above 20 °C, it appears that over time the $NO_x$ emissions of the vehicle abruptly rise from approximately 150 to 450 mg per ECE cycle. The time of this sudden rise in $NO_x$ emissions lies within the twelfth to fourteenth ECE cycle of a UDC test. The increase in $NO_x$ emissions is (partly) caused by the adjusted method

of controlling the EGR system, which regulations the quantity of EGR. Other engine parameters (such as the fuel injection strategy) may also influence the $NO_x$ emissions. These have not been examined.

*Partial conclusion 17:*
With the same ambient temperatures and the same preconditioning cycles, the $NO_x$ emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 2 in 4*UDC tests on the test track and on the chassis dynamometer appears to be almost identical. From this it can be concluded that the emission behaviour of the vehicle on the test track can be reproduced on the chassis dynamometer, that the emission behaviour on the dynamometer and on the test track are almost identical, and that the different types of measuring equipment produce similar results.

*Partial conclusion 18:*
In tests with a cold start and constant speeds of 110 and 130 km/h there is a strongly varying $NO_x$ emission. After the cold start, the NOx emission is around 800 mg/km. This drops after 2 minutes by activating the low-pressure EGR system to 230 mg/km and then drops to 43 mg/km after the fourth minute due to a LNT regeneration. After the eighth minute the low-pressure EGR system partially closes and the average $NO_x$ emission rises to 272 - 293 mg/km and then rises to 446 mg/km when the LNT regenerations are no longer carried out from the 28th minute onwards. It is unclear why the LNT regenerations no longer take place then. This was not examined further.

*Partial conclusion 19:*
In four RDE tests with engine calibration 2 and at average ambient temperatures of 15 to 19 °C, the measured $CO_2$ emissions are 129 - 137 g/km and the $NO_x$ emissions are 399 to 619 mg/km. This spread of emissions is normal and fits the nature of RDE tests that may have a certain variation in execution.

*Partial conclusion 20:*
In an NEDC test with engine calibration 2, which is carried out according to the type-approval test requirements on the chassis dynamometer, the $CO_2$ emissions are 118.5 g/km, which is 12% higher than the type-approval value specified by the manufacturer. The measured $NO_x$ emission is 63.5 mg/km, this is 21% below the Euro 6 limit value. This test vehicle with engine calibration 2 meets the Euro 6 NOx limit values.

*Partial conclusion 21:*
The results of NEDC tests on the chassis dynamometer with engine calibration 2 and different driving resistance curves, show that $CO_2$ emissions increase as the driving resistance increases. An increase in the driving resistance (RL1 to RL5) results in an increase in the engine load, which leads to an increase in $CO_2$ emissions from 119 to 175-178 g/km (+ 48%). At the same time, the $NO_x$ emissions also increase from 64 to 120-141 mg/km (+ 87% to + 120%).

*Partial conclusion 22:*
The $CO_2$ and $NO_x$ emissions of the Suzuki Vitara with engine calibration 2, measured by the SEMS mobile measurement system, deviate slightly from the test results determined according to the legal measuring method on the dynamometer. These deviations are 6.6 to 9.0% for $CO_2$ and -2.3 to 2.6% for $NO_x$.

For the partial conclusions that relate to the $NO_x$ emissions in this study, the above-mentioned differences in measurement results from the SEMS system and the legal method on the chassis dynamometer do not have any consequences, since all these deviations are small.

*Partial conclusion 23:*
The measured overpressure to which the $NO_x$-$O_2$ sensor, which is mounted after the LNT, is exposed in this test program is small (maximum 4 kPa) and the corresponding correction of the measured NOx concentration is 1.5 - 2.7%, based on the pressure measurements.
The occuring pressures at the two $NO_x$-$O_2$ sensors do explain part of the remaining constant differences in $NO_x$ emissions as measured before and after the LNT.
The pressure sensor may not be able to fully follow the peak values. The measurements after the LNT are at lower overpressures and were validated against the laboratory results. The measurement before the LNT should be considered as more of an indication, with greater measurement inaccuracy, due to the measurement conditions before the LNT.

*Partial conclusion 24:*
The $NO_x$ emissions of the Suzuki Vitara Euro 6b diesel with engine calibrations 1 and 2 are similar in many tests and circumstances. This has been determined on both the chassis dynamometer and the test track. Engine calibration 2 appears to regenerate the LNT more frequently at constant speeds only during the first 1800 s after the cold start and changes the control strategy of the low-pressure EGR system at a later time than with motor calibration 1.

# 9 Abbreviations

| | |
|---|---|
| ADC | Analogue Digital Convertor |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| ECE | United Nations Economic Commission for Europe |
| ECT | Engine Coolant Temperature |
| EGR | Exhaust Gas Recirculation |
| EUDC | Extra Urban Driving Cycle |
| IAT | Inlet Air Temperature |
| ISC | In Service Conformity |
| $NO_x$ | Nitrogen oxides, NO en $NO_2$ |
| THC | Total Hydrocarbons |
| MAF | Mass Air Flow rate |
| NEDC | New European Driving Cycle |
| OBD | On Board Diagnostics |
| OEM | Original Equipment Manufacturer |
| PEMS | Portable Emission Measurement System |
| PM | Particulate Matter |
| PN | Particle Number |
| RDW | Netherlands Vehicle Authority |
| RDE | Real Driving Emissions |
| SEMS | Smart Emission Measurement System |
| TA | Type Approval |
| TCL | Test Centre Lelystad |
| TNO | Netherlands Organisation for Applied Scientific Research |
| UDC | Urban Driving Cycle |
| VSS | Vehicle Speed Sensor |

# 10 References

[RDW 2017] Emissions Tests Programme RDW, July 2017, RDW

# 11 Signature

The Hague, 24 September 2019

TNO

Peter van der Mark
Project manager

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Author

# A Reference fuel certificates

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HORIBA EUROPE GMBH
Monika Spengel
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61440 OBERURSEL

**Certificate 100000121736**

| | |
|---|---|
| Date: | 07.11.2017 |
| Customer PO: | 4510565089 |
| Delivery Note: | 80101799 000010 |
| Order No.: | 66100455 000010 |
| Customer No.: | 1750282 |

| | |
|---|---|
| GMID: | 357707 |
| Material: | Diesel, EURO-6 Cert Fuel B7<br>172 KG LINED STEEL DRUM 1A1 |
| Cust. Mat.: | |
| Batch: | EJ0603T477 |
| Orig. Batch: | 37 |
| Sample No.: | 30030144 |
| Analyzed: | 13.10.2017 |
| Dlvy. Qty: | 172,0 KG |
| Vehicle: | M-DH 6087 |
| Ship from: | Shipping Point Hamburg Hamburg 02 Germany |

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| Feature | Units | Results | Limits Minimum | Maximum | Method |
|---|---|---|---|---|---|
| Cetane Number (CFR) | (*1) | 52,2 | 52,0 | 56,0 | EN ISO 5165 |
| Cetane Index | | 58,6 | 46,0 | - | EN ISO 4264 |
| Density at 15°C | kg/m3 | 834,6 | 833,0 | 837,0 | EN ISO 12185 |
| Distillation IBP | °C | 216,8 | | | EN ISO 3405 |
| Dist. 50% v/v | °C | 285,1 | 245,0 | - | EN ISO 3405 |
| Dist. 95% v/v | °C | 350,3 | 345,0 | 360,0 | EN ISO 3405 |
| Distillation FBP | °C | 365,3 | - | 370,0 | EN ISO 3405 |
| Flash Point | °C | 94,5 | 55,0 | - | EN ISO 2719 |
| Cloud Point | °C | -21 | - | -10 | EN 23015 |
| Viscosity at 40°C | mm2/s | 3,234 | 2,300 | 3,300 | EN ISO 3104 |
| Aromatics, Poly (2+3) | % w | 3,5 | 2,0 | 4,0 | EN 12916 |
| Sulfur | mg/kg | < 3,0 | - | 10,0 | EN ISO 20846 |
| Corrosion - Copper | - | 1A max. 1 | - | - | EN ISO 2160 |
| Carbon Residue - 1 | % w | < 0,10 | - | 0,20 | EN ISO 10370 |
| Ash Content (*1) | % w | < 0,001 | - | 0,010 | EN ISO 6245 |
| Water | mg/kg | 45 | - | 200 | EN ISO 12937 |
| Particulate Matter | mg/kg | 16,6 | - | 24,0 | EN 12662 |
| Strong Acid Number | mg KOH/g | < 0,02 | - | 0,10 | ASTM D974 |
| Oxidation Stabilit | Hour | 66,7 | 20,0 | - | EN 15751 |

Sitz der Gesellschaft: Hamburg, Amtsgericht Hamburg * HRB 118570 * USt-ID/VAT-ID: DE915285855 *
Geschäftsführung: Dr. Uwe Nickel (Vorsitz), Peter Stubbe, Henrik Krüpper
Commerzbank AG * Konto 6152128 * Bankleitzahl 20040000 * IBAN DE20 2004 0000 0615 2128 00 * SWIFT Code COBADEFFXXX

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HANS-MESS-STRASSE 6
61440 OBERURSEL

Delivery item/date
80101799 000010 / 09.11.2017

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| Feature | | Units | Results | Limits Minimum | Maximum | Method |
|---|---|---|---|---|---|---|
| HFRR (WSD) | | µm | 156 | - | 400 | EN ISO 12156-1 |
| FAME | | %(V) | 6,8 | 6,0 | 7,0 | EN 14078 |
| Oxygen Content | (*3) | % w | 0,86 | | | EN 14078 |
| Hydrogen | (*2) | % w | 13,45 | | | RWL-HM-28 |
| Carbon | (*2) | % w | 85,69 | | | RWL-HM-28 |
| C:H Ratio (H=1) | (*2) | | 6,37 | | | RWL-HM-28 |
| H:C Ratio (C=1) | (*2) | | 0,157 | | | RWL-HM-28 |
| Net Heating Value | (*2) | MJ/kg | 42,887 | | | RWL-HM-27 |
| Net Heating Value | (*2) | Btu/lb | 18436 | | | RWL-HM-27 |

(*1) : tested by subcontractor
(*2) : not accredited
(*3) : modified

The certificate is electronically generated and valid without signature.

Laboratory is accredited acc DIN EN ISO / IEC 17025, DAkkS D-PL-17640-01-00
Robert Geisler, Phone ++49-40-33318-149

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Commerzbank AG * Konto 6152128 * Bankleitzahl 20040000 * IBAN DE20 2004 0000 0615 2128 00 * SWIFT Code COBADEFFXXX

# B Results of dynamometer emission testing

| Overview Chassis Dynamometer tests Suzuki Vitara motorkalibratie 1 | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test type | Road | Calibration | Phase | HC | CO | | CO2 | NOx | NO | NMHC | | CH4 | NMOG | HC+NOx | FC | Particle | |
| | | Load | | | | | | | | | | | | | | | Grav. | counts |
| | | | | | [mg/km] | [mg/km] | | [g/km] | [mg/km] | [mg/km] | [mg/km] | | [mg/km] | [mg/km] | [mg/km] | [l/100km] | [mg/km] | [1/km] |
| 15-8-2018 | UDC cold | 1 | 1 | 1 | 111.2 | 579.0 | | 155.2 | 124.3 | 87.6 | 94.4 | | 14.8 | 102.0 | 235.5 | 5.94 | | 4.21E+10 |
| 15-8-2018 | EUDC | 1 | 1 | 2 | 22.4 | 41.0 | | 106.1 | 59.0 | 38.5 | 5.0 | | 17.9 | 6.9 | 81.4 | 4.03 | | 5.28E+10 |
| 15-8-2018 | NEDC cold | 1 | 1 | 1+2 | 54.9 | 238.5 | | 124.2 | 82.9 | 56.5 | 37.9 | | 19.5 | 41.9 | 137.9 | 4.73 | 0.15 | 4.89E+10 |
| | | | | | | | | | | | | | | | | | | |
| 16-8-2018 | UDC cold | 1 | 1 | 1 | 99.4 | 540.0 | | 133.2 | 88.2 | 63.4 | 87.2 | | 9.7 | 94.5 | 187.7 | 5.10 | | 3.69E+10 |
| 16-8-2018 | EUDC | 1 | 1 | 2 | 26.1 | 59.0 | | 104.2 | 51.0 | 34.8 | 6.8 | | 20.1 | 8.9 | 77.0 | 3.96 | | 5.28E+10 |
| 16-8-2018 | NEDC cold | 1 | 1 | 1+2 | 53.2 | 236.9 | | 114.9 | 64.9 | 45.4 | 36.5 | | 19.1 | 40.6 | 118.1 | 4.38 | 0.12 | 4.70E+10 |
| | | | | | | | | | | | | | | | | | | |
| 17-8-2018 | UDC cold | 1 | 1 | 1 | 86.4 | 476.0 | | 137.6 | 121.2 | 87.0 | 75.2 | | 9.0 | 81.8 | 207.5 | 5.26 | | 3.75E+10 |
| 17-8-2018 | EUDC | 1 | 1 | 2 | 22.4 | 52.0 | | 105.3 | 60.9 | 41.6 | 5.5 | | 16.9 | 7.9 | 83.3 | 4.00 | | 5.90E+10 |
| 17-8-2018 | NEDC cold | 1 | 1 | 1+2 | 45.9 | 207.5 | | 117.2 | 83.1 | 58.3 | 31.1 | | 16.9 | 35.0 | 129.0 | 4.46 | 0.27 | 5.11E+10 |
| | | | | | | | | | | | | | | | | | | |
| 20-8-2018 | UDC cold | 2 | 1 | 1 | 79.5 | 567.0 | | 145.5 | 121.2 | 86.4 | 68.3 | | 8.7 | 74.4 | 200.7 | 5.56 | | 3.78E+10 |
| 20-8-2018 | EUDC | 2 | 1 | 2 | 25.5 | 34.0 | | 113.8 | 126.8 | 83.9 | 5.2 | | 21.7 | 6.6 | 152.2 | 4.32 | | 3.46E+10 |
| 20-8-2018 | NEDC cold | 2 | 1 | 1+2 | 45.2 | 229.5 | | 125.4 | 124.8 | 84.6 | 28.4 | | 19.2 | 31.5 | 169.9 | 4.78 | 0.35 | 3.58E+10 |
| | | | | | | | | | | | | | | | | | | |
| 23-8-2018 | UDC cold | 2 | 1 | 1 | 81.4 | 425.0 | | 139.3 | 117.4 | 83.3 | 71.1 | | 7.8 | 77.9 | 198.8 | 5.32 | | 5.23E+10 |
| 23-8-2018 | EUDC | 2 | 1 | 2 | 23.0 | 32.0 | | 112.2 | 59.0 | 38.5 | 4.3 | | 18.8 | 6.7 | 82.0 | 4.26 | | 6.85E+10 |
| 23-8-2018 | NEDC cold | 2 | 1 | 1+2 | 44.5 | 176.7 | | 122.2 | 80.5 | 54.9 | 28.9 | | 17.9 | 32.9 | 125.0 | 4.65 | 0.18 | 6.26E+10 |
| | | | | | | | | | | | | | | | | | | |
| 28-8-2018 | UDC cold | 1 | 1 | 1 | 76.4 | 431.0 | | 140.1 | 108.1 | 83.3 | 65.4 | | 7.9 | 72.3 | 184.5 | 5.35 | | 3.30E+10 |
| 28-8-2018 | EUDC | 1 | 1 | 2 | 9.9 | 8.0 | | 101.1 | 57.8 | 42.3 | 1.9 | | 5.9 | 4.7 | 67.7 | 3.84 | | 3.38E+10 |
| 28-8-2018 | NEDC cold | 1 | 1 | 1+2 | 34.5 | 165.0 | | 115.5 | 76.3 | 57.3 | 25.4 | | 10.3 | 29.8 | 110.7 | 4.40 | - | 3.35E+10 |
| | | | | | | | | | | | | | | | | | | |
| 30-8-2018 | UDC cold | 3 | 1 | 1 | 55.9 | 379.0 | | 148.2 | 128.6 | 95.7 | 45.8 | | 6.4 | 52.6 | 184.5 | 5.65 | | 6.45E+10 |
| 30-8-2018 | EUDC | 3 | 1 | 2 | 24.9 | 144.0 | | 121.2 | 51.6 | 34.8 | 6.0 | | 17.7 | 9.8 | 76.4 | 4.61 | | 8.28E+10 |
| 30-8-2018 | NEDC cold | 3 | 1 | 1+2 | 36.4 | 230.6 | | 131.1 | 79.7 | 57.2 | 20.6 | | 18.1 | 25.6 | 116.2 | 4.99 | - | 7.61E+10 |
| | | | | | | | | | | | | | | | | | | |
| 13-9-2018 | UDC cold | 4 | 1 | 1 | 92.0 | 676.0 | | 176.1 | 246.7 | 171.5 | 78.1 | | 2.5 | 93.6 | 338.6 | 6.73 | | 1.68E+11 |
| 13-9-2018 | EUDC | 4 | 1 | 2 | 24.2 | 108.0 | | 137.7 | 121.2 | 75.2 | 4.8 | | 12.7 | 13.7 | 145.4 | 5.23 | | 8.80E+10 |
| 13-9-2018 | NEDC cold | 4 | 1 | 1+2 | 49.3 | 318.0 | | 151.9 | 167.6 | 110.7 | 31.9 | | 20.0 | 43.2 | 216.9 | 5.79 | 0.20 | 1.17E+11 |

**Overview Chassis Dynamometer tests Suzuki Vitara motorkalibratie 1**

| | Test type | Road | Calibration | Phase | HC | CO | | CO2 | NOx | NO | NMHC | | CH4 | NMOG | HC+NOx | FC | Particle | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Load | | | | | | | | | | | | | | | Grav. | counts |
| | | | | | [mg/km] | [mg/km] | | [g/km] | [mg/km] | [mg/km] | [mg/km] | | [mg/km] | [mg/km] | [mg/km] | [l/100km] | [mg/km] | [1/km] |
| | | | | | | | | | | | | | | | | | | |
| 14-8-2018 | UDC cold | 1 | 1 | 1 | 25.5 | 27.0 | | 108.3 | 198.2 | 120.5 | 5.5 | | 21.2 | 7.1 | 223.7 | 4.12 | | - |
| 14-8-2018 | UDC cold | 1 | 1 | 2 | 22.4 | 16.0 | | 106.5 | 61.5 | 34.8 | 2.3 | | 21.1 | 4.1 | 83.9 | 4.04 | | - |
| 14-8-2018 | UDC cold | 1 | 1 | 3 | 25.5 | 48.0 | | 104.7 | 58.4 | 32.3 | 6.1 | | 18.6 | 9.6 | 83.9 | 3.98 | | - |
| 14-8-2018 | UDC cold | 1 | 1 | 4 | | | | | | | | | | | | | | - |
| 14-8-2018 | 4* UDC cold | 1 | 1 | 1-4 | 24.4 | 30.1 | | 106.5 | 105.9 | 62.5 | 4.6 | | 22.6 | | 130.3 | 4.05 | | - |
| | | | | | | | | | | | | | | | | | | |
| 21-8-2018 | UDC cold | 2 | 1 | 1 | 74.6 | 482.0 | | 144.1 | 100.7 | 72.7 | 63.0 | | 10.9 | 67.3 | 175.2 | 5.50 | | 4.13E+10 |
| 21-8-2018 | UDC cold | 2 | 1 | 2 | 20.5 | 9.0 | | 128.0 | 113.7 | 78.9 | 13.3 | | 5.8 | 16.5 | 134.2 | 4.86 | | 3.82E+10 |
| 21-8-2018 | UDC cold | 2 | 1 | 3 | 18.6 | 11.0 | | 124.1 | 206.3 | 139.2 | 12.9 | | 2.7 | 17.2 | 224.9 | 4.71 | | 2.30E+10 |
| 21-8-2018 | UDC cold | 2 | 1 | 4 | 26.7 | 14.0 | | 125.2 | 318.1 | 214.4 | 22.0 | | 1.3 | 26.6 | 344.9 | 4.75 | | 1.56E+10 |
| 21-8-2018 | 4* UDC cold | 2 | 1 | 1-4 | 35.1 | 129.1 | | 130.3 | 184.8 | 126.3 | 27.8 | | 8.4 | | 220.0 | 4.96 | 0.23 | 2.95E+10 |
| | | | | | | | | | | | | | | | | | | |
| 3-9-2018 | UDC cold | 3 | 1 | 1 | 42.3 | 298.0 | | 156.0 | 102.5 | 75.2 | 31.7 | | 6.2 | 38.3 | 144.8 | 5.94 | | 7.39E+10 |
| 3-9-2018 | UDC cold | 3 | 1 | 2 | 10.6 | 15.0 | | 136.3 | 93.8 | 64.0 | 3.0 | | 2.1 | 8.7 | 104.4 | 5.17 | | 4.16E+10 |
| 3-9-2018 | UDC cold | 3 | 1 | 3 | 9.3 | 19.0 | | 131.4 | 237.4 | 163.4 | 4.8 | | 0.0 | 10.5 | 246.7 | 4.99 | | 2.44E+10 |
| 3-9-2018 | UDC cold | 3 | 1 | 4 | 12.4 | 17.0 | | 131.6 | 374.1 | 259.7 | 8.6 | | 0.0 | 14.5 | 386.5 | 5.00 | | 1.81E+10 |
| 3-9-2018 | 4* UDC cold | 3 | 1 | 1-4 | 18.6 | 87.1 | | 138.8 | 202.1 | 140.8 | 12.0 | | 7.5 | | 220.7 | 5.27 | 0.02 | 3.95E+10 |

**Overview Chassis Dynamometer tests Suzuki Vitara motorkalibratie 2**

| | Test type | Road Load | Calibration | Phase | HC | CO | CO2 | NOx | NO | NMHC | CH4 | NMOG | HC+NOx | FC | Particle Grav. | counts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | [mg/km] | [mg/km] | [g/km] | [mg/km] | [mg/km] | [mg/km] | [mg/km] | [mg/km] | [mg/km] | [l/100km] | [mg/km] | [1/km] |
| 10-12-2018 | UDC cold | 1 | 2 | 1 | 98.2 | 683.0 | 141.7 | 80.8 | 60.3 | 88.5 | 9.1 | 93.9 | 179.0 | 5.43 | | 2.55E+10 |
| 10-12-2018 | EUDC | 1 | 2 | 2 | 31.7 | 174.0 | 104.9 | 53.4 | 36.7 | 12.1 | 17.1 | 17.2 | 85.1 | 4.00 | | 3.25E+10 |
| 10-12-2018 | NEDC cold | 1 | 2 | 1+2 | 56.1 | 362.1 | 118.5 | 63.5 | 45.3 | 40.3 | 18.1 | 45.5 | 119.6 | 4.53 | 0.17 | 2.99E+10 |
| | | | | | | | | | | | | | | | | |
| 13-12-2018 | UDC cold | 5 | 2 | 1 | 28.6 | 325.0 | 174.9 | 141.1 | 100.0 | 21.3 | 3.8 | 26.6 | 169.6 | 6.66 | | 5.16E+10 |
| 13-12-2018 | EUDC | 5 | 2 | 2 | 0.6 | 39.0 | 149.6 | 274.0 | 152.9 | 0.0 | 0.0 | 2.5 | 274.6 | 5.68 | | 5.02E+10 |
| 13-12-2018 | NEDC cold | 5 | 2 | 1+2 | 11.0 | 143.7 | 158.9 | 225.4 | 133.5 | 7.8 | 3.7 | 11.4 | 236.4 | 6.04 | 0.20 | 5.07E+10 |
| | | | | | | | | | | | | | | | | |
| 30-1-2019 | UDC cold | 5 | 2 | 1 | 51.6 | 478.0 | 178.1 | 119.9 | 83.9 | 41.9 | 9.7 | 45.1 | 171.5 | 6.79 | | 6.15E+10 |
| 30-1-2019 | EUDC | 5 | 2 | 2 | 1.9 | 53.0 | 149.5 | 318.8 | 174.0 | 1.1 | 0.0 | 2.0 | 320.6 | 5.68 | | 3.85E+10 |
| 30-1-2019 | NEDC cold | 5 | 2 | 1+2 | 20.0 | 208.2 | 160.0 | 245.9 | 141.0 | 16.0 | 4.6 | 17.7 | 265.9 | 6.08 | 0.03 | 4.69E+10 |
| | | | | | | | | | | | | | | | | |
| 11-12-2018 | UDC cold | 5 | 2 | 1 | 50.3 | 497.0 | 185.9 | 127.4 | 89.4 | 44.6 | 6.4 | 46.4 | 177.7 | 7.09 | | 5.91E+10 |
| 11-12-2018 | UDC cold | 5 | 2 | 2 | 15.5 | 84.0 | 169.3 | 99.4 | 62.1 | 12.9 | 3.5 | 13.4 | 115.0 | 6.43 | | 4.69E+10 |
| 11-12-2018 | UDC cold | 5 | 2 | 3 | 13.7 | 80.0 | 167.1 | 164.0 | 101.9 | 11.6 | 2.2 | 12.1 | 177.7 | 6.35 | | 4.01E+10 |
| 11-12-2018 | UDC cold | 5 | 2 | 4 | 14.3 | 75.0 | 166.7 | 393.9 | 244.2 | 13.5 | 0.4 | 14.1 | 408.2 | 6.41 | | 1.95E+10 |
| 11-12-2018 | 4* UDC cold | 5 | 2 | 1-4 | 23.4 | 183.4 | 172.8 | 196.1 | 124.4 | 20.6 | 3.1 | 21.5 | 219.5 | 6.57 | 0.13 | 4.14E+10 |
| | | | | | | | | | | | | | | | | |
| 12-12-2018 | UDC cold | 5 | 2 | 1 | 35.4 | 342.0 | 185.6 | 111.9 | 80.8 | 26.7 | 3.7 | 33.6 | 147.3 | 7.07 | | 6.74E+10 |
| 12-12-2018 | UDC cold | 5 | 2 | 2 | 7.5 | 58.0 | 165.8 | 88.2 | 56.5 | 1.7 | 0.7 | 7.3 | 95.7 | 6.30 | | 5.02E+10 |
| 12-12-2018 | UDC cold | 5 | 2 | 3 | 6.8 | 58.0 | 163.1 | 159.1 | 99.4 | 1.7 | 0.0 | 7.2 | 165.9 | 6.19 | | 4.01E+10 |
| 12-12-2018 | UDC cold | 5 | 2 | 4 | 6.8 | 56.0 | 163.7 | 389.6 | 238.6 | 3.5 | 0.0 | 8.5 | 396.4 | 6.22 | | 1.90E+10 |
| 12-12-2018 | 4* UDC cold | 5 | 2 | 1-4 | 14.1 | 128.4 | 169.5 | 187.2 | 118.8 | 8.4 | 6.5 | 14.1 | 201.3 | 6.44 | 0.19 | 4.17E+10 |

# C Test track and dynamometer SEMS results

| Overzicht test programma Suzuki Vitara, engine calibration C1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| No | Test | Start | Datum | Tambient | Time | CO2 | NOx | Locatie |
| | | | | [°C] | | [g/km] | [mg/km] | |
| 1 | NEDC | warm | 2018-3-22 | 10.4 | 13:48 | 204 | 805 | Testbaan |
| 2 | 120 kph | warm | 2018-3-27 | 7.0 | 7:39 | 192 | 1204 | Testbaan |
| 3 | NEDC | warm | 2018-3-27 | 10.9 | 9:08 | 152 | 845 | Testbaan |
| 4 | NEDC + auxiliaries | warm | 2018-3-27 | 11.6 | 9:30 | 143 | 782 | Testbaan |
| 5 | 3* EUDC | warm | 2018-3-27 | 11.5 | 9:53 | 131 | 535 | Testbaan |
| 6 | NEDC | cold | 2018-3-28 | 10.4 | 6:17 | - | - | Testbaan |
| 7 | NEDC | warm | 2018-3-28 | 9.3 | 6:38 | 146 | 693 | Testbaan |
| 8 | NEDC + auxiliaries | warm | 2018-3-28 | 9.5 | 7:00 | 152 | 732 | Testbaan |
| 9 | 120 kph | warm | 2018-3-28 | 10.1 | 8:03 | 164 | 868 | Testbaan |
| 10 | NEDC +10% | warm | 2018-3-28 | 10.2 | 8:16 | 142 | 672 | Testbaan |
| 11 | NEDC -10% | warm | 2018-3-28 | 10.6 | 8:38 | 127 | 639 | Testbaan |
| 12 | EUDC-UDC | warm | 2018-3-28 | 11.0 | 8:59 | 136 | 502 | Testbaan |
| 13 | RDE warm | warm | 2018-3-28 | 9.3 | 10:56 | 137 | 708 | Testbaan |
| 14 | 3* EUDC | warm | 2018-3-28 | 9.2 | 12:47 | 134 | 688 | Testbaan |
| 15 | NEDC | cold | 2018-3-29 | 5.8 | 6:18 | 169 | 937 | Testbaan |
| 16 | NEDC | warm | 2018-3-29 | 6.2 | 6:39 | 141 | 547 | Testbaan |
| 17 | EUDC | warm | 2018-3-29 | 6.9 | 7:13 | 144 | 771 | Testbaan |
| 18 | EUDC-UDC | warm | 2018-3-29 | 7.3 | 7:23 | 135 | 579 | Testbaan |
| 19 | NEDC No Start | warm | 2018-3-29 | 8.7 | 7:57 | 157 | 917 | Testbaan |
| 20 | RDE warm | warm | 2018-3-29 | 12.5 | 12:17 | 123 | 811 | Testbaan |
| 21 | 120 kph | warm | 2018-4-6 | 12.9 | 9:31 | 203 | 1204 | Testbaan |
| 22 | 3* EUDC | warm | 2018-4-6 | 13.0 | 9:56 | 138 | 531 | Testbaan |
| 23 | NEDC | cold | 2018-4-9 | 19.6 | 13:03 | 143 | 303 | Testbaan |
| 24 | 3* EUDC | warm | 2018-4-9 | 18.6 | 13:27 | 122 | 282 | Testbaan |
| 25 | 4* UDC cold | cold | 2018-4-10 | 22.1 | 11:22 | 162 | 326 | Testbaan |
| 26 | 120 kph | warm | 2018-4-10 | 22.7 | 12:58 | 206 | 468 | Testbaan |
| 27 | 4* UDC warm | warm | 2018-4-10 | 23.1 | 13:10 | 134 | 261 | Testbaan |
| 28 | 120 kph | warm | 11-4-2018 | 20.0 | 13:58 | 164 | 746 | Testbaan |
| 29 | 3*EUDC | warm | 11-4-2018 | 20.1 | 13:15 | 125 | 350 | Testbaan |
| 30 | 4* UDC cold | cold | 16-4-2018 | 18.9 | 13:14 | 143 | 554 | Testbaan |
| 31 | 120 kph | warm | 16-4-2018 | 18.6 | 14:51 | 157 | 842 | Testbaan |
| 32 | 4* UDC warm | warm | 16-4-2018 | 19.0 | 15:04 | 134 | 610 | Testbaan |
| 33 | 130 kph | warm | 18-4-2018 | 23.0 | 12:18 | 211 | 1416 | Testbaan |
| 34 | 3*EUDC | warm | 18-4-2018 | 23.7 | 12:44 | 123 | 165 | Testbaan |
| 35 | 4* UDC cold | cold | 19-4-2018 | 30.6 | 14:27 | 139 | 255 | Testbaan |
| 36 | 4* UDC warm | warm | 19-4-2018 | 31.3 | 15:29 | 131 | 435 | Testbaan |
| 37 | 3*EUDC | warm | 19-4-2018 | 31.0 | 16:23 | 128 | 411 | Testbaan |
| 38 | 4* UDC cold | cold | 24-4-2018 | 13.1 | 08:27 | 148 | 708 | Testbaan |
| 39 | 120 kph | warm | 24-4-2018 | 13.5 | 09:42 | 206 | 936 | Testbaan |
| 40 | 4* UDC warm | warm | 24-4-2018 | 13.6 | 09:55 | 140 | 563 | Testbaan |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 41 | 120 kph | warm | 24-4-2018 | 15.4 | 11:34 | 173 | 1060 | Testbaan |
| 42 | 3*EUDC | warm | 24-4-2018 | 15.4 | 11:47 | 128 | 567 | Testbaan |
| 43 | NEDC cold | cold | 7-5-2018 | 25.6 | 12:51 | 139 | 272 | Testbaan |
| 44 | 120 kph | warm | 7-5-2018 | 25.4 | 13:11 | 155 | 283 | Testbaan |
| 45 | 4* UDC warm | warm | 7-5-2018 | 27.0 | 13:25 | 130 | 384 | Testbaan |
| 46 | 4* UDC warm | warm | 7-5-2018 | 29.5 | 14:40 | 131 | 524 | Testbaan |
| 47 | 120 kph | warm | 7-5-2018 | 30.5 | 16:17 | 164 | 626 | Testbaan |
| 48 | 3*EUDC | warm | 7-5-2018 | 30.3 | 16:32 | - | | Testbaan |
| 49 | NEDC cold | cold | 8-5-2018 | 28.7 | 13:34 | 139 | 214 | Testbaan |
| 50 | 3*EUDC | warm | 8-5-2018 | 39.0 | 14:05 | 131 | 298 | Testbaan |
| 51 | 4* UDC cold | cold | 9-5-2018 | 26.9 | 14:59 | 148 | 265 | Testbaan |
| 52 | 9* ECE | warm | 9-5-2018 | 26.8 | 16:15 | 138 | 441 | Testbaan |
| 53 | 4* UDC warm | warm | 9-5-2018 | 27.3 | 16:21 | 146 | 437 | Testbaan |
| 54 | 3*EUDC | warm | 11-5-2018 | 14.0 | 09:19 | 142 | 451 | Testbaan |
| 55 | NEDC cold | cold | 14-5-2018 | 27.4 | 14:12 | 141 | 259 | Testbaan |
| 56 | NEDC warm | warm | 14-5-2018 | 28.6 | 14:36 | 140 | 329 | Testbaan |
| 57 | 3*EUDC | warm | 14-5-2018 | 28.7 | 15:02 | 148 | 440 | Testbaan |
| 58 | ? | cold | 22-5-2018 | 25.3 | 14:04 | 161 | 178 | Testbaan |
| 59 | UDC | warm | 22-5-2018 | 25.3 | 15:45 | 141 | 324 | Testbaan |
| 60 | 3*EUDC | warm | 22-5-2018 | 25.0 | 16:39 | 128 | 255 | Testbaan |
| 61 | 4* UDC cold | cold | 25-5-2018 | 19.8 | 08:06 | 144 | 291 | Testbaan |
| 62 | 120 kph | warm | 25-5-2018 | 22.0 | 09:23 | 184 | 772 | Testbaan |
| 63 | 4* UDC warm | warm | 25-5-2018 | 22.0 | 09:36 | 136 | 219 | Testbaan |
| 64 | 120 kph | warm | 25-5-2018 | 25.0 | 11:44 | 166 | 597 | Testbaan |
| 65 | 3*EUDC | warm | 25-5-2018 | 25.0 | 11:57 | 127 | 281 | Testbaan |
| 66 | 120 kph | warm | 29-5-2018 | 33.1 | 14:50 | 181 | 520 | Testbaan |
| 67 | 3*EUDC | warm | 29-5-2018 | 33.0 | 15:10 | 127 | 249 | Testbaan |
| 68 | NEDC cold | cold | 30-5-2018 | 27.2 | 13:35 | 140 | 102 | Testbaan |
| 69 | 3*EUDC | warm | 30-5-2018 | 27.4 | 14:00 | 126 | 88 | Testbaan |
| 70 | NEDC cold | cold | 31-5-2018 | 27.0 | 12:01 | 139 | 89 | Testbaan |
| 71 | 120 kph | warm | 31-5-2018 | 20.3 | 12:58 | 185 | 694 | Testbaan |
| 72 | Coastdown | warm | 31-5-2018 | 23.0 | 13:15 | 126 | 286 | Testbaan |
| 73 | 120 kph | warm | 31-5-2018 | 23.0 | 16:04 | 202 | 847 | Testbaan |
| 74 | 3*EUDC | warm | 31-5-2018 | 23.6 | 16:18 | 122 | 105 | Testbaan |
| 75 | RDE warm | warm | 6-6-2018 | 25.9 | 11:40 | 127 | 426 | Testbaan |
| 76 | 4* UDC cold | cold | 14-8-2018 | | | | | Testbaan |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 77 | 3*EUDC | warm | 14-8-2018 | 23.0 | 11:48 | 114 | 111 | Rollenbank |
| 78 | NEDC cold | cold | 15-8-2018 | 23.0 | 11:11 | 129 | 95 | Rollenbank |
| 79 | 3*EUDC | warm | 15-8-2018 | 23.0 | 13:13 | 112 | 100 | Rollenbank |
| 80 | NEDC cold | cold | 16-8-2018 | 23.0 | 11:07 | 118 | 79 | Rollenbank |
| 81 | 3*EUDC | warm | 16-8-2018 | 23.0 | 11:47 | 111 | 90 | Rollenbank |
| 82 | NEDC cold | cold | 17-8-2018 | 23.0 | 11:28 | 98 | 74 | Rollenbank |
| 83 | 3*EUDC | warm | 17-8-2018 | 23.0 | 13:16 | 119 | 96 | Rollenbank |
| 84 | 4*UDC cold | cold | 20-8-2018 | 23.0 | 13:53 | 131 | 148 | Rollenbank |
| 85 | 4*UDC cold | cold | 21-8-2018 | 23.0 | 11:14 | 131 | 182 | Rollenbank |
| 86 | 3*EUDC | warm | 21-8-2018 | 23.0 | 12:28 | 161 | 405 | Rollenbank |
| 87 | NEDC cold | cold | 22-8-2018 | 23.0 | 15:30 | 127 | 163 | Rollenbank |
| 88 | 3*EUDC | warm | 22-8-2018 | 23.0 | 16:26 | 116 | 141 | Rollenbank |
| 89 | NEDC cold | cold | 23-8-2018 | 23.0 | 11:58 | 126 | 90 | Rollenbank |
| 90 | 4*UDC warm | warm | 24-8-2018 | 23.0 | 13:16 | 136 | 195 | Rollenbank |
| 91 | ? | cold | 27-8-2018 | 23.0 | 10:20 | - | - | Rollenbank |
| 92 | ? | warm | 27-8-2018 | 23.0 | 16:34 | - | - | Rollenbank |
| 93 | NEDC cold | cold | 28-8-2018 | 23.0 | 10:43 | - | - | Rollenbank |
| 94 | ? | warm | 28-8-2018 | 23.0 | 11:27 | - | - | Rollenbank |
| 95 | ? | cold | 29-8-2018 | 23.0 | 14:35 | 93 | 50 | Rollenbank |
| 96 | 3*EUDC | warm | 29-8-2018 | 23.0 | 15:16 | 129 | 148 | Rollenbank |
| 97 | NEDC cold | cold | 30-8-2018 | 23.0 | 14:00 | 113 | 90 | Rollenbank |
| 98 | 3*EUDC | warm | 30-8-2018 | 23.0 | 14:49 | 130 | 149 | Rollenbank |
| 99 | 4*UDC cold | cold | 3-9-2018 | 23.0 | | | | Rollenbank |
| 100 | NEDC cold | cold | 13-9-2018 | 23.0 | 16:29 | - | - | Rollenbank |
| | | | | | | | | |
| 101 | Road load | warm | 17-10-2018 | | 16:07 | 185 | 1266 | Testbaan |
| 102 | Road load | warm | 19-10-2018 | | 14:46 | 171 | 1541 | Testbaan |
| | | | | | | | | |

| Overzicht test programma Suzuki Vitara, engine calibration C2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| No | Test | Start | Date | Tambient | Time | CO2 | NOx | Locatie | Opmerking |
| | | | | [°C] | | [g/km] | [mg/km] | | |
| 1 | NEDC | | 26-6-2018 | 18 | 09:34 | 161 | 368 | Testbaan | Start-stop not active |
| 2 | 120 kph | warm | 26-6-2018 | 18 | 10:33 | 158 | 287 | Testbaan | Start-stop not active |
| 3 | NEDC | warm | 26-6-2018 | 18 | 10:47 | 145 | 350 | Testbaan | Start-stop not active |
| 4 | NEDC | warm | 26-6-2018 | 18 | 11:08 | 140 | 173 | Testbaan | Start-stop not active |
| 5 | NEDC | warm | 26-6-2018 | 19 | 11:29 | 136 | 74 | Testbaan | Start-stop not active |
| 6 | NEDC | warm | 26-6-2018 | 19 | 13:50 | 143 | 156 | Testbaan | Start-stop not active |
| 7 | NEDC | warm | 26-6-2018 | 19 | 14:19 | 138 | 255 | Testbaan | Start-stop not active |
| 8 | Failed test | | 27-6-2018 | 24 | 15:25 | 158 | 275 | Testbaan | Start-stop not active |
| 9 | 120 kph | warm | 17-7-2018 | 23 | 14:32 | 208 | 665 | Testbaan | Start-stop not active |
| 10 | 3* EUDC | warm | 17-7-2018 | 23 | 14:52 | 125 | 275 | Testbaan | Start-stop not active |
| 11 | NEDC | cold | 18-7-2018 | 23 | 08:22 | 142 | 114 | Testbaan | Start-stop not active |
| 12 | Failed test | | 18-7-2018 | 23 | 10:45 | 176 | 349 | Testbaan | Start-stop not active |
| 13 | Failed test | | 18-7-2018 | 23 | 10:54 | 168 | 561 | Testbaan | Start-stop not active |
| 14 | 4*UDC | warm | 18-7-2018 | 23 | 11:10 | 145 | 361 | Testbaan | Start-stop not active |
| 15 | 3*EUDC | warm | 18-7-2018 | 23 | 12:04 | 127 | 423 | Testbaan | Start-stop not active |
| 16 | Failed test | | 19-7-2018 | - | - | - | - | Testbaan | Start-stop not active |
| 17 | Failed test | | 19-7-2018 | - | - | - | - | Testbaan | Start-stop not active |
| 18 | 130 kph | warm | 30-8-2018 | 18 | 13:05 | 190 | 664 | Testbaan | Start-stop not active |
| 19 | 3*EUDC | warm | 17-9-2018 | 23 | 14:24 | 135 | 305 | Testbaan | Start-stop not active |
| 20 | NEDC | cold | 18-9-2018 | 24 | 13:37 | 154 | 198 | Testbaan | Start-stop not active |
| 21 | 3*EUDC | warm | 18-9-2018 | 24 | 14:13 | 130 | 279 | Testbaan | Start-stop not active |
| 22 | 4*UDC | warm | 18-9-2018 | 24 | 14:47 | 167 | 398 | Testbaan | Start-stop not active |
| 23 | 3*EUDC | warm | 18-9-2018 | 23 | 15:42 | 168 | 640 | Testbaan | Start-stop not active |
| 24 | 4*UDC | cold | 19-9-2018 | 23 | 13:37 | 173 | 220 | Testbaan | Start-stop not active |
| 25 | ? | cold | 25-9-2018 | 14 | 09:39 | 183 | 946 | Testbaan | Start-stop not active |
| 26 | 3*EUDC | warm | 25-9-2018 | 14 | 09:54 | 130 | 127 | Testbaan | Start-stop not active |
| 27 | 4*UDC | cold | 26-9-2018 | 10 | 08:02 | 171 | 316 | Testbaan | Start-stop not active |
| 28 | 3*EUDC | warm | 26-9-2018 | 13 | 09:00 | 130 | 251 | Testbaan | Start-stop not active |
| 29 | ? | warm | 26-9-2018 | 17 | 15:36 | 176 | 498 | Testbaan | Start-stop not active |
| | | | | | | | | | |

| No | Test | Start | Date | Tambient | Time | CO2 | NOx | Locatie | Opmerking |
|---|---|---|---|---|---|---|---|---|---|
| | | | | [°C] | | [g/km] | [mg/km] | | |
| | | | | | | | | | |
| 30 | Warming up | cold | 16-10-2018 | 20 | 11:00 | 173 | 569 | Testbaan | |
| 31 | Coast down | warm | 16-10-2018 | 20 | 11:12 | 140 | 939 | Testbaan | |
| 32 | Coast down | warm | 16-10-2018 | 23 | 12:31 | 125 | 308 | Testbaan | |
| 33 | Coast down | warm | 16-10-2018 | 23 | 12:37 | 126 | 218 | Testbaan | |
| 34 | Coast down | warm | 16-10-2018 | 23 | 12:44 | 124 | 152 | Testbaan | |
| 35 | 3*EUDC | warm | 18-10-2018 | 15 | 16:31 | 127 | 240 | Testbaan | |
| 36 | 4* UDC | cold | 24-10-2018 | 25-18 | 14:16 | 160 | 148 | Testbaan | |
| 37 | 120 kph | warm | 24-10-2018 | 18 | 15:50 | 199 | 785 | Testbaan | |
| 38 | 3*EUDC | warm | 24-10-2018 | 17 | 16:03 | 127 | 156 | Testbaan | |
| 39 | RDE | warm | 1-11-2018 | 16 | 10:27 | 137 | 619 | Testbaan | |
| 40 | 3*EUDC | warm | 1-11-2018 | 16 | 12:20 | 128 | 160 | Testbaan | |
| 41 | NEDC cold | cold | 6-11-2018 | 25-13 | 08:52 | 150 | 312 | Testbaan | |
| 42 | NEDC hot | warm | 6-11-2018 | 13 | 09:16 | 142 | 210 | Testbaan | |
| 43 | 80 kph | warm | 6-11-2018 | 13 | 09:37 | 101 | 121 | Testbaan | |
| 44 | NEDC cold | cold | 7-11-2018 | 25-17 | 13:22 | 151 | 297 | Testbaan | |
| 45 | 3*EUDC | warm | 7-11-2018 | 17 | 13:45 | 129 | 243 | Testbaan | |
| 46 | 8* UDC | cold | 8-11-2018 | 25-13 | 08:18 | 157 | 388 | Testbaan | |
| 47 | | | 16-11-2018 | | | | | Testbaan | |
| 48 | NEDC + RLS1 | cold | 7-12-2018 | 23 | 12:40 | - | - | Rollenbank | |
| 49 | 3*EUDC | warm | 7-12-2018 | 23 | 13:29 | 122 | 153 | Rollenbank | |
| 50 | NEDC cold | cold | 10-12-2018 | 23 | 15:42 | 135 | 103 | Rollenbank | |
| 51 | NEDC + RLS2 | warm | 10-12-2018 | 23 | 16:30 | - | - | Rollenbank | |
| 52 | 3*EUDC | warm | 10-12-2018 | 14 | 17:14 | 167 | 679 | Rollenbank | |
| 53 | 4* UDC | cold | 11-12-2018 | 14 | 08:50 | 193 | 207 | Rollenbank | |
| 54 | 3*EUDC | warm | 11-12-2018 | 14 | 10:48 | 165 | 804 | Rollenbank | |
| 55 | 4* UDC | cold | 12-12-2018 | 14 | 08:26 | 198 | 204 | Rollenbank | |
| 56 | 3*EUDC | warm | 12-12-2018 | 23 | 10:36 | 172 | 642 | Rollenbank | |
| 57 | NEDC cold | cold | 13-12-2018 | 23 | 10:49 | 158 | 334 | Rollenbank | |
| 58 | 80 km/h | warm | 13-12-2018 | 14 | 12:07 | 158 | 301 | Rollenbank | |
| 59 | 80 km/h | cold | 14-12-2018 | 14 | 09:34 | 149 | 360 | Rollenbank | |
| 60 | 3* EUDC | warm | | 23 | | - | - | Rollenbank | |
| 61 | NEDC cold | cold | 30-1-2019 | 23 | | - | - | Rollenbank | |
| 62 | Trial | warm | 16-4-2019 | | | - | - | Testbaan | |
| 63 | Trial | warm | 16-4-2019 | | | 368 | 2228 | Testbaan | |
| 64 | 120 km/h | warm | 16-4-2019 | 20 | | 200 | 799 | Testbaan | |
| 65 | 110 km/h | warm | 17-4-2019 | 20 | | 168 | 270 | Testbaan | |
| 66 | 3*EUDC | warm | 17-4-2019 | 19 | | 132 | 166 | Testbaan | |
| 67 | NEDC | cold | 18-4-2019 | 23 | | 151 | 225 | Testbaan | |
| 68 | 3*EUDC | warm | 18-4-2019 | 23 | | 132 | 281 | Testbaan | |
| 69 | 4*UDC | cold | 23-4-2019 | 23 | | 164 | 228 | Testbaan | |
| 70 | 3*EUDC | warm | 23-4-2019 | 25 | | 130 | 163 | Testbaan | |
| 71 | 80 kph | warm | 24-4-2019 | 19 | | 108 | 105 | Testbaan | |
| 72 | 120 kph | warm | 02.05-2019 | 15 | 12:30 | 172 | 323 | Testbaan | |
| 73 | 3*EUDC | warm | 02.05-2019 | 15 | 12:54 | 132 | 198 | Testbaan | |
| 74 | 8*UDC | cold | 7-5-2019 | 26-13 | 07:31 | 161 | 375 | Testbaan | |
| 75 | 2* zaagtand | warm | 7-5-2019 | 12 | 09:48 | 126 | 514 | Testbaan | |
| 76 | 50-100-50 kph zaagtand | warm | 7-5-2019 | 15 | 12:27 | 105 | 147 | Testbaan | |
| 77 | RDE | warm | 21-5-2019 | | 08:43 | 129 | 399 | Testbaan | |
| 78 | RDE | warm | 28-5-2019 | | 12:23 | 129 | 461 | Testbaan | |
| 79 | RDE | warm | 29-5-2019 | | 10:09 | 136 | 493 | Testbaan | |
| 80 | 110 kph | cold | 12-7-2019 | | | | | Testbaan | |

# D Dynamometer specifications

Horiba Europe GMBH performs emission tests in its laboratory in accordance with ISO 17025 standards and is certified to do this.

The following measuring equipment is installed in the test room:

**Chassis Test Cell**

**Air conditioning**
Weiss Umwelttechnik
cooling performance 150 kW
air circulation 30,000 m³/h
fresh air 2,000 m³/h
CVS dilution air 1,200 m³/h
waste air 2,000 – 4,000 m³/h

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

**Exhaust Measurement Equipment**
**MEXA ONE D1-EGR**
Exhaust gas analyser,
Undiluted (direct) for:
$O_2$, CO, $CO_2$, $NO_x$/NO, THC and $CH_4$,
separate EGR analyser

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

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

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

- o **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.
- o **Horiba MEXA ONE 2-OV**, Exhaust Gas Analysing System for dilute bag & continuous measurement with the following analysers: $O_2$, CO, $CO_2$, $NO_x$/NO, THC, CH4.
- o **Horiba MEXA 2100 SPCS**, Solid Particle Counting System.
- o **Horiba MEXA ONE CVS**, Constant Volume Sampler System, 6 $m^3$/min to 18 $m^3$/h.
- o **Horiba DLS 7000**, Particulate Measuring System with Dilution Tunnel DLT 18.
- o Different temperature and pressure regulators (according to the test application), max. 16 temperature inputs (Type K) and 8 voltage- and current analogue inputs.
- o **Horiba VETS One**, Host Computer and evaluation of measuring data with DIVA.
- o **Horiba PWS-ONE**, Particle measurement and conditioning chamber with micro balance and robot.