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**TNO report**

**TNO 2019 R11859**

**Research into NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission of 157-191 mg/km is measured in an NEDC test on the test track. The only circumstances under which the NO<sub>x</sub> 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<sub>x</sub> storage capacity of the LNT is maximised at the start of an emission test. During the emission test, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions at different ambient temperatures. With an ambient temperature of 6 °C the NO<sub>x</sub> 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<sub>x</sub> emission increases. The ambient temperature seems to have a bigger influence on the NO<sub>x</sub> 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<sub>x</sub> emissions of the engine abruptly rise from 300 to 450 mg per ECE cycle. The timing of this sudden increase in NO<sub>x</sub> emissions varies in the different tests, but no explanation for this has been found. The increase in NO<sub>x</sub> 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<sub>x</sub> emissions. These have not been examined. In UDC tests with a warm start at an ambient temperature above 20 °C, the NO<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission is dependent on the ambient temperature. Substantially higher NO<sub>x</sub> 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<sub>2</sub> emissions are 114.9 – 117.2 g/km, which is 8 - 11% higher than the value specified by the manufacturer. The measured NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> 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<sub>2</sub> emissions from 115 to 152 g/km (+ 32%). The NO<sub>x</sub> emission varies between 65 and 168 mg/km and has no direct relationship with increasing driving resistance.

*Partial conclusion 11:*

The CO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> and -2.3 – 2.6% for NO<sub>x</sub>. For the partial conclusions that relate to the NO<sub>x</sub> 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<sub>x</sub> emission increases if the ambient temperatures drop. Furthermore, the number and duration of the LNT regenerations in the preconditioning test influences the NO<sub>x</sub> emissions in the NEDC test. With an ambient temperature above 20 °C and a standard preconditioning cycle (3\* EUDC), an NO<sub>x</sub> 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<sub>x</sub> buffer capacity varies at the start of an emission test and this influences the NO<sub>x</sub> emissions from the emission test.

*Partial conclusion 15:*

The NEDC NO<sub>x</sub> emissions with a cold start of engine calibration 2 are substantially higher than the NO<sub>x</sub> 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<sub>x</sub> emissions of the vehicle abruptly rise from approximately 150 to 450 mg per ECE cycle. The time of this sudden rise in NO<sub>x</sub> emissions lies within the 12th to 14th ECE cycle of a UDC test.

The increase in NO<sub>x</sub> 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<sub>x</sub> emissions. These have not been examined.

*Partial conclusion 17:*

With the same ambient temperatures and the same preconditioning cycles, the NO<sub>x</sub> 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<sub>x</sub> emission. After the cold start, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> emissions are 129 - 137 g/km and the NO<sub>x</sub> 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<sub>2</sub> emissions are 118.5 g/km, which is 12% higher than the type-approval value specified by the manufacturer. The measured NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> 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<sub>2</sub> emissions from 119 to 175-178 g/km (+ 48%). At the same time, the NO<sub>x</sub> emissions also increase from 64 to 120-141 mg/km (+ 87% to + 120%).

*Partial conclusion 22:*

The CO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> and -2.3 to 2.6% for NO<sub>x</sub>.

For the partial conclusions that relate to the NO<sub>x</sub> 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<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> concentration is 1.5 - 2.7%, based on the pressure measurements. The occurring pressures at the two NO<sub>x</sub>-O<sub>2</sub> sensors do explain part of the remaining constant differences in NO<sub>x</sub> 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<sub>x</sub> 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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## **Appendices**

- A Reference fuel certificates
- B Results of dynamometer emission testing
- C Test track and dynamometer SEMS results
- D Dynamometer specifications



# 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission was 274 mg/km and in a test with a cold start at an ambient temperature of 14 °C, the NO<sub>x</sub> emission was 377 mg/km.

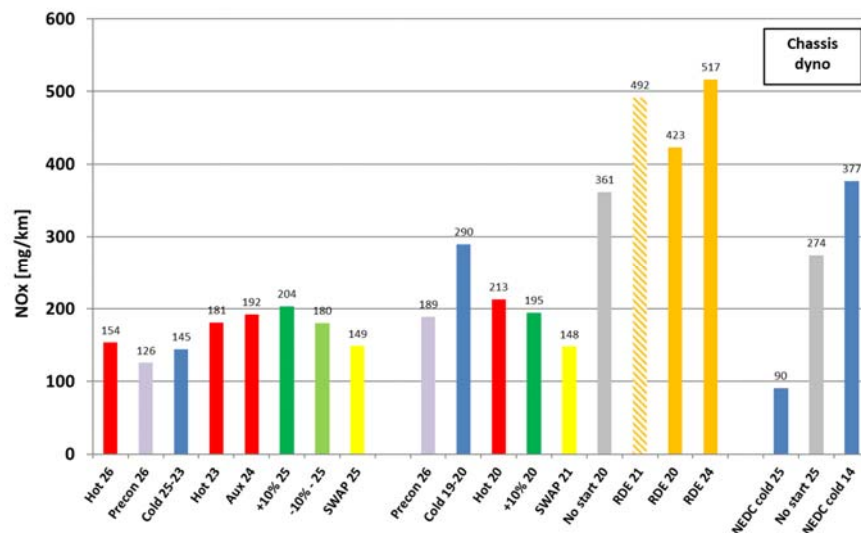


Figure 1-1: NO<sub>x</sub> test results from initial exploratory measurements in a RDW study from 2017 on a Suzuki Vitara Euro 6b diesel. The diesel particulate filter has been regenerated in the RDE test using the shaded bar.

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<sub>x</sub> 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<sub>x</sub> emission behaviour of this vehicle with both engine calibrations. The measured emission behaviour with the original engine calibration shows increased NO<sub>x</sub> 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<sub>x</sub> 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

<u>Date of period</u>	<u>Activity</u>
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 track
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.

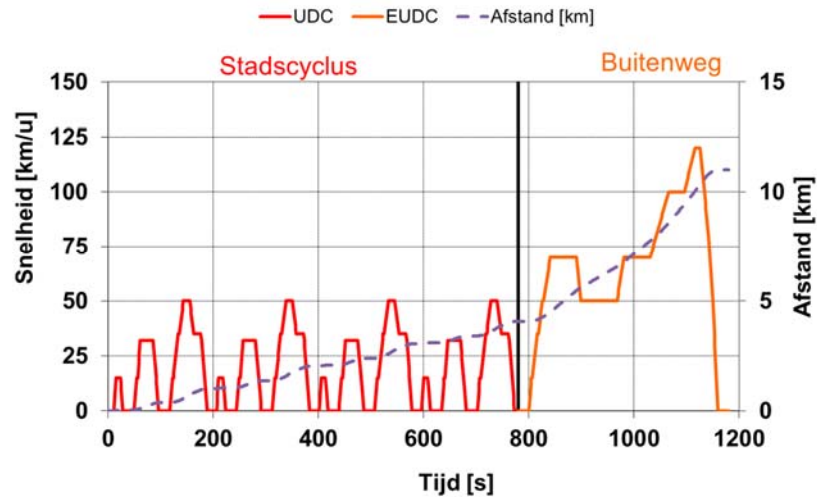


Figure 2-2: NEDC test cycle used in the type-approval on the chassis dynamometer with urban and out of the town road cycle parts.

## 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 ( $F_{\text{total}}$ , in Newton) at constant speeds ( $v$ ) is calculated with the following equation.

$$F_{\text{total}} = F_0 + F_1 \cdot v + F_2 \cdot v^2$$

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 <sup>2</sup> /h <sup>2</sup> )]	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.

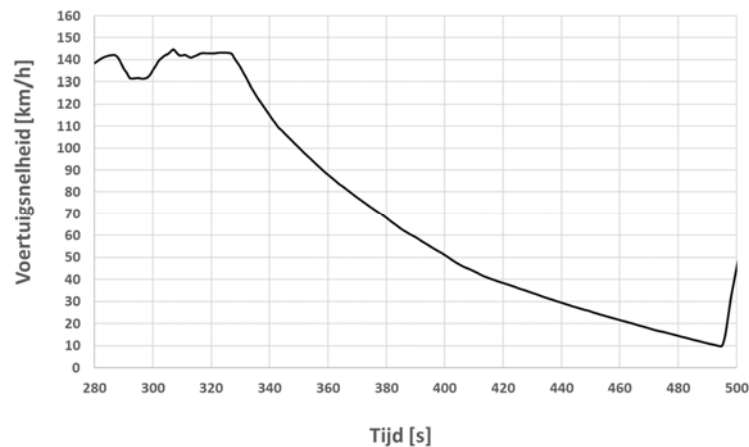


Figure 2-3: Example of a test result to determine the driving resistance of a vehicle. This test is repeated a number of times (not shown here). Y-axis: vehicle speed, X-axis: time in seconds.

## 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.



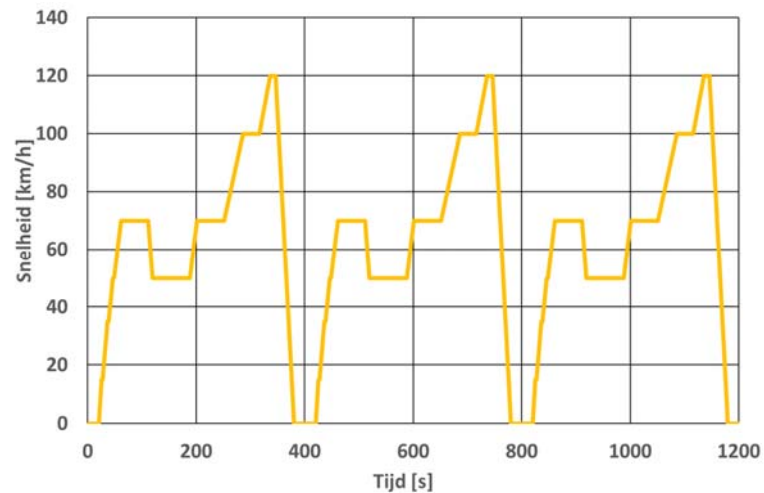


Figure 2-4: Test Cycle (3\*EUDC) for preconditioning of the Suzuki Vitara.

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<sub>x</sub>, 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 <sub>x</sub>	THC+NO <sub>x</sub>	PM	PN
[mg/km]	[mg/km]	[mg/km]	[mg/km]	[#/km]
500	80	170	4.5	6.0 * 10 <sup>11</sup>

The CO<sub>2</sub> 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<sub>2</sub> 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.

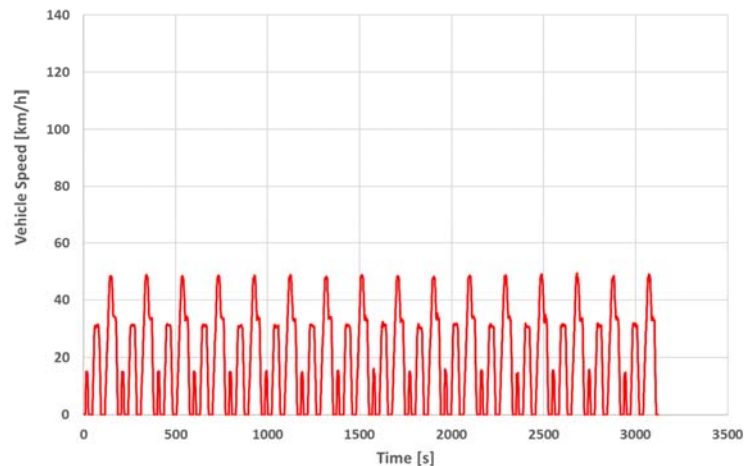


Figure 2-5: 4\*UDC test cycles, 16 kilometres in total

## 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<sub>2</sub> and NO<sub>x</sub> 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 2. TSML YD81S00183218
Engine displacement	[cm <sup>3</sup> ]	1598
Max. Power	[kW]	88
Gear box		Manual 6v
Emission class	[-]	Euro 6b
Emission systems		Low and high-pressure EGR system Lean NO <sub>x</sub> 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	[km]	95,068
Mileage of vehicle 2		40,500
Date of first registration		8 July 2015 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  $\text{NO}_x$  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  $\text{NO}_x$ .
- 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  $\text{NO}_x$ .
- The Lean  $\text{NO}_x$  Trap (LNT) (also known as NSC), which initially stores  $\text{NO}_x$  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.

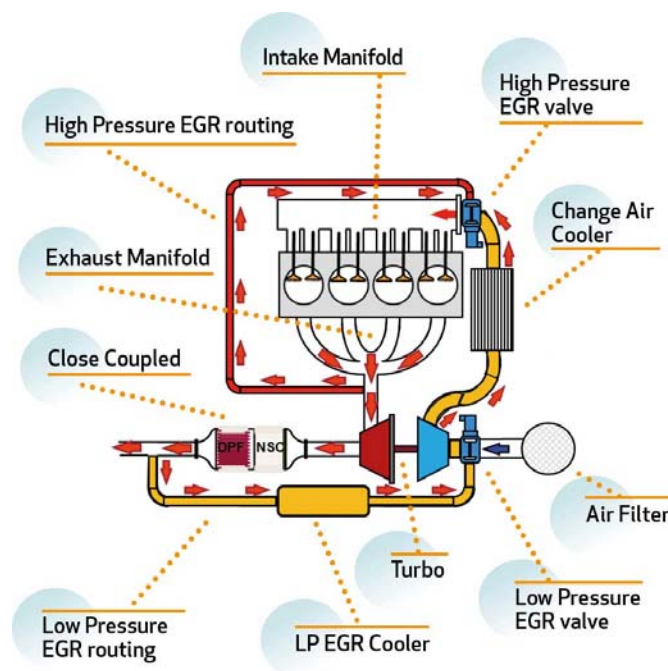


Figure 3-1: Schematic representation of the Euro 6b diesel engine of the Suzuki Vitara with high and low-pressure EGR systems.

## 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  $\text{NO}_x\text{-O}_2$  sensors installed in the exhaust system before and after the Lean  $\text{NO}_x$  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  $\text{NO}_x$  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.

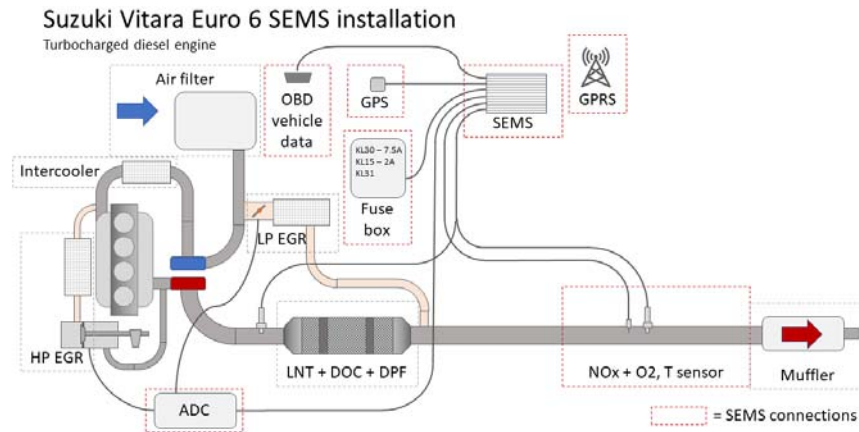


Figure 3-3: Schematic representation of the Euro 6b diesel engine of the Suzuki Vitara and the SEMS measurement system.

### 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 [kg]	F0 [N]	F1 [N/km]	F2 [N/km <sup>2</sup> ]
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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions that varied from 321 to 905 mg/km.

In the two RDE tests performed with the second vehicle, NO<sub>x</sub> emissions of respectively 831 and 905 mg/km were measured. With a test at a constant speed of 130 km/h, the measured NO<sub>x</sub> emission is 1354 mg/km.

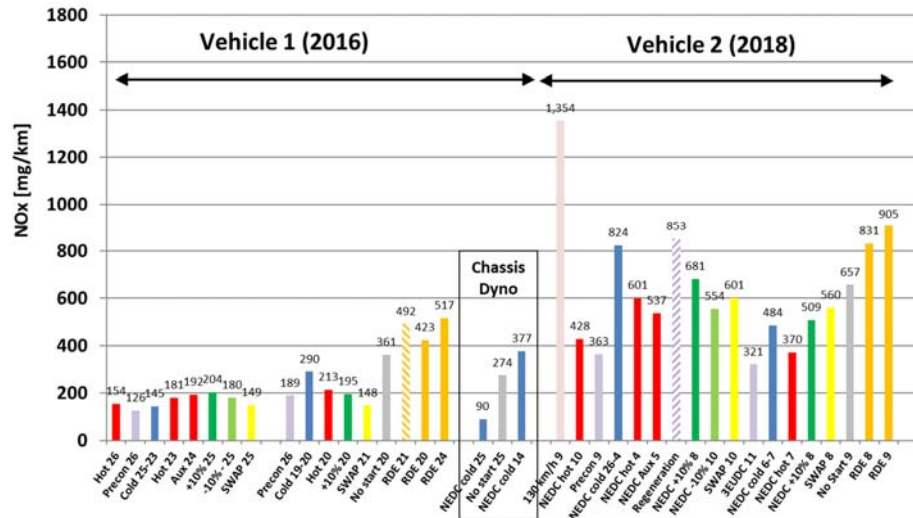


Figure 4-1: Measured NO<sub>x</sub> emissions from the first exploratory test track measurements of the two investigated Suzuki Vitaras Euro 1 diesel with engine calibration 1. The first vehicle was tested by RDW in 2016 at ambient temperatures of 20-26 °C on the test track and on the chassis dynamometer. 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 NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> emission is 139 to 143 g/km. In one test carried out at an ambient temperature of 6 °C, the NO<sub>x</sub> emission is 897 mg/km and the CO<sub>2</sub> 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<sub>x</sub> 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 <sub>2</sub> [g/km]	NO <sub>x</sub> [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.

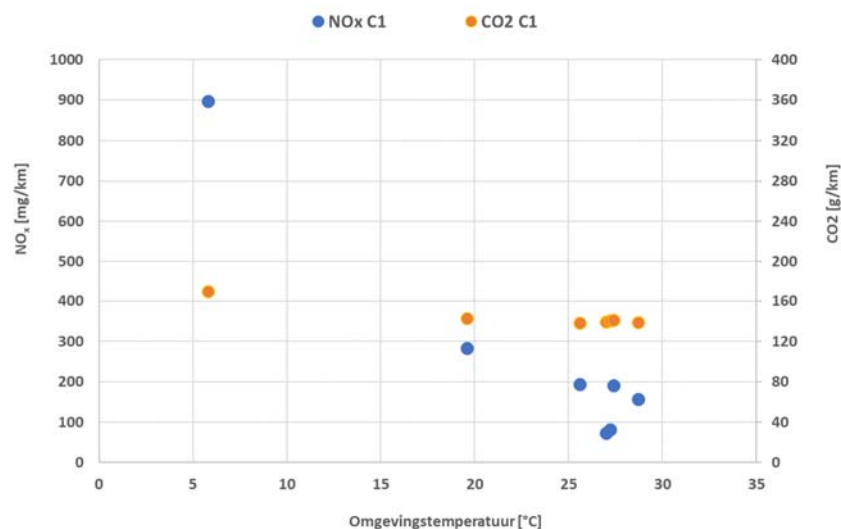


Figure 4-2: Corrected NO<sub>x</sub> and CO<sub>2</sub> emissions of NEDC tests with a cold start, measured on the test track with engine calibration 1 at different ambient temperatures.

*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<sub>x</sub> 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<sub>x</sub> emission of 157-191 mg/km is measured in an NEDC on the test track. The only circumstances under which the NO<sub>x</sub> 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<sub>x</sub> emission in the emission test with engine calibration 1*

This section discusses partial objective 11 from section 1.2.

Given the spread of NO<sub>x</sub> 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<sub>x</sub> trap is filled) and the regeneration frequency.

*Background:*

A Lean NO<sub>x</sub> Trap (LNT) is capable of storing a certain amount of NO<sub>x</sub>. 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<sub>x</sub> into other components (H<sub>2</sub>O, CO<sub>2</sub>, N<sub>2</sub> and O<sub>2</sub>). After the regeneration, the LNT is "empty" and is able to store NO<sub>x</sub> 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<sub>2</sub> 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<sub>x</sub> concentration measured by the sensor appears to be very high after the LNT for 3-4 seconds. The measured high NO<sub>x</sub> concentration at the time of LNT regenerations is further investigated in chapter 5.

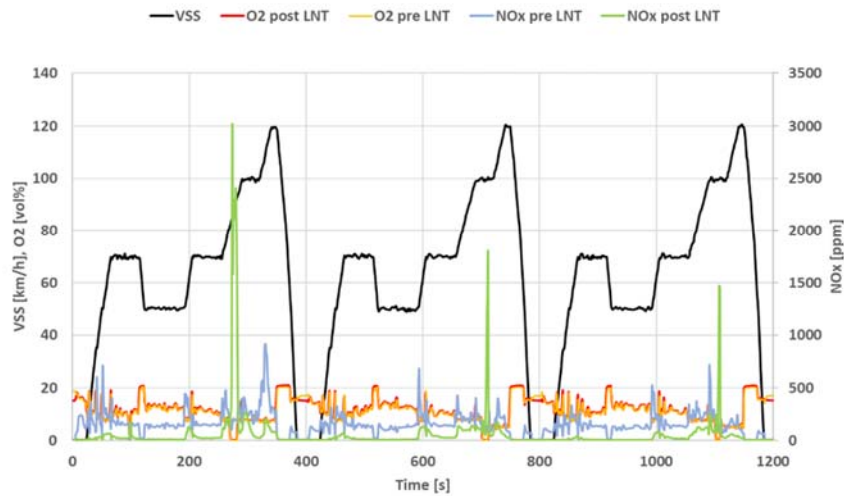


Figure 4-3: 3\*EUDC test with engine calibration 1 and warm start, conducted on 18-04-2018 on the test track, at an ambient temperature of 24 °C. The LNT is regenerated three times for 10-12 seconds.

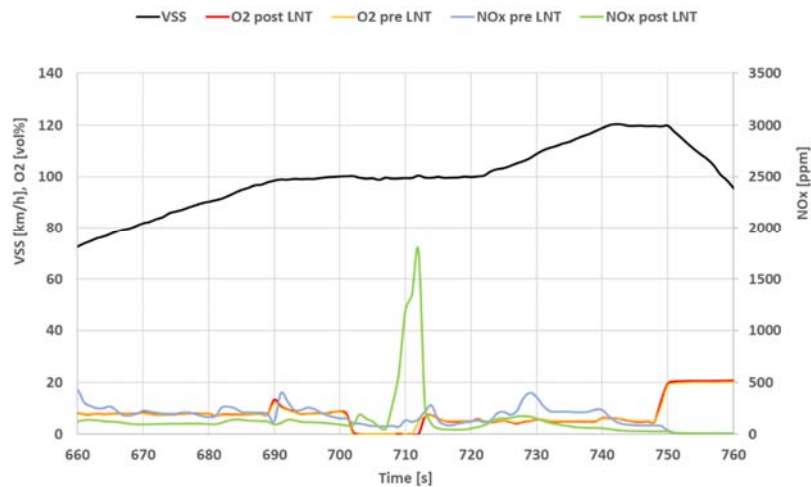


Figure 4-4: LNT regeneration of a 3\*EUDC test with engine calibration 1 and warm start, conducted on 18-04-2018 on the test track, at an ambient temperature of 24 °C. The LNT is regenerated for about 10 seconds and the oxygen concentration in the exhaust gas is nil. During the LNT regeneration, the sensor briefly measured a very high NO<sub>x</sub> 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<sub>x</sub> emissions in the NEDC test.

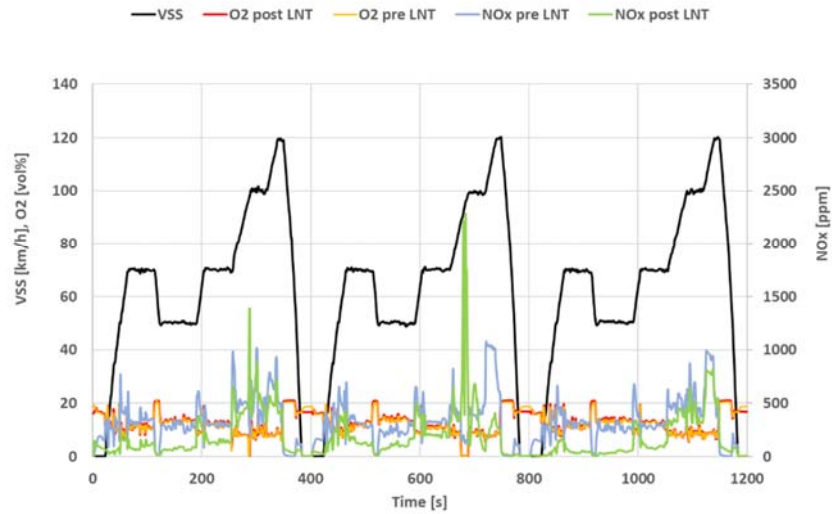


Figure 4-5: 3\*EUDC test with engine calibration 1 and warm start, conducted on 24-04-2018 on the test track, at an ambient temperature of 15 °C. The LNT is first regenerated for 3 seconds and then 13 seconds, but in the last ECE cycle the LNT is not regenerated.

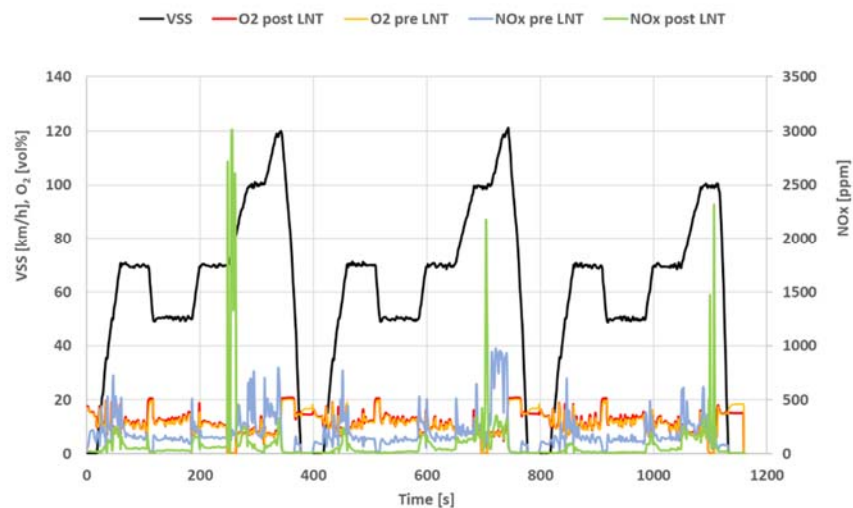


Figure 4-6: 3\*EUDC test with engine calibration 1 and warm start, conducted on 29-05-2018 on the test track, at an ambient temperature of 28 °C. The LNT is regenerated three times for 10-13 seconds. The last EUDC cycle ended after the 100 km/h part of the LNT regeneration.

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<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> storage capacity of the LNT is maximised at the start of an emission test. During the emission test, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions are 937 and 547 mg/km in tests with cold and warm starts. With ambient temperatures between 27 and 29 °C, the NO<sub>x</sub> emission in the NEDC test with a cold start decrease significantly (up to 259 mg/km on the test track). The NO<sub>x</sub> emissions in an NEDC test with a warm start are 329 mg/km.



Table 4-2: NO<sub>x</sub> and CO<sub>2</sub> emissions of NEDC tests with cold and warm starts on the test track with engine calibration 1.

Date	T environment [°C]	CO <sub>2</sub> [g/km]	NO <sub>x</sub> [mg/km]	CO <sub>2</sub> [g/km]	NO <sub>x</sub> [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<sub>x</sub> emissions (533 mg/km) compared to the NEDC test with a cold start (897 mg/km). However, there is an increase in NO<sub>x</sub> 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<sub>x</sub> emissions, there might be other factors that influence the NO<sub>x</sub> emission behaviour.

The cause of the differences in NO<sub>x</sub> 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 (T<sub>ambient</sub>), the position signal of the high-pressure EGR valve, and the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission is 191 mg/km, see Figure 4-8.

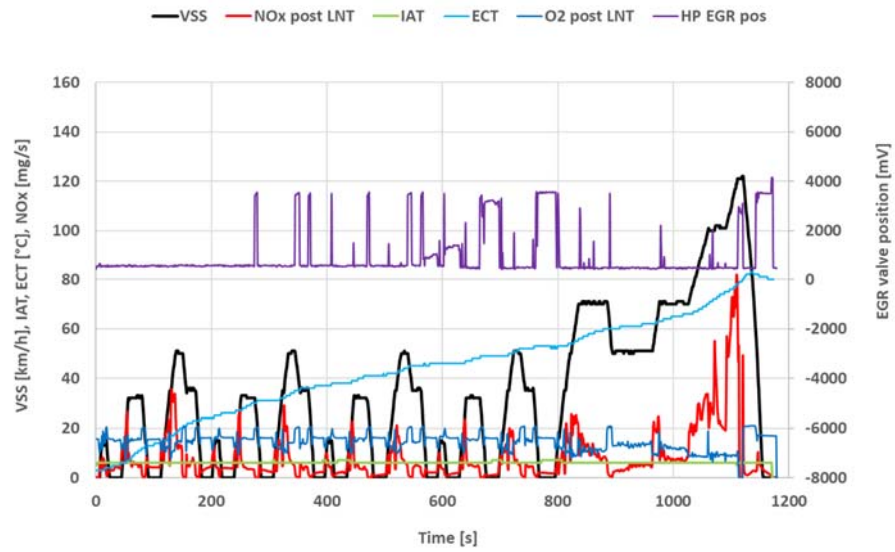


Figure 4-7: NEDC test of 29-03-2018, with engine calibration 1 and a cold start, conducted on the test track at an ambient temperature of 6 °C. The NO<sub>x</sub> emission is 897 mg/km. A regeneration of 8 seconds takes place at 120 km/h. A preconditioning test with 3 LNT regenerations (10-12 seconds) was conducted prior to this NEDC test on 28-03-2018.

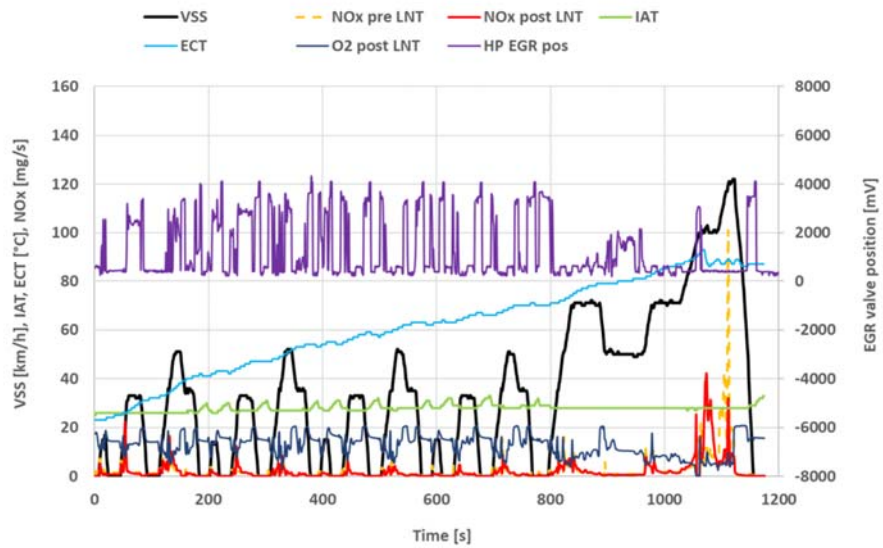


Figure 4-8: NEDC test of 14-05-2018, with engine calibration 1 and a cold start, conducted on the test track at an ambient temperature of 27-28 °C. The NO<sub>x</sub> emission is 191 mg/km. A LNT regeneration of 8 seconds takes place at 95 km/h. A preconditioning test with 3 LNT regenerations (12-12-1 seconds) was conducted prior to this NEDC test on 11-03-2018.

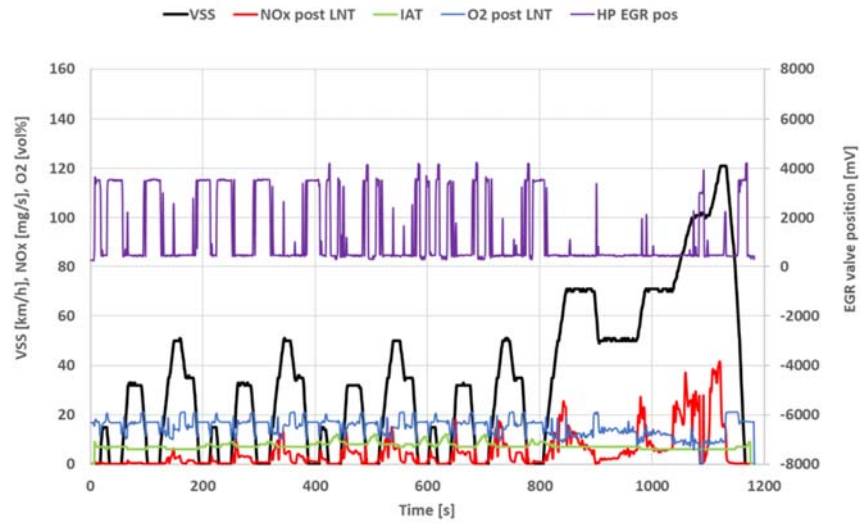


Figure 4-9: NEDC test of 29-03-2018, with engine calibration 1 and a cold start, conducted on the test track at an ambient temperature of 6 °C. The NO<sub>x</sub> emission is 533 mg/km. A preconditioning test with 1 LNT regeneration (8 seconds) was conducted prior to this NEDC test on 29-03-2018.

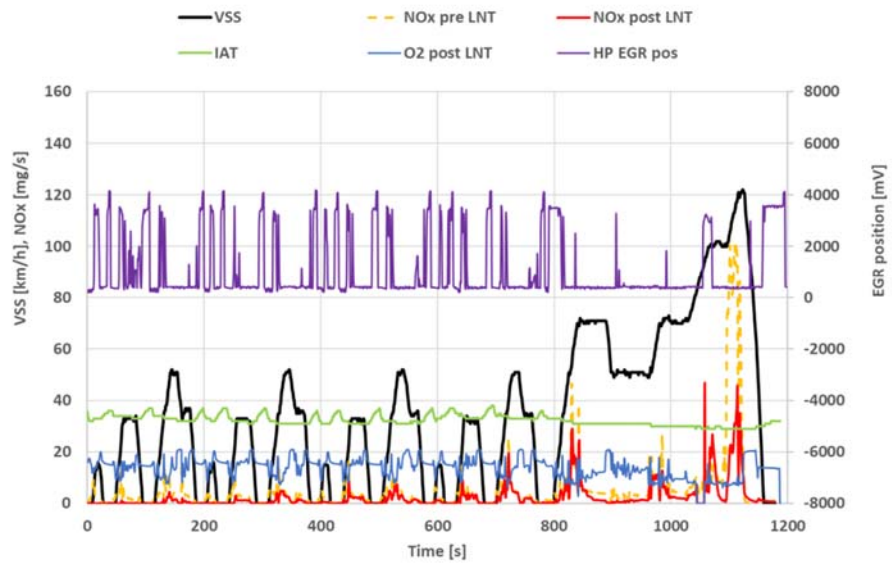


Figure 4-10: NEDC test of 14-05-2018, with engine calibration 1 and a warm start, conducted on the test track at an ambient temperature of 26-28 °C. The NO<sub>x</sub> emission is 266 mg/km. A LNT regeneration of 14 seconds takes place at approximately 90 km/h. A preconditioning test with 1 LNT regeneration (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<sub>x</sub> emission is 533 mg/km, see Figure 4-9. With an ambient temperature of 27-28 °C, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission behaviour.

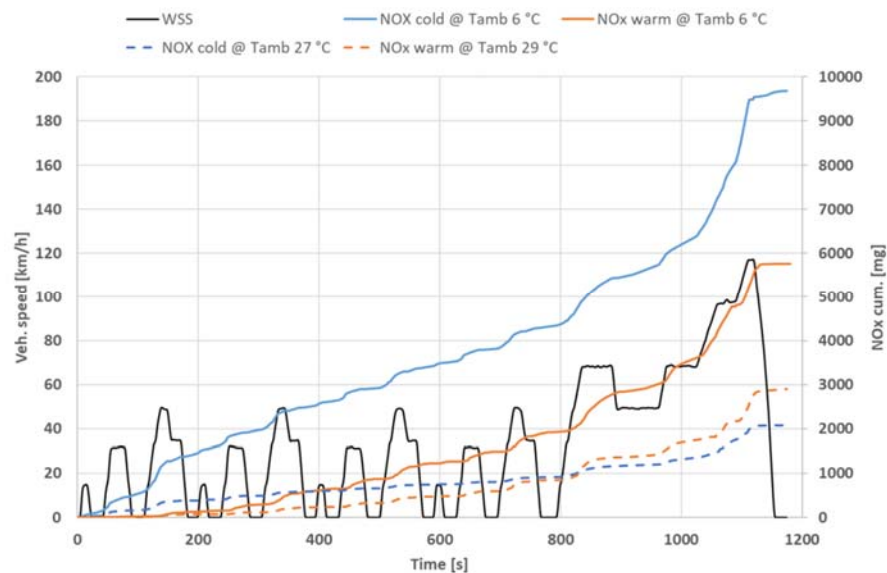


Figure 4-11: Cumulative NO<sub>x</sub> emissions from engine calibration 1 in NEDC tests with a cold and warm starts at different ambient temperatures.

*Partial conclusion 4:*

The thermal condition of the engine with engine calibration 1 has a different effect on NO<sub>x</sub> emissions at different ambient temperatures. With an ambient temperature of 6 °C the NO<sub>x</sub> 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<sub>x</sub> emission increases. The ambient temperature seems to have a bigger influence on the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission is substantially higher than in the first part. Since the NO<sub>x</sub> emission before the LNT was also measured and it has a similar variation to the NO<sub>x</sub> emission after the LNT, the NO<sub>x</sub> 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<sub>x</sub>. This is evident from the fact that the NO<sub>x</sub> 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<sub>x</sub> emissions per ECE cycle are approximately the same as in the test in Figure 4-12, but the NO<sub>x</sub> emissions increase sharply from the tenth ECE cycle to ultimately more than 400 mg per ECE cycle.

This jump in NO<sub>x</sub> emissions can be attributed to the engine adjustment (changed EGR system setting or fuel injection) because the NO<sub>x</sub> emission before the LNT rises from 250 to 450 mg per ECE cycle. Furthermore, the NO<sub>x</sub> buffer of the LNT is slowly filled, this is evident from the measured decreasing difference in NO<sub>x</sub> emissions before and after the LNT. This NO<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission jump can be observed in the tenth ECE cycle. This jump in NO<sub>x</sub> emissions can be attributed to the engine adjustment (changed EGR system setting or fuel injection) because the NO<sub>x</sub> 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<sub>x</sub> 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.

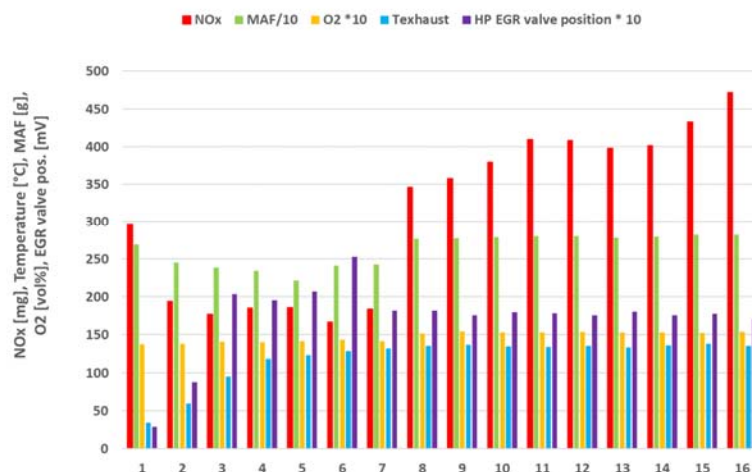


Figure 4-12: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a cold start, performed on 10-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 22°C. Preconditioning 3\*EUDC with a warm start, conducted on 09-04-2018, with three LNT regenerations of 13, 13 and 5 seconds.

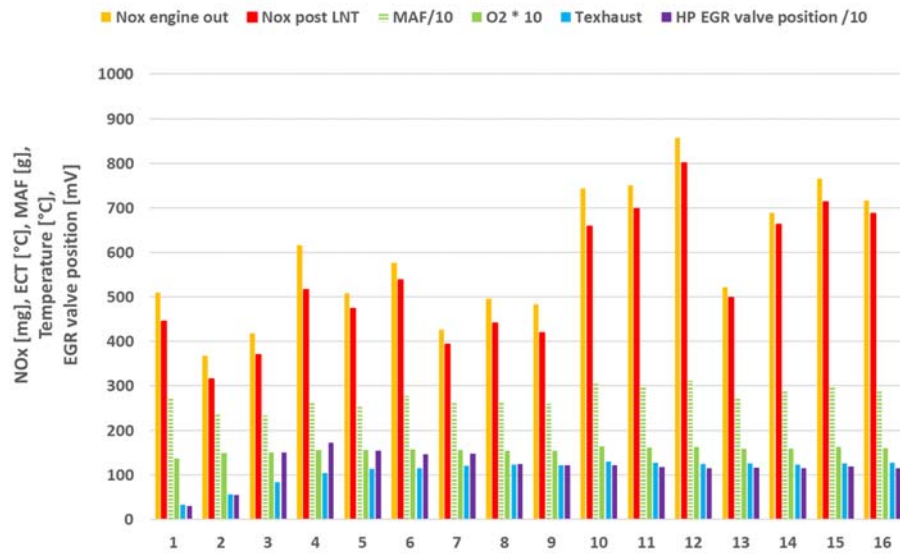


Figure 4-13: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a cold start, performed on 16-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 18°C. Preconditioning 3\*EUDC with a warm start, conducted on 11-04-2018, with three LNT regenerations of 2, 15 and 14 seconds.

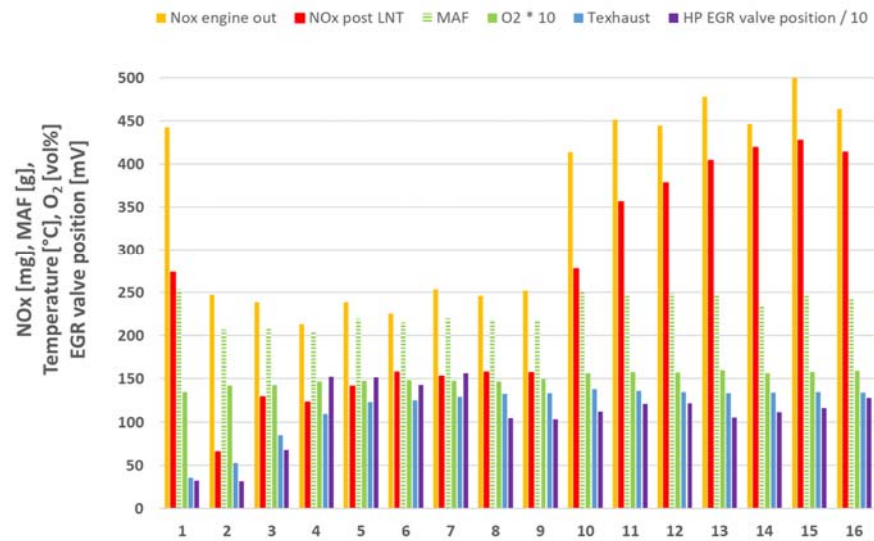


Figure 4-14: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a cold start, performed on 19-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 30-32°C. Preconditioning 3\*EUDC with a warm start, conducted on 18-04-2018, with three LNT regenerations of 12, 10 and 7 seconds.

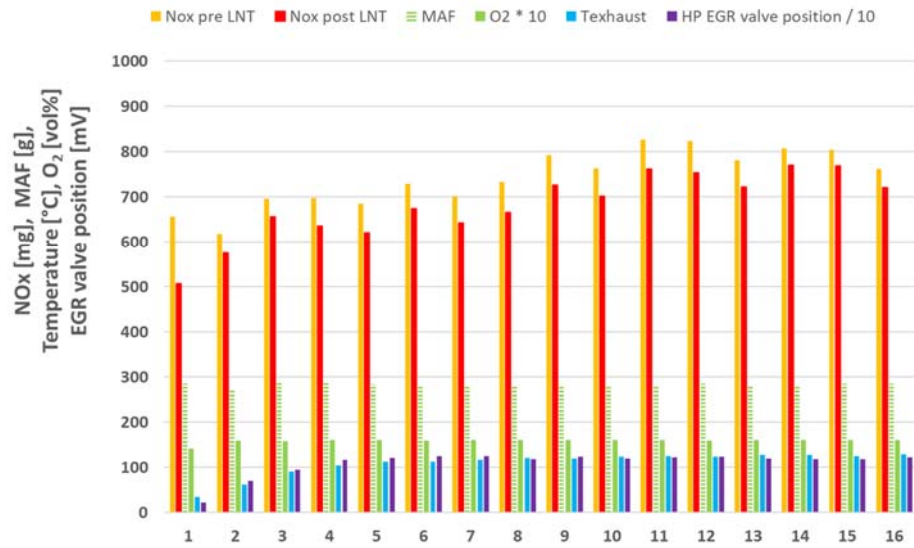


Figure 4-15: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a cold start, performed on 24-04-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 13°C. Preconditioning 3\*EUDC with a warm start, conducted on 19-04-2019, with one LNT regeneration of 10 seconds in the first EUDC.

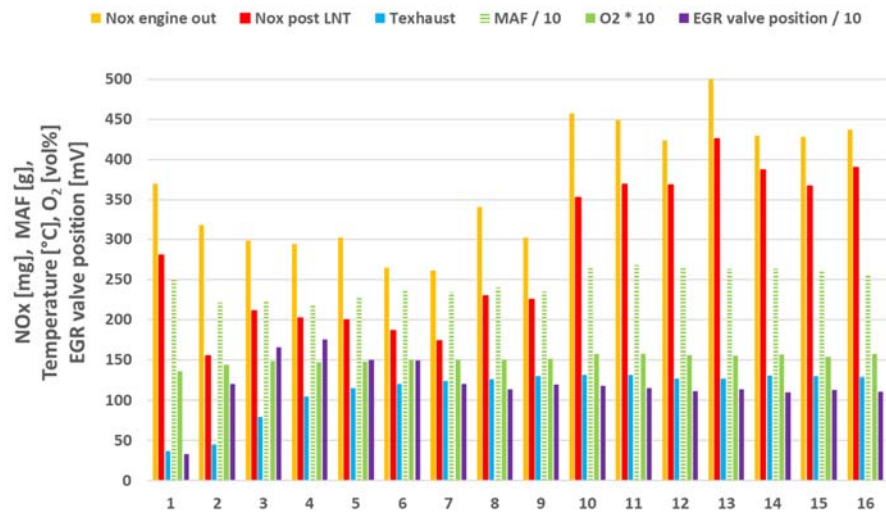


Figure 4-16: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a cold start, performed on 25-05-2018. The test was started in a conditioning room of 26°C and was conducted on the test track of the RDW at an ambient temperature of 20°C. Preconditioning 3\*EUDC with 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<sub>x</sub> 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<sub>x</sub> emission per ECE cycle of the engine is 540-905 mg. After the LNT, the NO<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> 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<sub>x</sub> emission per ECE cycle of the engine is 430-520 mg. After the LNT, the NO<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> 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<sub>x</sub> emission per ECE cycle of the engine is 700-840 mg. After the LNT, the NO<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> 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<sub>x</sub> emission per ECE cycle of the engine is 450-500 mg. After the LNT, the NO<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> 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<sub>x</sub> emission per ECE cycle of the engine is 350-400 mg. After the LNT, the NO<sub>x</sub> 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<sub>x</sub> 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 NO<sub>x</sub> buffer of the LNT is almost completely filled during this 3120-second emission test.

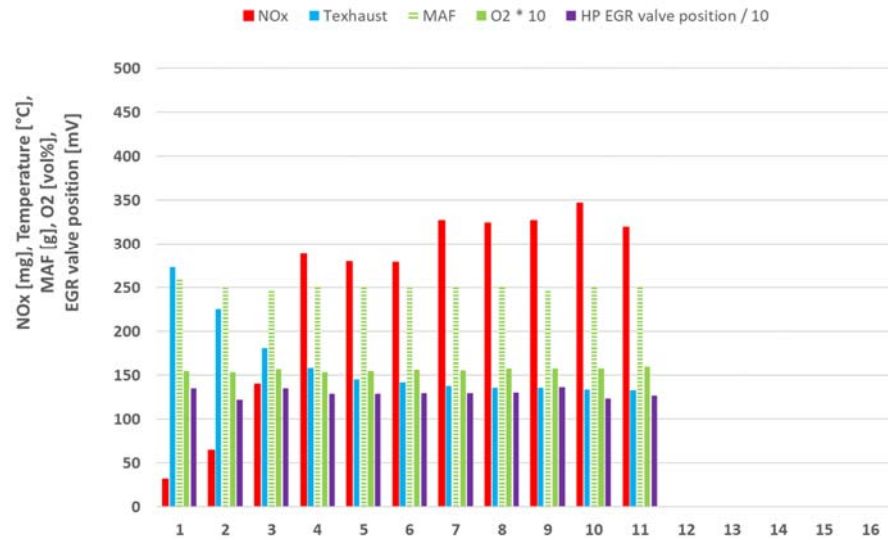


Figure 4-17: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a warm start, performed on 10-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 22 °C. Preconditioning 10 minutes @ 120 km/h with a warm start with various LNT regenerations.

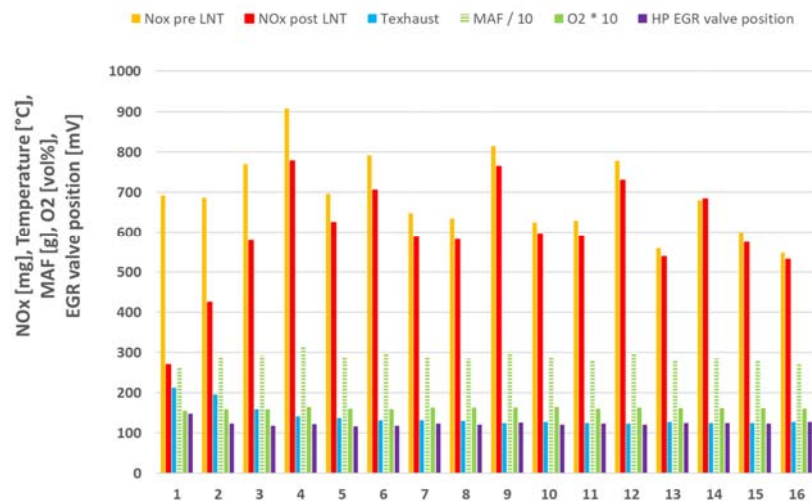


Figure 4-18: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a warm start, performed on 16-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 18 °C. Preconditioning 10 minutes @ 120 km/h with a warm start without LNT regenerations.

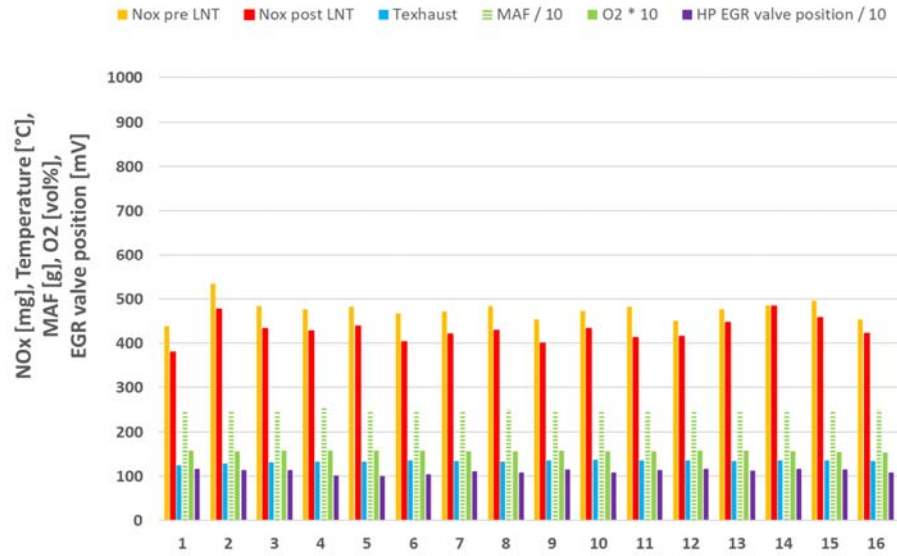


Figure 4-19: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a warm start, performed on 19-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 30-32 °C. Preconditioning 4\*UDC with a cold start without LNT regenerations.

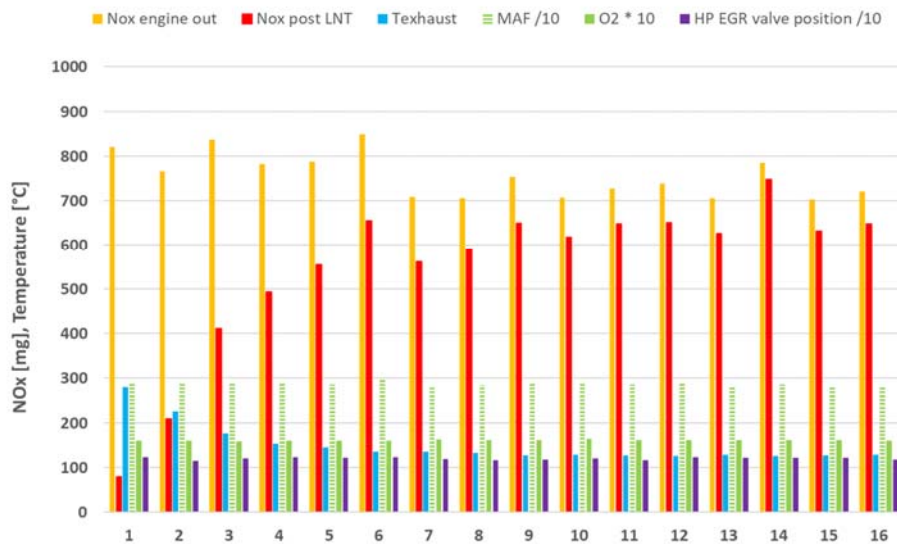


Figure 4-20: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a warm start, performed on 24-04-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 14 °C. Preconditioning 120 km/h with a warm start with various LNT regenerations.

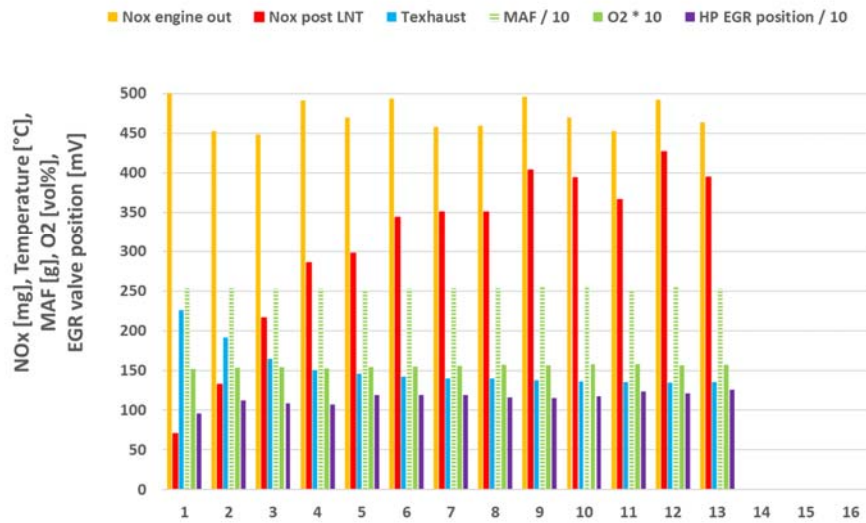


Figure 4-21: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a warm start, performed on 22-05-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 25 °C. Preconditioning 3\*EUDC with warm start, with 3 LNT regenerations.

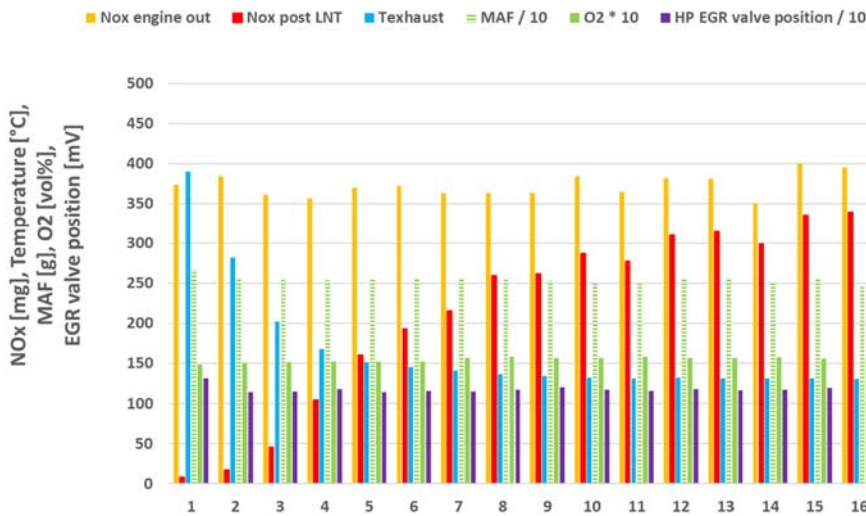


Figure 4-22: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a warm start, performed on 25-05-2018. The test was started and driven on the test track of the RDW at an ambient temperature of 22 °C. Preconditioning 120 km/h with warm start, with 5 LNT regenerations.

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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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.

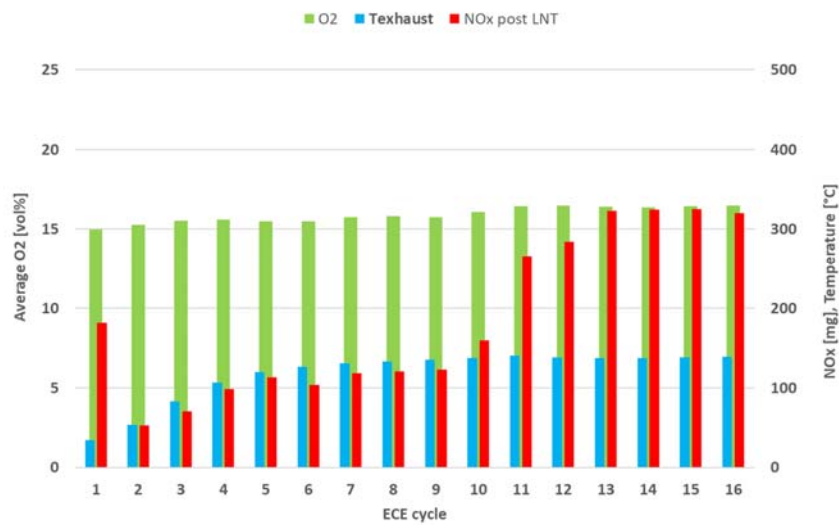


Figure 4-23: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with cold start, performed on 21-08-2018. The test was driven on the chassis dynamometer with road load setting 2 and an ambient temperature of 23 °C. Preconditioning 3\*EUDC test on 17-08-2018 with a warm start with 3 LNT regenerations with a duration of 13 seconds.

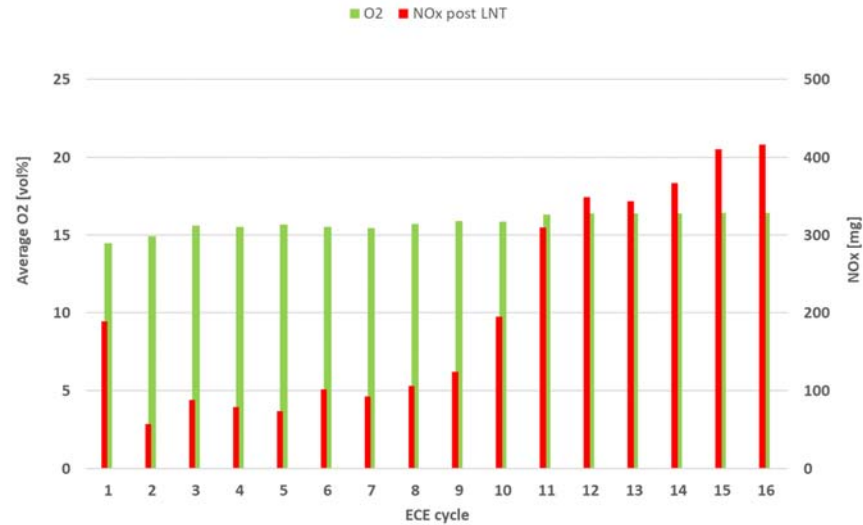


Figure 4-24: NO<sub>x</sub> emissions per ECE cycle with engine calibration 1 in a 4\*UDC test with a cold start, performed on 03-09-2018. The test was driven on the chassis dynamometer with road load setting 3 and an ambient temperature of 23 °C. Preconditioning 3\*EUDC test on 02-09-2018 with a warm 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<sub>x</sub> emission behaviour of the Suzuki Vitara Euro 6b diesel with engine calibration 1:

#### *What is the influence of the ambient temperature on the NO<sub>x</sub> emissions of the engine?*

Above an ambient temperature of 20 °C, the measured NO<sub>x</sub> emission of the engine is initially 250 - 530 mg per ECE cycle, and at ambient temperatures of 13 to 14 °C the NO<sub>x</sub> emission of the engine is 620 - 900 mg per ECE cycle. With an ambient temperature of 18 °C, the NO<sub>x</sub> emission of the engine varies between 360 and 860 mg per ECE cycle. The NO<sub>x</sub> emission of the engine depends on the ambient temperature.

#### *What is the nature of NO<sub>x</sub> 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<sub>x</sub> emissions in the eighth, ninth, tenth or eleventh ECE cycle. At ambient temperatures below 20 °C, this jump in NO<sub>x</sub> emissions does not occur. This non-constant emission behaviour (the jump in NO<sub>x</sub> emission) was not observed in 4\*UDC tests with a warm start. Furthermore, this NO<sub>x</sub> 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<sub>x</sub> emissions?*

A LNT stores NO<sub>x</sub> as long as the buffer capacity is not fully used. Whether there is NO<sub>x</sub> buffering, can be determined by measuring the NO<sub>x</sub> emissions before and after LNT, and calculating the difference. If there is no difference between the measured NO<sub>x</sub> emissions before and after LNT, no NO<sub>x</sub> 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<sub>x</sub> 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, NO<sub>x</sub> 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<sub>x</sub> buffer of the LNT is relatively empty at the start of a 4\*UDC test and NO<sub>x</sub> is stored during the 4\*UDC tests. Buffering of NO<sub>x</sub> has taken place in many tests because the measured NO<sub>x</sub> emission before the LNT is higher than the measured NO<sub>x</sub> emission after the LNT. This buffering decreases in the course of the performed emission tests.

In 4\*UDC tests, the LNT catalyst involves NO<sub>x</sub> buffering and the LNT is not regenerated.

*Is there a difference in NO<sub>x</sub> emissions in 4\*UDC tests with a cold and warm start?*

With ambient temperatures above 20 °C, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions occurring during the course of the test and the NO<sub>x</sub> emission levels are virtually the same.

*What changes in engine conditions occur during the jump in NO<sub>x</sub> 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<sub>x</sub> emission increases substantially. The jump in NO<sub>x</sub> 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<sub>x</sub> emissions of the engine abruptly rise from 300 to 450 mg per ECE

cycle. The timing of this sudden increase in NO<sub>x</sub> emissions varies in the different tests, but no explanation for this has been found. The increase in NO<sub>x</sub> 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<sub>x</sub> emissions. These have not been examined.

In UDC tests with a warm start at an ambient temperature above 20 °C, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions increase slowly during the test from 10 to 90 mg/s and have a cyclical nature. Also during this test the O<sub>2</sub> 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<sub>x</sub> 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.



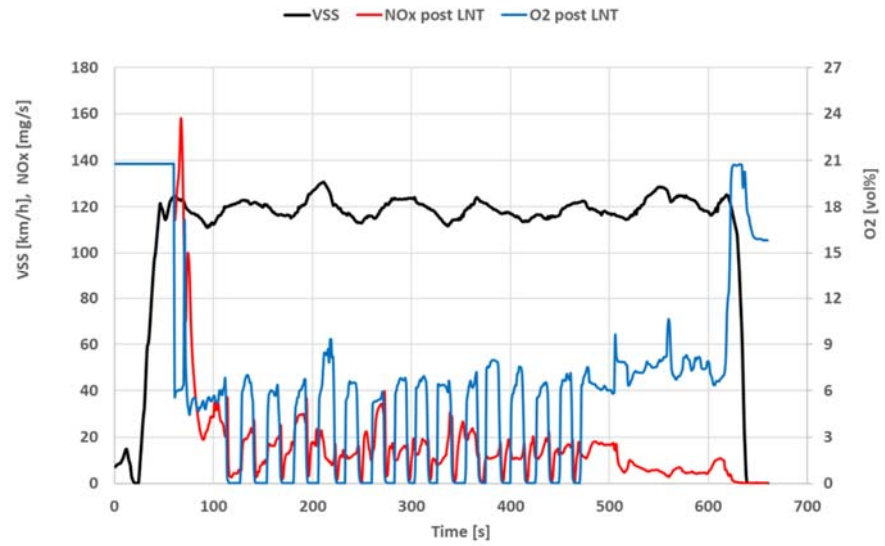


Figure 4-25: NO<sub>x</sub> and O<sub>2</sub> emissions at 120 km/h with engine calibration 1, performed on the test track on 10-04-2018 at an ambient temperature of 23 °C.

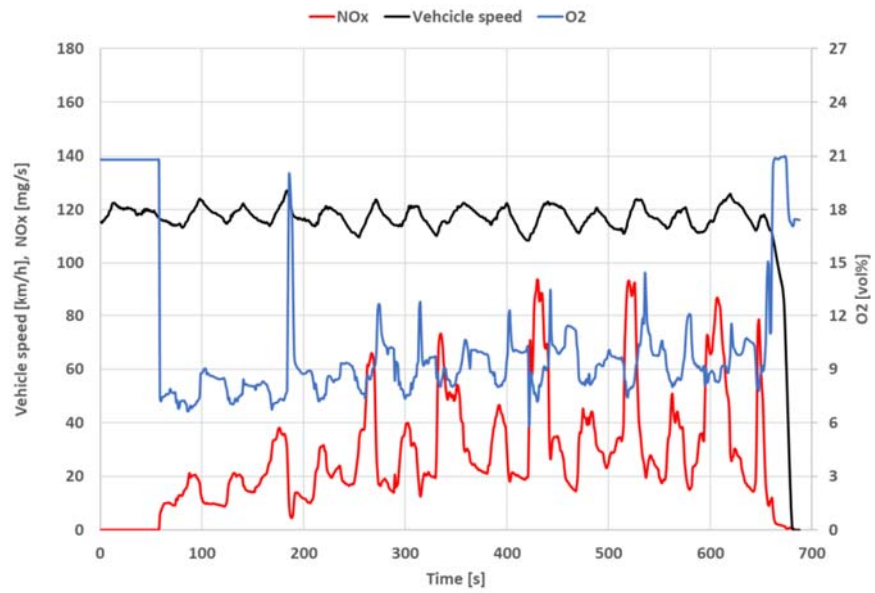


Figure 4-26: NO<sub>x</sub> and O<sub>2</sub> emissions at 120 km/h with engine calibration 1, performed on the test track on 06-12-2018 at an ambient temperature of 18-20 °C.

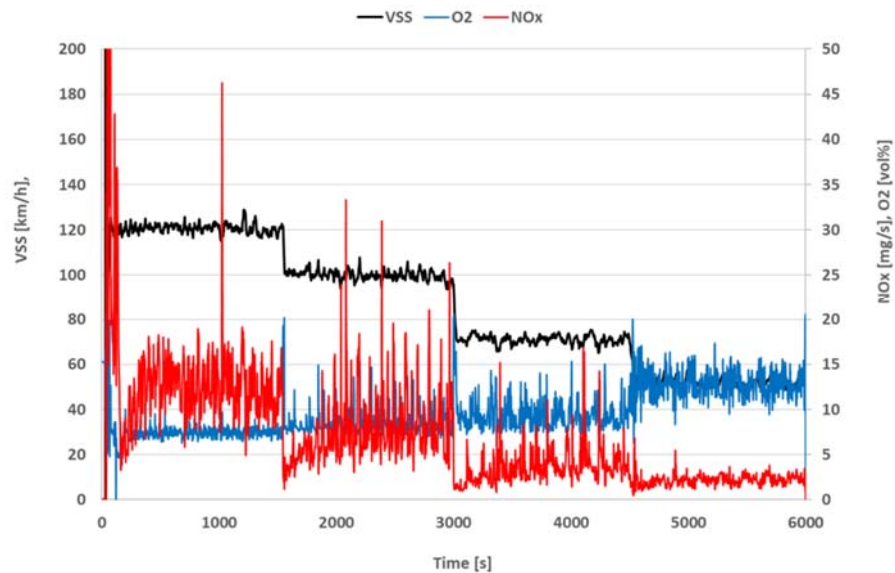


Figure 4-27: NO<sub>x</sub> and O<sub>2</sub> emissions at 120, 100, 70 and 50 km/h with engine calibration 1, performed on the test track on 31-05-2018 at an ambient temperature of 21-24 °C.

*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<sub>x</sub> 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<sub>x</sub> 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 <sub>2</sub> [g/km]	NO <sub>x</sub> [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<sub>x</sub> 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<sub>x</sub> emission was 420 mg/km and LNT regenerations were carried out for 13 seconds. Since the NO<sub>x</sub> emission for the LNT is 507 mg/km, the NO<sub>x</sub> 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<sub>x</sub> emission is substantially higher in this test than the NO<sub>x</sub> emission of the RDE test at an ambient temperature of 26 °C.

*Partial conclusion 8:*

In RDE tests with engine calibration 1, the NO<sub>x</sub> emission is dependent on the ambient temperature. Substantially higher NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub>, PM, and PN emissions are lower than the Euro 6 limit values. In addition, the CO<sub>2</sub> emissions of 114.9 – 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<sub>x</sub> 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 <sub>2</sub>	CO	NO <sub>x</sub>	THC+NO <sub>x</sub>	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 <sup>11</sup>
NEDC RL 1*	-	131.2	37.7	77.1	0.95	1.4 * 10 <sup>11</sup>
NEDC RL 1*	124.2	238.5	82.9	137.9	0.15	4.9 * 10 <sup>10</sup>
NEDC RL 1	114.9	236.9	64.9	118.1	0.12	4.7 * 10 <sup>10</sup>
NEDC RL 1	117.2	207.5	83.1	129.0	0.27	5.1 * 10 <sup>10</sup>
NEDC RL 1	115.5	165.0	76.3	110.7	-	3.4 * 10 <sup>10</sup>

\*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<sub>2</sub> emissions are 114.9 – 117.2 g/km, which is 8 - 11% higher than the value specified by the manufacturer. The measured NO<sub>x</sub> emission is 64.9 - 83.1 and is on average 7% below the Euro 6 limit values. This test vehicle with engine calibration 1 meets the Euro 6 NO<sub>x</sub> 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<sub>2</sub> emissions increase from 114.9 - 117.2 g/km to 151.9 g/km. The NO<sub>x</sub> 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 <sub>2</sub>	CO	NO <sub>x</sub>	THC+NO <sub>x</sub>	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 <sup>11</sup>
NEDC RL 1*	-	131.2	37.7	77.1	0.95	1.4 * 10 <sup>11</sup>
NEDC RL 1*	124.2	238.5	82.9	137.9	0.15	4.9 * 10 <sup>10</sup>
NEDC RL 1	114.9	236.9	64.9	118.1	0.12	4.7 * 10 <sup>10</sup>
NEDC RL 1	117.2	207.5	83.1	129.0	0.27	5.1 * 10 <sup>10</sup>
NEDC RL 1	115.5	165.0	76.3	110.7	-	3.4 * 10 <sup>10</sup>
NEDC RL 2	125.4	229.5	124.8	169.9	0.35	3.6 * 10 <sup>10</sup>
NEDC RL 2	122.2	176.7	80.5	125.0	0.18	6.3 * 10 <sup>10</sup>
NEDC RL 3	131.1	230.6	79.7	116.2	-	7.6 * 10 <sup>10</sup>
NEDC RL 4	151.9	318.0	167.6	216.9	0.20	1.2 * 10 <sup>11</sup>

\*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<sub>2</sub> 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<sub>2</sub> emissions from 115 to 152 g/km (+ 32%). The NO<sub>x</sub> 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<sub>x</sub>-O<sub>2</sub> 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<sub>2</sub> emissions of five different NEDC emission tests are shown in Figure 4-28. The measured SEMS CO<sub>2</sub> 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<sub>x</sub> emissions. The measured SEMS NO<sub>x</sub> 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<sub>2</sub> 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<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> and -2.3 – 2.6% for NO<sub>x</sub>. For the partial conclusions that relate to the NO<sub>x</sub> 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.

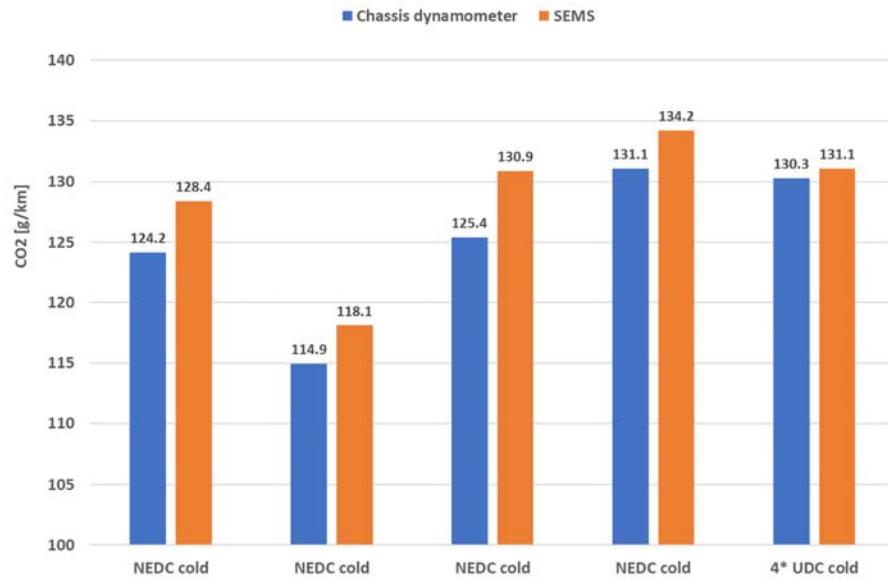


Figure 4-28: CO<sub>2</sub> emissions with engine calibration 1 from different chassis dynamometer tests measured with the chassis dynamometer equipment and with the SEMS.

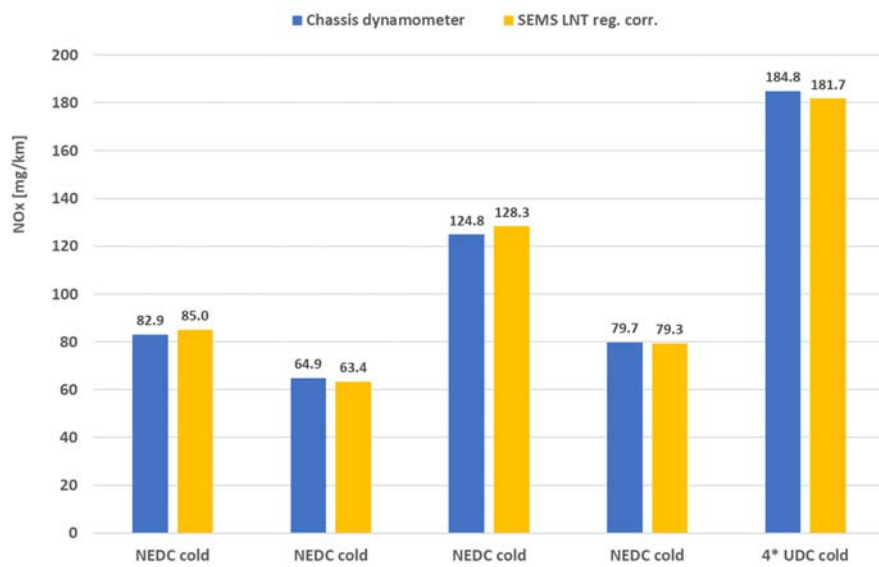


Figure 4-29: NO<sub>x</sub> emissions with engine calibration 1 from five chassis dynamometer tests measured with the dynamometer equipment and with the SEMS.

#### 4.2.4 Effects LNT regenerations on the measured NO<sub>x</sub> emissions

##### Background:

In section 4.1.3, during all 3\*EUDC tests, at the time of the LNT regenerations, NO<sub>x</sub> peak emissions were measured by the NO<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> peak emissions are very large and this means that the effect on the end results of a test can be substantial.

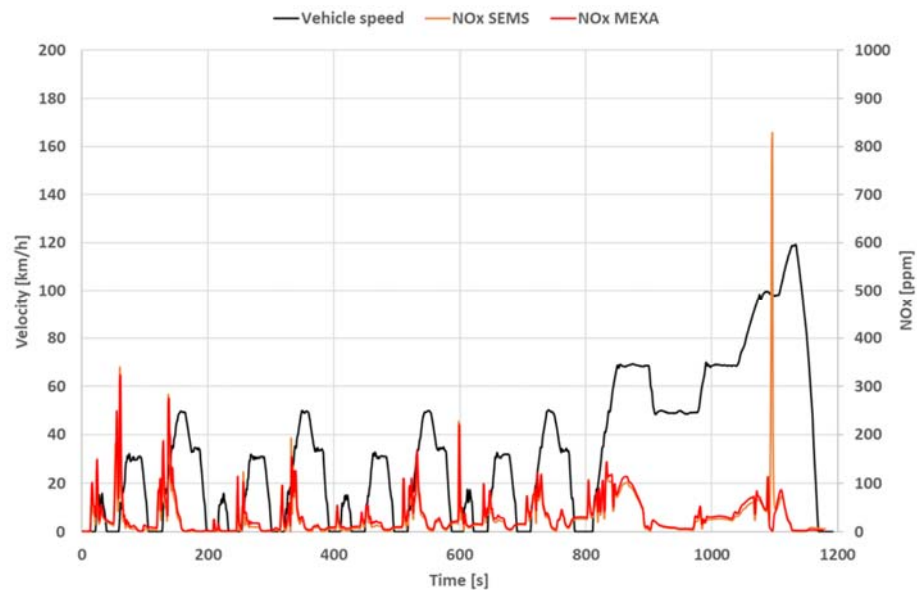


Figure 4-30: NO<sub>x</sub> emissions with engine calibration 1 of an NEDC test conducted on 15-08-2018 on the chassis dynamometer measured with the chassis dynamometer equipment (MEXA) and with SEMS.

##### 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<sub>x</sub> and O<sub>2</sub> 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<sub>x</sub>-O<sub>2</sub> sensor even measures a negative oxygen concentration. Now, during LNT regenerations, the NO<sub>x</sub> concentration measured by SEMS appears to have a peak value of more than 800 ppm, while the measured NO<sub>x</sub> concentration by the dynamometer analyser is 0 ppm.

The product specifications of the NO<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> concentrations measured by the dynamometer (MEXA) at the time of a LNT regeneration are 0 ppm. Therefore, in this research project the NO<sub>x</sub> concentrations for LNT regenerations (measured O<sub>2</sub> <= 0.00 vol%) are set at 0 ppm.

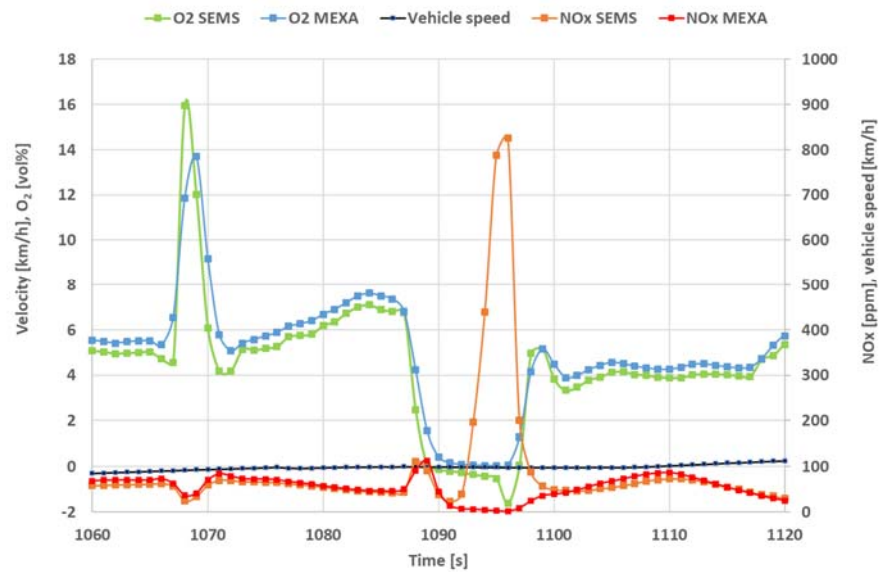


Figure 4-31: NO<sub>x</sub> emissions with engine calibration 1 of an NEDC test conducted on 15-08-2018 on the chassis dynamometer measured with the dynamometer equipment (MEXA) and with SEMS.

*Partial conclusion:*

NO<sub>x</sub> 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<sub>x</sub>-O<sub>2</sub> sensor, and the results are different. All measured values are therefore corrected on the basis of measured values provided by the NO<sub>x</sub> 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.

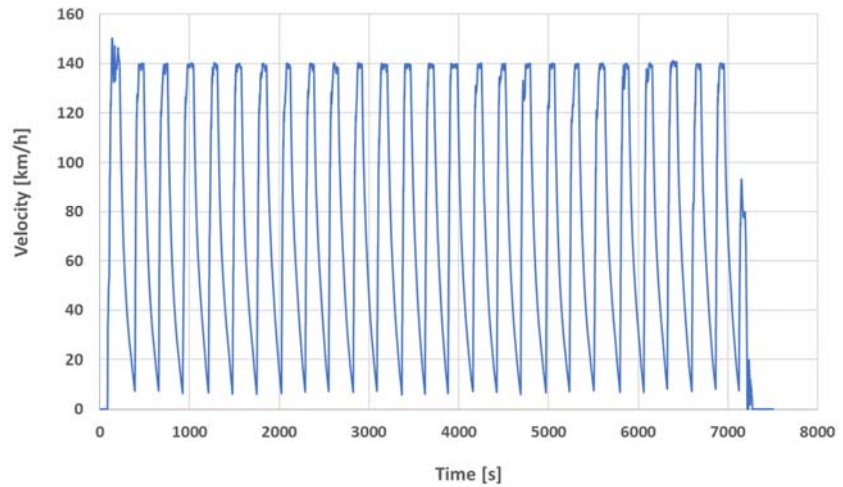


Figure 5-1: Road load testing of the Suzuki Vitara on the test track in Lelystad with six different starting points on the test track

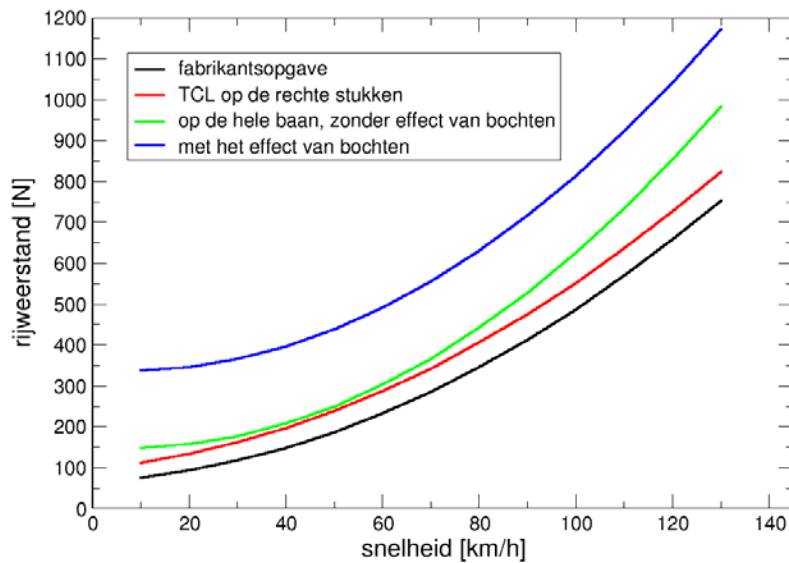


Figure 5-2: Driving resistance curves of the Suzuki Vitara under different conditions: black: according to the vehicle manufacturer, red: test track RDW Lelystad straight parts only, green: test track RDW without effect of turns, blue: test track of RDW including turns.

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

Source	Inertia	F0	F1	F2
	[kg]	[N]	[N/km]	[N/km <sup>2</sup> ]
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<sub>x</sub> emissions of the Suzuki Vitara with engine calibration 2.

The NO<sub>x</sub> 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.

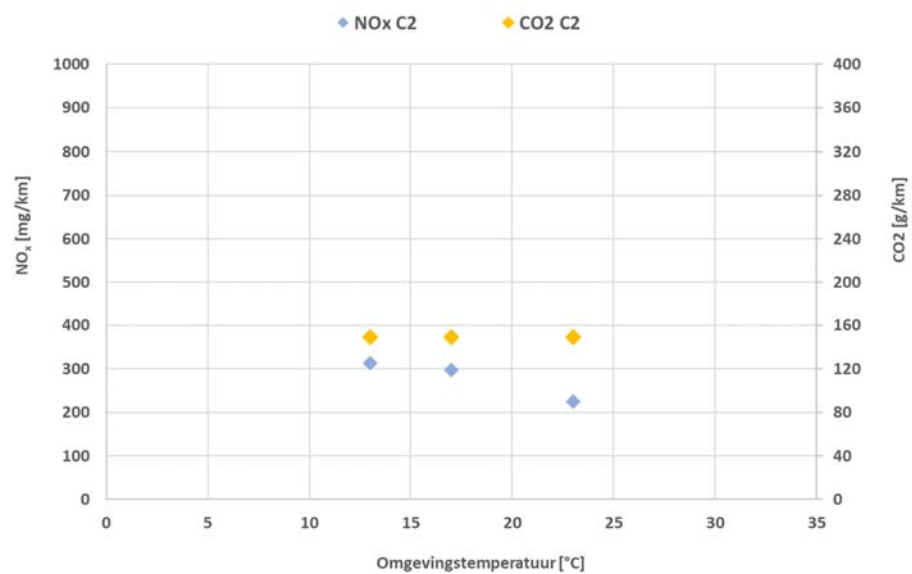
The NO<sub>x</sub> emission at ambient temperatures of 13 to 23°C and previously performed with a standard preconditioning test (3\*EUDC) is 200 to 293 mg/km, and appears to be related to the external temperature. The corresponding CO<sub>2</sub> emissions are the same in the three tests performed and 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 <sub>2</sub> [g/km]	NO <sub>x</sub> [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<sub>x</sub> and CO<sub>2</sub> 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<sub>x</sub> emission increases if the ambient temperatures drop. Furthermore, the number and duration of the LNT regenerations in the preconditioning test influences the NO<sub>x</sub> emissions in the NEDC test. With an ambient temperature above 20 °C and a standard preconditioning cycle (3\*EUDC), a NO<sub>x</sub> 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<sub>x</sub> emission in the emission test with engine calibration 2*

This section discusses partial objective 11 from section 1.2.

Given the spread of NO<sub>x</sub> emissions within NEDC tests, further research has been done into the condition of an LNT (the extent to which the NO<sub>x</sub> trap is filled) and the regeneration frequency.

*Background:*

A Lean NO<sub>x</sub> Trap (LNT) is capable of storing a certain amount of NO<sub>x</sub> 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<sub>x</sub> into harmless components (H<sub>2</sub>O, CO<sub>2</sub>, N<sub>2</sub> and O<sub>2</sub>). After the regeneration, the LNT is "empty" and is able to store NO<sub>x</sub> 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<sub>2</sub> 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.

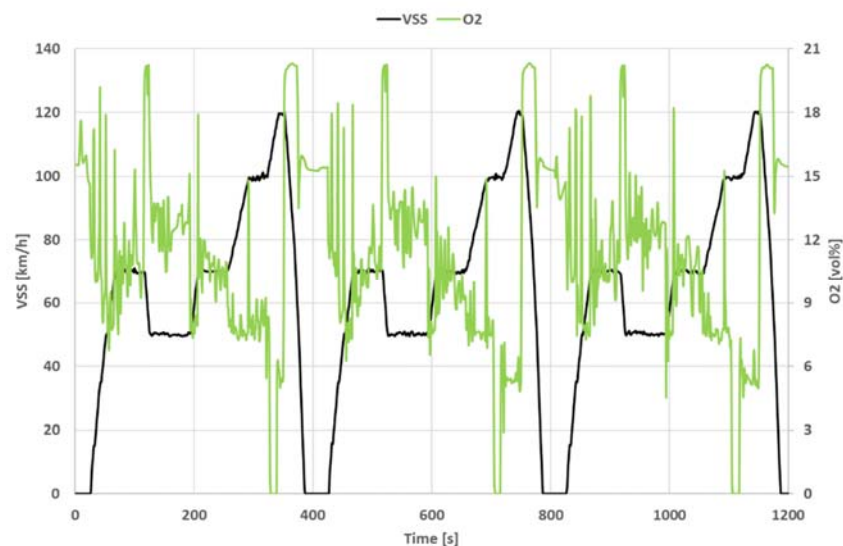


Figure 5-4: 3\*EUDC test with engine calibration 2 and warm start, conducted on 24-10-2018 on the test track, at an ambient temperature of 17 °C. The LNT is regenerated three times for 11-13 seconds.

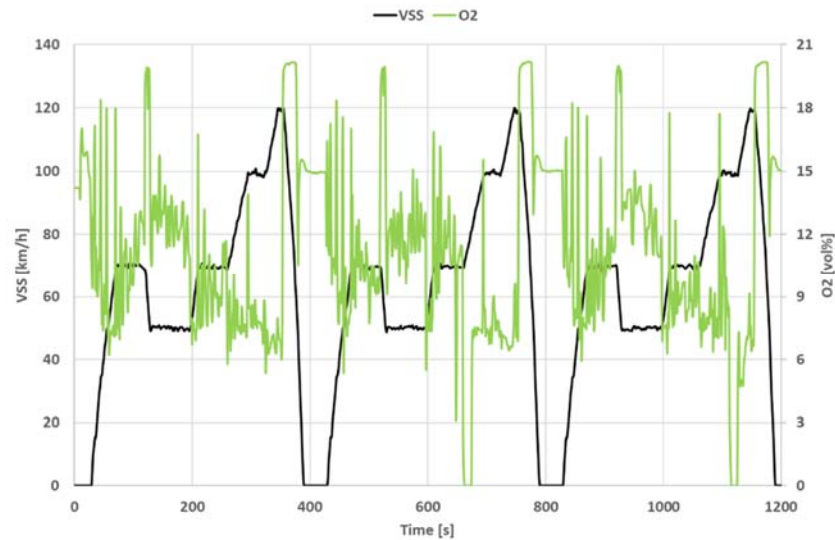


Figure 5-5: 3\*EUDC test with engine calibration 2 and warm start, conducted on 18-09-2018 on the test track, at an ambient temperature of 26 °C. The LNT is regenerated twice for 12-14 seconds.

*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<sub>x</sub> filling degree of the NO<sub>x</sub> 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<sub>x</sub> buffer capacity varies at the start of an emission test and this influences the NO<sub>x</sub> 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<sub>x</sub> and CO<sub>2</sub> emissions of NEDC tests with cold and warm starts on the test track with engine calibration 2

Date	T environment [°C]	CO <sub>2</sub> [g/km]	NO <sub>x</sub> [mg/km]	CO <sub>2</sub> [g/km]	NO <sub>x</sub> [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

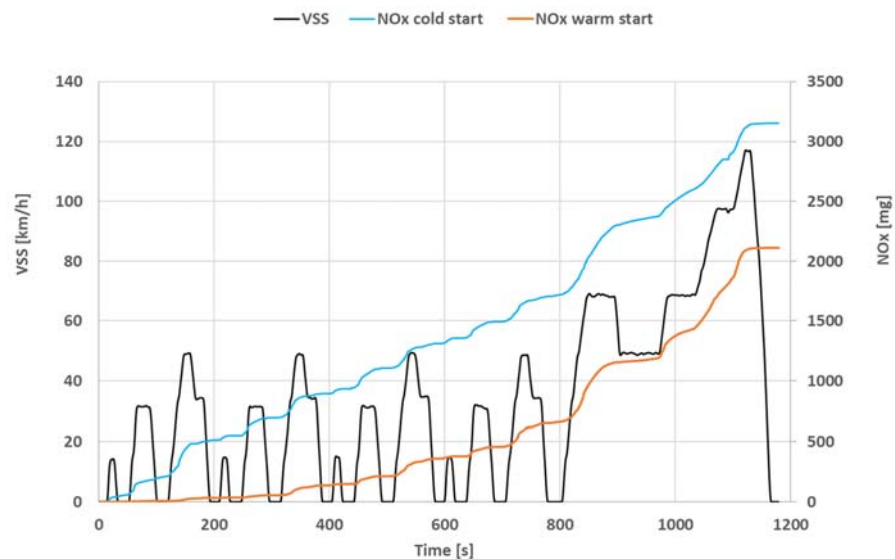


Figure 5-6: Cumulative NO<sub>x</sub> emissions from NEDC tests with a cold and warm start performed on 6-11-2018, at an ambient temperature of 13 °C on the test track with engine calibration 2. The cold one was started in a conditioning room with a temperature of 25 °C.

*Analysis:*

The NEDC NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions with a cold start of engine calibration 2 are substantially higher than the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission after the LNT through ECE cycle 13 is virtually stable. After ECE cycle 14 or 15, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission rises from approximately ECE cycle 14 to a level that is almost twice as high as the original NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions of

more than a factor of three over time (after ECE cycle 12 or 13). In these tests the NO<sub>x</sub> 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<sub>x</sub> emissions are 5%.

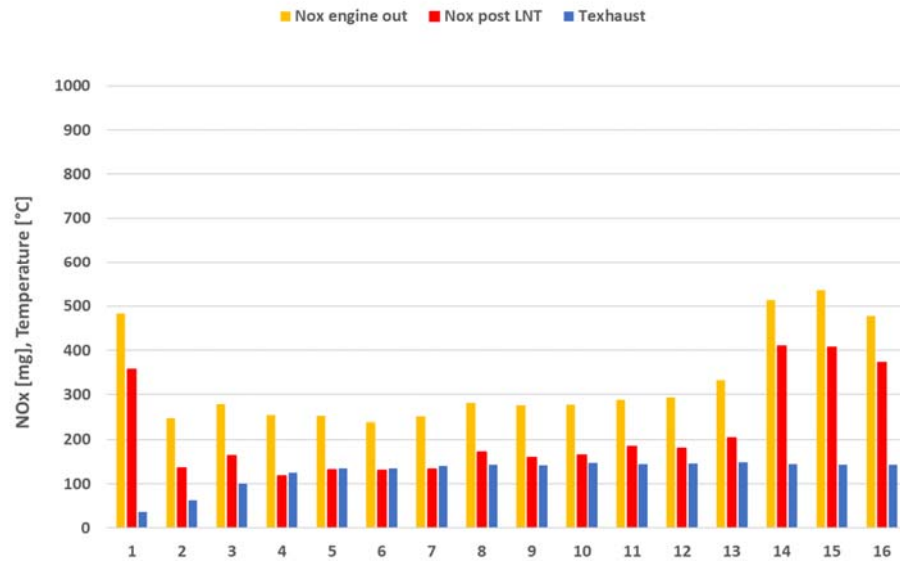


Figure 5-7: NO<sub>x</sub> emissions per ECE cycle with engine calibration 2 in a 4\*UDC test with a cold start, start-stop not active, performed on 19-09-2018. The test was started in a conditioning room of 26 °C and was conducted on the test track of the RDW at an ambient temperature of 26 °C. Preconditioning 3\*EUDC with a warm start, conducted on 18-09-2018, with three LNT regenerations of 14 seconds in the second EUDC cycle.

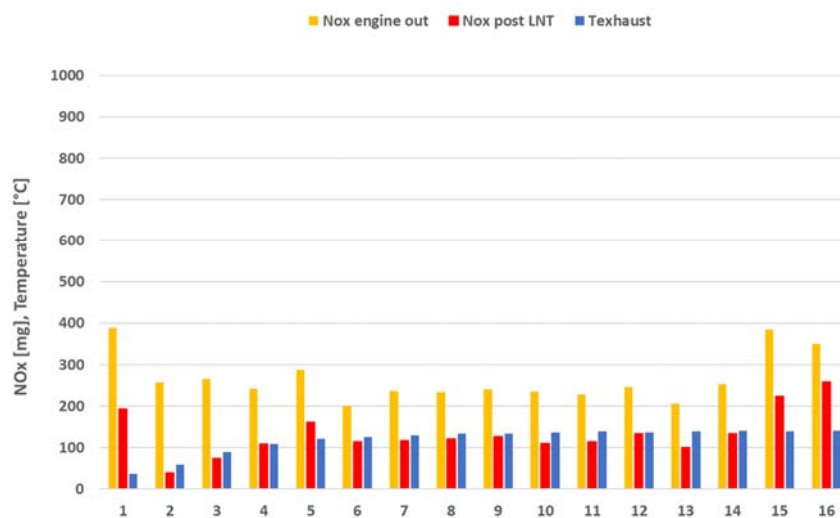


Figure 5-8: NO<sub>x</sub> emissions per ECE cycle with engine calibration 2 in a 4\*UDC test with a cold start, start-stop active, performed on 24-10-2018. The test was started in a conditioning room of 26 °C and was conducted on the test track of the RDW at an ambient temperature of 18 °C. Preconditioning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

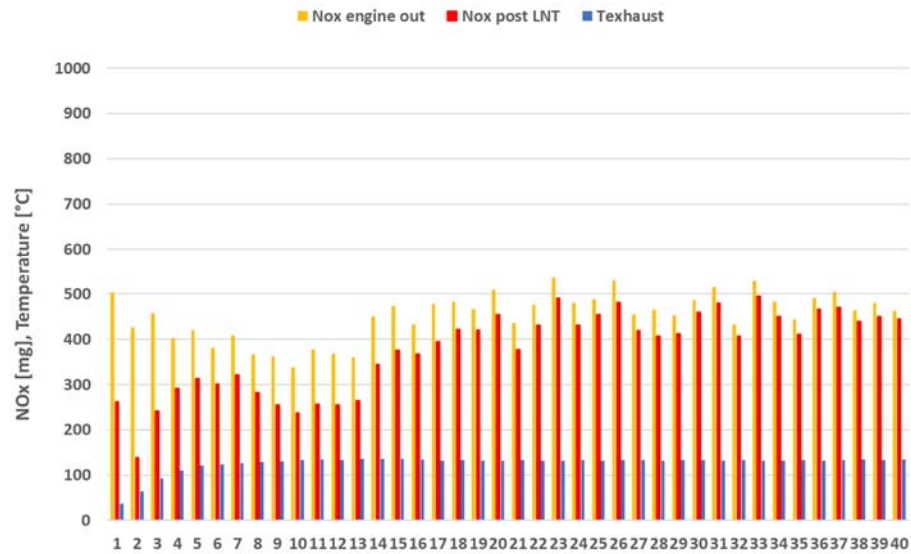


Figure 5-9: NO<sub>x</sub> emissions per ECE cycle with engine calibration 2 in a 10\*UDC test with a cold start, start-stop active, performed on 8-11-2018. The test was started in a conditioning room of 26 °C and was conducted on the test track of the RDW at an ambient temperature of 13 °C. Preconditioning 3\*EUDC with a warm start, conducted on 7-11-2018, with 2 LNT regenerations in the second and third EUDC cycles.

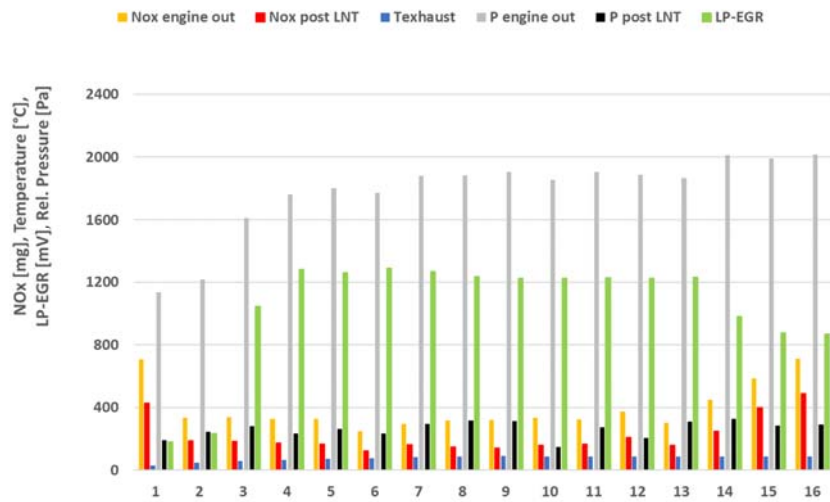


Figure 5-10: NO<sub>x</sub> emissions per ECE cycle with engine calibration 2 in a 10\*UDC test with a cold start, start-stop active, performed on 23-04-2019. The test was started in a conditioning room of 25 °C and was conducted on the test track of the RDW at an ambient temperature of 23 °C. Preconditioning 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<sub>x</sub> 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.

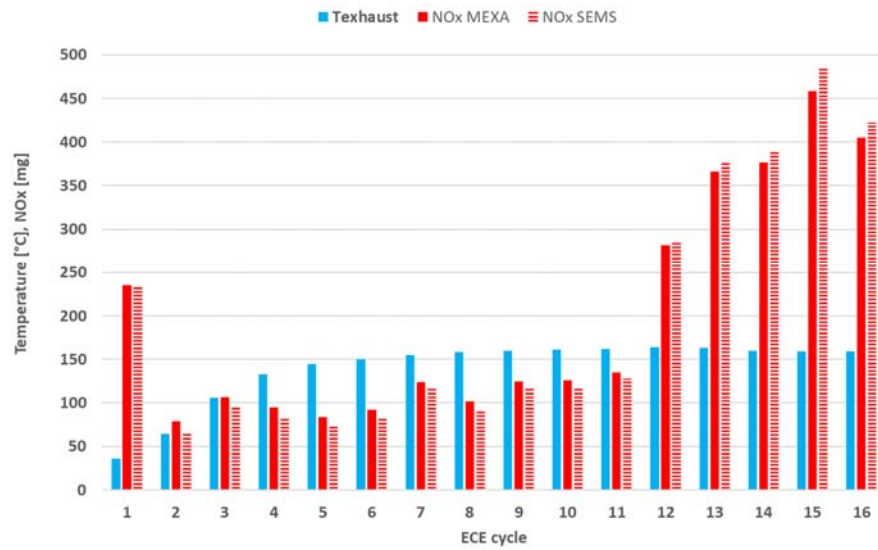


Figure 5-12: NO<sub>x</sub> measured with a chassis dynamometer analyser (MEXA) and with SEMS per ECE cycle with engine calibration 2 in a 4\*UDC test with a cold start, start-stop active, performed on 11-12-2018. The test was conducted on the chassis dynamometer at an ambient temperature of 23 °C. Preconditioning 3\*EUDC with a warm start, conducted on 10-12-2018, with 3 LNT regenerations in the second and third EUDC cycles.

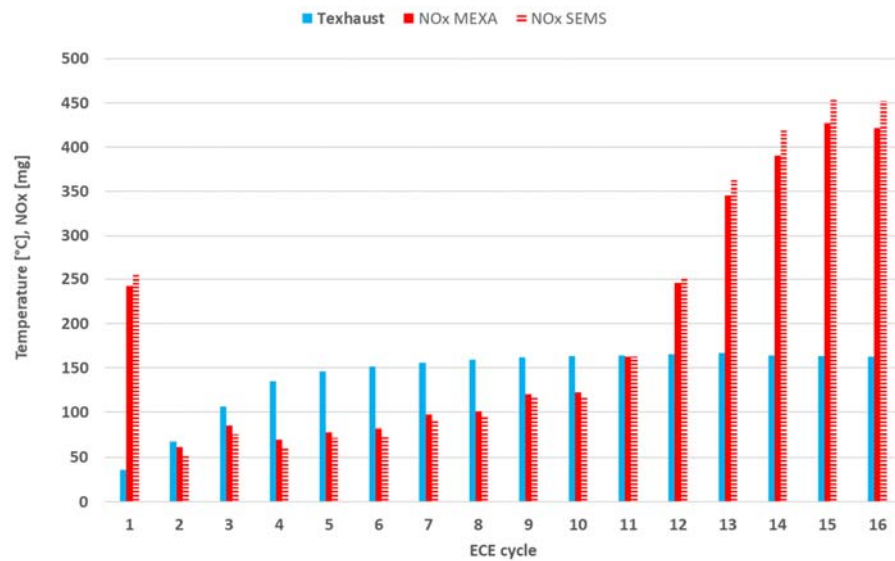


Figure 5-13: NO<sub>x</sub> measured with a chassis dynamometer analyser (MEXA) and with SEMS per ECE cycle with engine calibration 2 in a 4\*UDC test with a cold start, start-stop active, performed on 12-12-2018. The test was conducted on the chassis dynamometer at an ambient temperature of 23 °C. Preconditioning 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<sub>x</sub> emissions by a factor of three (from around 150 to 450 mg per ECE cycle) over time. This increase in NO<sub>x</sub> emissions usually takes place in or after the 14th ECE cycle. Simultaneously with the increase in NO<sub>x</sub> 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<sub>x</sub> emissions of the vehicle abruptly rise from approximately 150 to 450 mg per ECE cycle. The time of this sudden rise in NO<sub>x</sub> emissions lies within the twelfth to fourteenth ECE cycle of a UDC test. The increase in NO<sub>x</sub> 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<sub>x</sub> emissions. These have not been examined.

*Partial conclusion 17:*

With the same ambient temperatures and the same preconditioning cycles, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub>. 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 5-17 emission measurements are done at 130 km/h. At t = 400 s the oxygen concentration and the NO<sub>x</sub> 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.

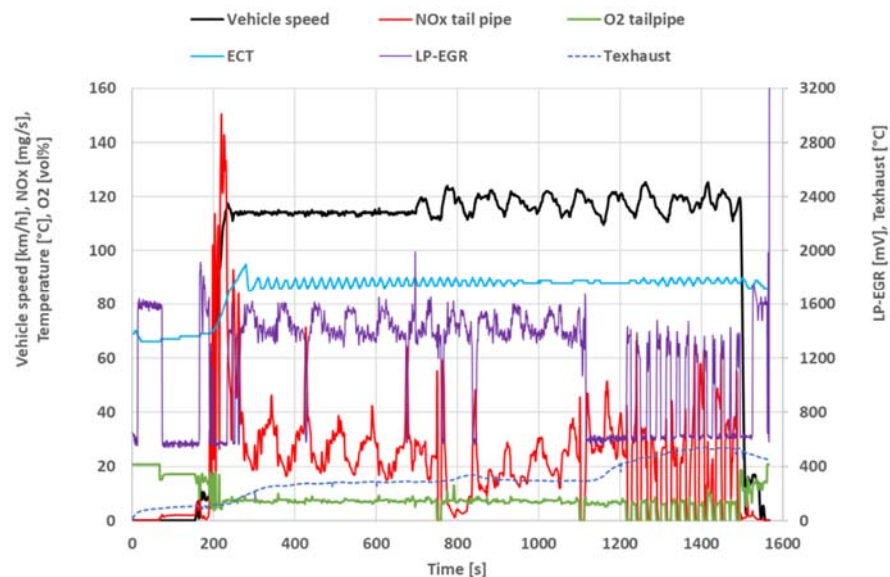


Figure 5-14: NO<sub>x</sub> and O<sub>2</sub> emissions measured at a constant speed of 115 - 120 km/h (warm start) with SEMS with engine calibration 2, performed on 16-04-2019. The test was conducted on the test track at an ambient temperature of 21 °C. The position signal of the low-pressure EGR valve is also shown. From t = 1100 - 1550 s the diesel particulate filter is regenerated.

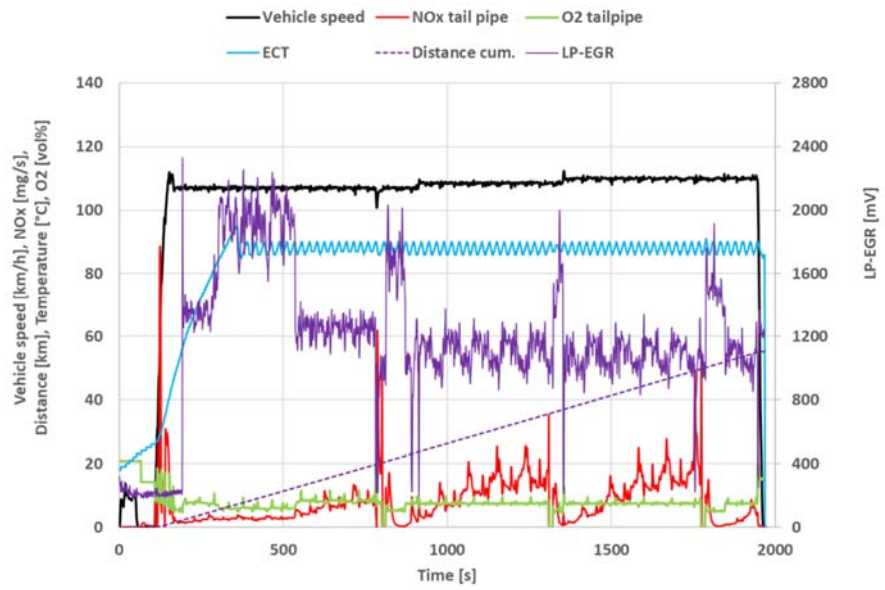


Figure 5-15: NO<sub>x</sub> and O<sub>2</sub> emissions measured with engine calibration 2 at a constant speed of 110 km/h (cold start) with SEMS, conducted on 17-04-2019. The test was conducted on the test track at an ambient temperature of 20 °C. The position signal of the low-pressure EGR valve is also shown.

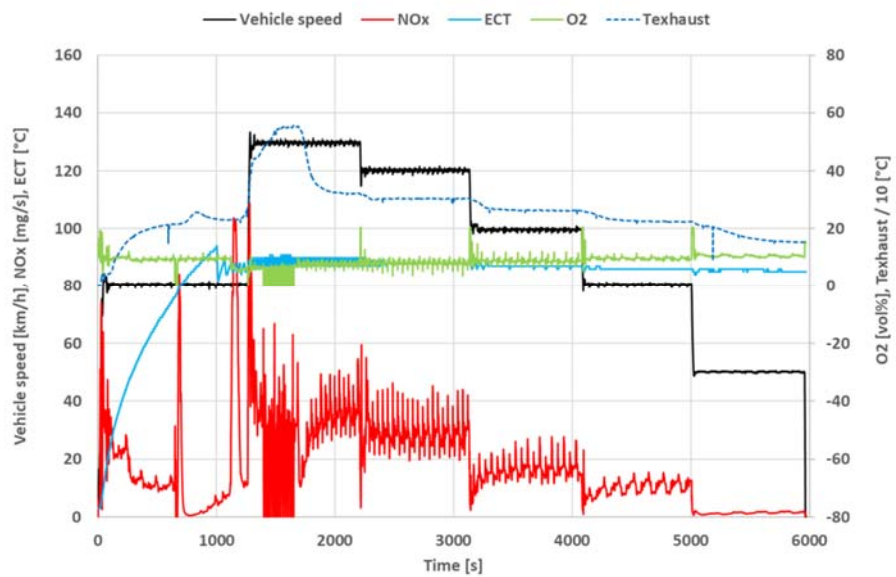


Figure 5-16: NO<sub>x</sub> and O<sub>2</sub> emissions measured with engine calibration 2, at a constant speed of 80, 130, 120, 100, 80 - 50 km/h (cold start) with SEMS with engine calibration 2, performed on 16-11-2018. The test was conducted on the test track at an ambient temperature of 6-10 °C. The diesel particulate filter is regenerated at 130 km/h.



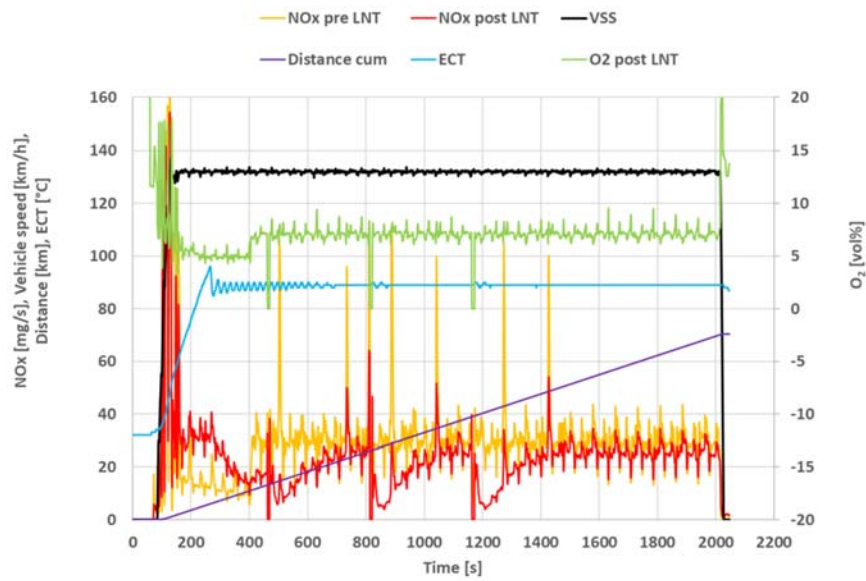


Figure 5-17: NO<sub>x</sub> and O<sub>2</sub> emissions measured with engine calibration 2 at a constant speed of 130 km/h after a cold start with SEMS, conducted on 31-08-2018. The test was conducted on the test track at an ambient temperature of 20-23 °C.

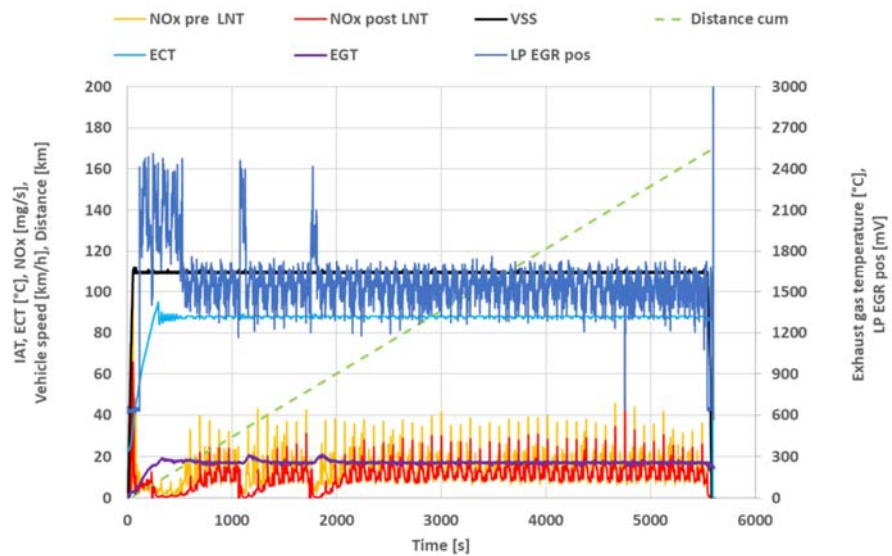


Figure 5-18: NO<sub>x</sub> and O<sub>2</sub> emissions measured at a constant speed of 110 km/h with SEMS and a vehicle with engine calibration 2, performed on 18-07-2019. The test was conducted on the test track at an ambient temperature of 26 °C. Preconditioning test 20 minutes @ 130 km/h.

**Analysis:**

There is strongly varying NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission is 446 mg/km.

Table 5-4: Average NO<sub>x</sub> 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 <sub>x</sub> 1	NO <sub>x</sub> 2	Distance	EGR pos ave	NO <sub>x</sub> 1	NO <sub>x</sub> 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

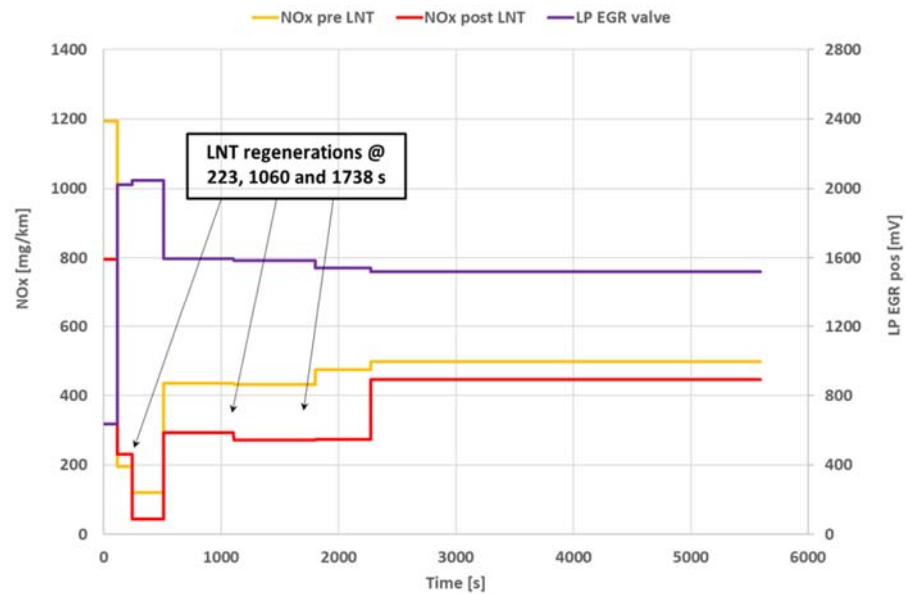


Figure 5-19: Average NO<sub>x</sub> emissions, measured at a constant speed of 110 km/h with SEMS and a vehicle with a cold engine start and engine calibration 2, performed on 18-07-2019. The test was conducted on the test track at an ambient temperature of 26°C. Preconditioning test 20 minutes @ 130 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<sub>x</sub> emission. After the cold start, the NO<sub>x</sub> 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<sub>x</sub> 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 <sub>2</sub> [g/km]	NO <sub>x</sub> [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<sub>2</sub> emissions of the first and last RDE test are 136-137 g/km and are higher than the CO<sub>2</sub> 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<sub>2</sub> emission.

In these four RDE tests, the measured NO<sub>x</sub> 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<sub>x</sub> emissions per RDE test. Therefore, the measured spread in NO<sub>x</sub> 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<sub>2</sub> emissions are 129 - 137 g/km and the NO<sub>x</sub> 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.

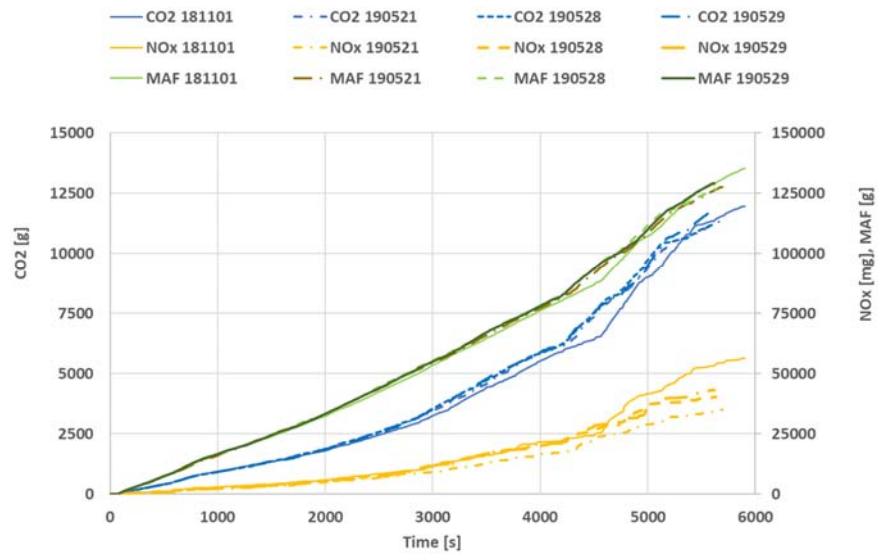


Figure 5-20: Cumulative CO<sub>2</sub> and NO<sub>x</sub> emissions measured in RDE tests with engine calibration 2.

### 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<sub>x</sub> 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<sub>2</sub> emissions of 118.5 g/km is 12% higher than the value of 106 g/km measured by the manufacturer. Furthermore, this increased CO<sub>2</sub> 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<sub>2</sub> 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<sub>x</sub> 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 <sub>2</sub>	CO	NO <sub>x</sub>	THC+NO <sub>x</sub>	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 <sup>11</sup>
NEDC RL 1*	-	131.2	37.7	77.1	0.95	1.4 * 10 <sup>11</sup>
NEDC RL 1	118.5	362.1	63.5	119.6	0.17	3.0 * 10 <sup>10</sup>

\*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<sub>2</sub> emissions are 118.5 g/km, which is 12% higher than the type-approval value specified by the manufacturer. The measured NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> emissions increase from 118.5 to 175-178 g/km. At the same time, the NO<sub>x</sub> 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 <sub>2</sub>	CO	NO <sub>x</sub>	THC+NO <sub>x</sub>	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 <sup>11</sup>
NEDC RL 1	118.5	362.1	63.5	119.6	0.17	3.0 * 10 <sup>10</sup>
NEDC RL 5	174.9	325.0	141.1	169.6	0.20	5.1 * 10 <sup>10</sup>
NEDC RL 5	178.1	478.0	119.9	171.5	0.03	4.7 * 10 <sup>10</sup>

\*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<sub>2</sub> 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<sub>2</sub> emissions from 119 to 175-178 g/km (+ 48%). At the same time, the NO<sub>x</sub> 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<sub>x</sub>-O<sub>2</sub> 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<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> emissions measured with SEMs are 6.6% to 9.0% higher than the CO<sub>2</sub> emissions measured on the chassis dynamometer. For NO<sub>x</sub>, SEMs measures emissions that are 1.8% lower to 2.2% higher than measured with the chassis dynamometer.

Table 5-8: CO<sub>2</sub> and NO<sub>x</sub> 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 <sub>2</sub>	CO <sub>2</sub>	NO <sub>x</sub>	NO <sub>x</sub>
	[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

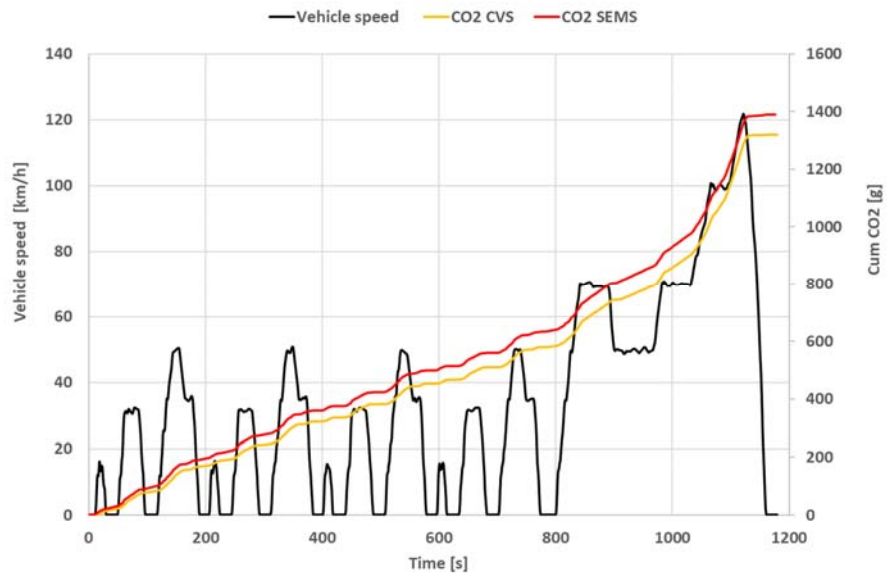


Figure 5-21: Cumulative CO<sub>2</sub> emissions with engine calibration 2 of an NEDC test conducted on 10-12-2018 on the chassis dynamometer, measured with the chassis dynamometer equipment and with SEMs.



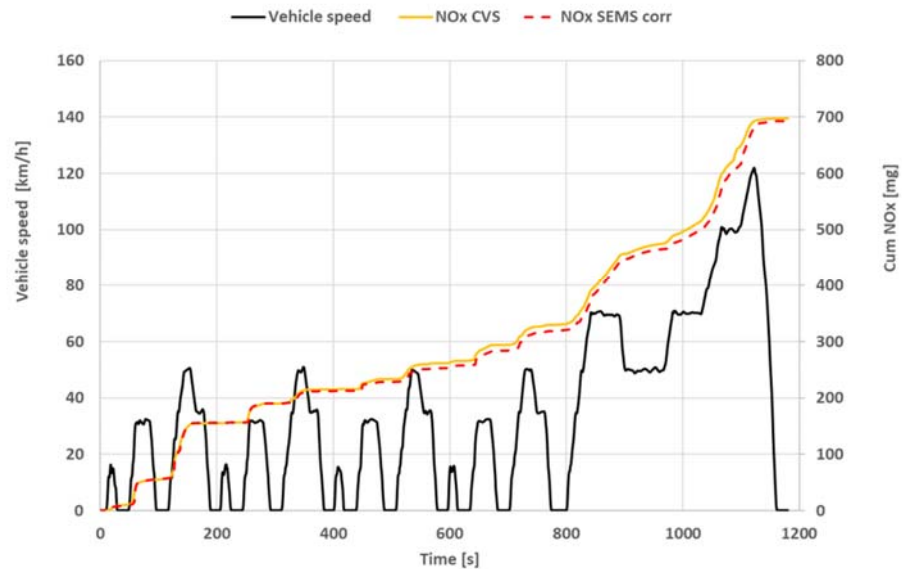


Figure 5-22: Cumulative NO<sub>x</sub> emissions with engine calibration 2 of an NEDC test conducted on 10-12-2018 on the chassis dynamometer measured with the dynamometer equipment and with SEMS.

*Partial conclusion 22:*

The CO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> and -2.3 to 2.6% for NO<sub>x</sub>. For the partial conclusions that relate to the NO<sub>x</sub> 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<sub>x</sub> emissions

*Background:*

The NO<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub>-O<sub>2</sub> sensor has on the measured NO<sub>x</sub> concentration has been investigated further. The reason for this research is the structural difference between the NO<sub>x</sub> 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<sub>x</sub>-O<sub>2</sub> sensors (before and after the LNT). A number of tests were then carried out on the test track and both the occurrence of NO<sub>x</sub> concentrations and the pressures were measured. The pressure dependence of the NO<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> 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<sub>x</sub> concentration of a certain calibration gas.

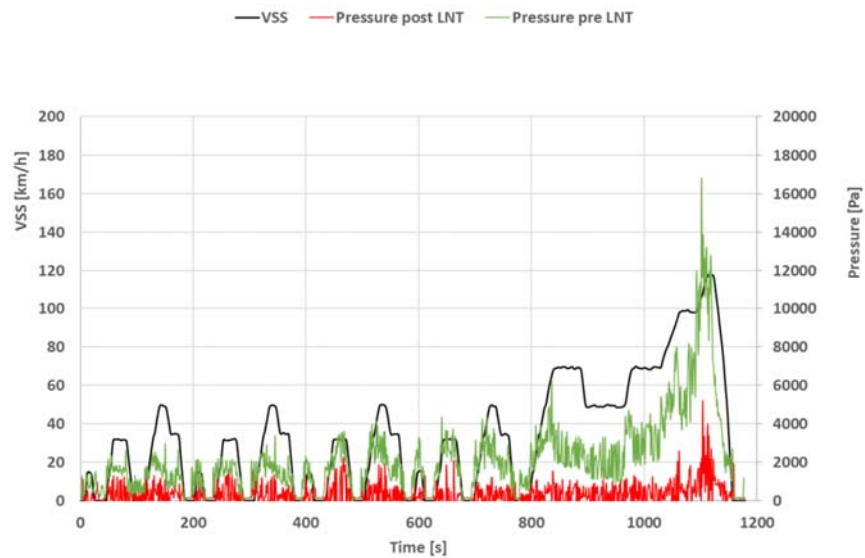


Figure 5-23: Measured relative pressures before and after diesel particulate filter/LNT with engine calibration 2 of an NEDC test performed on 18-04-2019 on the test track.

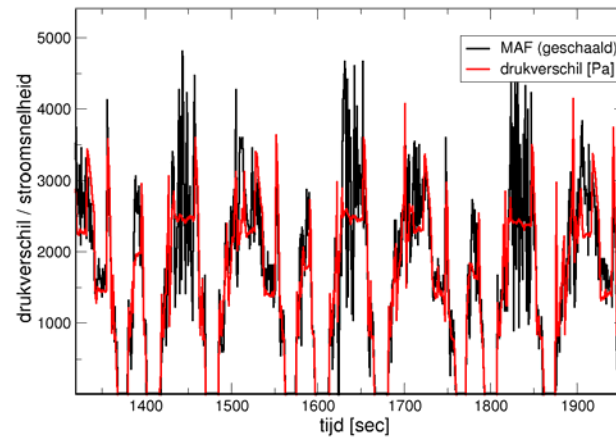


Figure 5-24: The measured pressure difference is correlated to the mass of the exhaust gas stream. This results in the pressures following the outlet flow, but that the faster variations are not all picked up.

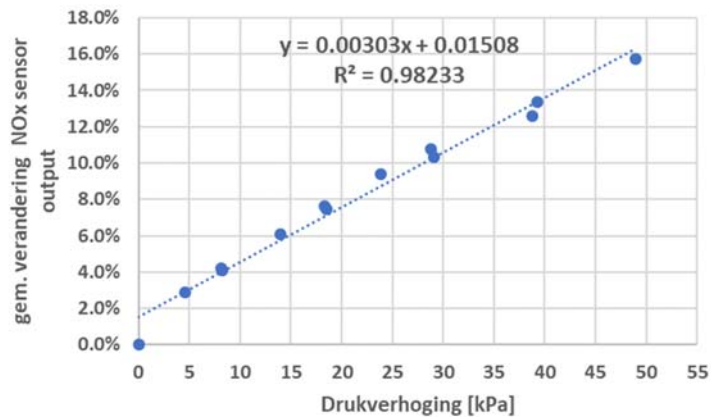


Figure 5-25: Influence of a stationary pressure on the NO<sub>x</sub> measurement value of the applied NO<sub>x</sub>-O<sub>2</sub> sensor of the SEMS measurement system

#### Analysis:

The measured overpressures at the NO<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> concentration of the NO<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> concentration of the NO<sub>x</sub>-O<sub>2</sub> sensor is a maximum of 5.8%.

*Partial conclusion 23:*

The measured overpressure to which the NO<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> concentration is 1.5 - 2.7%, based on the pressure measurements.

The occurring pressures at the two NO<sub>x</sub>-O<sub>2</sub> sensors do explain part of the remaining constant differences in NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions is measured for both engine calibrations.
- In NEDC tests on the test track at an ambient temperature above 20°C, the NO<sub>x</sub> limit value of 80 mg/km is not met for both engine calibrations. The NO<sub>x</sub> emission is then approximately 150 - 200 mg/km for both engine calibrations.
- In NEDC tests on the test track, the NO<sub>x</sub> emission for both engine calibrations is dependent on the ambient temperatures and the NO<sub>x</sub> emission increases below 20 °C, see Figure 6-1.

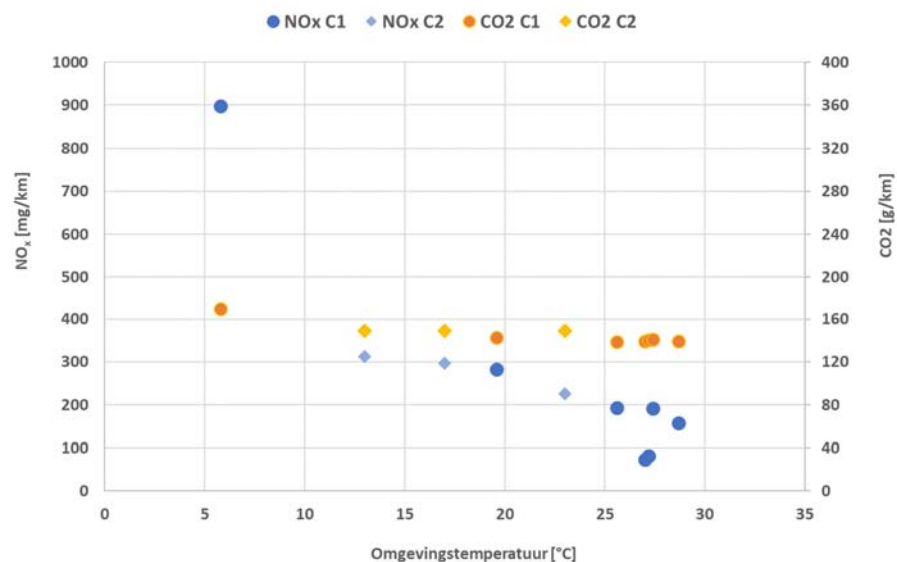


Figure 6-1: Corrected NO<sub>x</sub> and CO<sub>2</sub> emissions of NEDC tests with a cold start, measured on the test track with engine calibration 1 and 2 at different ambient temperatures.

- 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<sub>x</sub> emission of the subsequent emission test.

- In UDC tests at an ambient temperature higher than 20°C, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions are dependent on the ambient temperature. Above 20°C the RDE NO<sub>x</sub> emission is approximately 400 mg/km and at an ambient temperature of 13 °C the NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions.

*What are the considerations for applying a Lean NO<sub>x</sub> Trap (LNT)?*

The Suzuki Vitara Euro 6b diesel is equipped with a LNT. This LNT is needed for an additional NO<sub>x</sub> reduction, because the two EGR systems that also ensure a certain reduction in NO<sub>x</sub> 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<sub>x</sub> and this is dependent on, among other things, the operating temperature.

During normal operation the LNT will store  $\text{NO}_x$  until the  $\text{NO}_x$  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  $\text{NO}_x$  buffer is almost completely filled.

*How does regeneration of a LNT work and which  $\text{NO}_x$  emission pattern is created?*

During the regeneration of the LNT, the stored  $\text{NO}_x$ , with the help of fuel, is converted into  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{N}_2$  and  $\text{O}_2$ , 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  $\text{NO}_x$  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  $\text{NO}_x$  concentrations during a test on the test track with a constant speed of 130 km/hour.

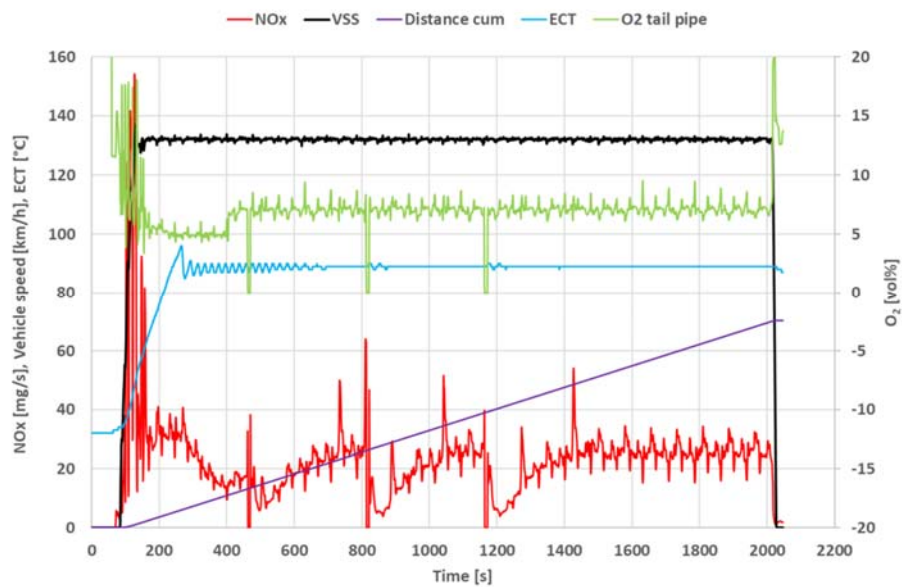


Figure 7-1:  $\text{NO}_x$  concentrations at a constant speed of 130 km/h. Due to the operation of the LNT, the  $\text{NO}_x$  emission up to  $t = 1500$  s varies between 5 and 25 mg/s. After that, the LNT is no longer regenerated and the  $\text{NO}_x$  emission remains stable.



## 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 NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission of 157-191 mg/km is measured in an NEDC on the test track. The only circumstances under which the NO<sub>x</sub> 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<sub>x</sub> storage capacity of the LNT is maximised at the start of an emission test. During the emission test, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emissions at different ambient temperatures. With an ambient temperature of 6 °C the NO<sub>x</sub> 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<sub>x</sub> emission

increases. The ambient temperature seems to have a bigger influence on the NO<sub>x</sub> 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<sub>x</sub> emissions of the engine abruptly rise from 300 to 450 mg per ECE cycle. The timing of this sudden increase in NO<sub>x</sub> emission varies in the different tests, but no explanation for this has been found. The increase in NO<sub>x</sub> 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<sub>x</sub> emissions. These have not been examined.

In UDC tests with a warm start at an ambient temperature above 20 °C, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> 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<sub>x</sub> emission is dependent on the ambient temperature. Substantially higher NO<sub>x</sub> 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<sub>2</sub> emissions are 114.9 – 117.2 g/km, which is 8 - 11% higher than the value specified by the manufacturer. The measured NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> 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<sub>2</sub> emissions from 115 to 152 g/km (+ 32%). The NO<sub>x</sub> emission varies between 65 and 168 mg/km and has no direct relationship with increasing driving resistance.

*Partial conclusion 11:*

The CO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> and -2.3 – 2.6% for NO<sub>x</sub>. For the partial conclusions that relate to the NO<sub>x</sub> 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<sub>x</sub> emission increases if the ambient temperatures drop. Furthermore, the number and duration of the LNT regenerations in the preconditioning test influences the NO<sub>x</sub> emissions in the NEDC test. With an ambient temperature above 20 °C and a standard preconditioning cycle (3\*EUDC), a NO<sub>x</sub> 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<sub>x</sub> buffer capacity varies at the start of an emission test and this influences the NO<sub>x</sub> emissions from the emission test.

*Partial conclusion 15:*

The NEDC NO<sub>x</sub> emissions with a cold start of engine calibration 2 are substantially higher than the NO<sub>x</sub> 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<sub>x</sub> emissions of the vehicle abruptly rise from approximately 150 to 450 mg per ECE cycle. The time of this sudden rise in NO<sub>x</sub> emissions lies within the twelfth to fourteenth ECE cycle of a UDC test. The increase in NO<sub>x</sub> 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<sub>x</sub> emissions. These have not been examined.

*Partial conclusion 17:*

With the same ambient temperatures and the same preconditioning cycles, the NO<sub>x</sub> 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<sub>x</sub> emission. After the cold start, the NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> emissions are 129 - 137 g/km and the NO<sub>x</sub> 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<sub>2</sub> emissions are 118.5 g/km, which is 12% higher than the type-approval value specified by the manufacturer. The measured NO<sub>x</sub> 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<sub>x</sub> 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<sub>2</sub> 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<sub>2</sub> emissions from 119 to 175-178 g/km (+ 48%). At the same time, the NO<sub>x</sub> emissions also increase from 64 to 120-141 mg/km (+ 87% to + 120%).

*Partial conclusion 22:*

The CO<sub>2</sub> and NO<sub>x</sub> 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<sub>2</sub> and -2.3 to 2.6% for NO<sub>x</sub>.

For the partial conclusions that relate to the NO<sub>x</sub> 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<sub>x</sub>-O<sub>2</sub> 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<sub>x</sub> concentration is 1.5 - 2.7%, based on the pressure measurements.

The occurring pressures at the two NO<sub>x</sub>-O<sub>2</sub> sensors do explain part of the remaining constant differences in NO<sub>x</sub> 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<sub>x</sub> 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 <sub>2</sub>	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 <sub>x</sub>	Nitrogen oxides, NO en NO <sub>2</sub>
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

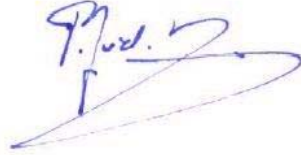
## 10 References

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

## 11 Signature

The Hague, 24 September 2019

TNO

A handwritten signature in blue ink, appearing to read 'P. van der Mark', with a large, sweeping flourish extending to the right.

Peter van der Mark  
Project manager

A handwritten signature in blue ink, appearing to read 'G. Kadijk', with a large, sweeping flourish extending to the right.

Gerrit Kadijk  
Author



# A Reference fuel certificates



Haltermann Carless Deutschland GmbH  
Schlengendeich 17 21107 Hamburg Germany

HORIBA EUROPE GMBH  
Monika Spengel  
HANS-MESS-STRASSE 6  
61440 OBERURSEL

**Certificate 100000121736**

Date: 07.11.2017  
Customer PO: 4510565089  
Delivery Note: 80101799 000010  
Order No: 65100455 000010  
Customer No.: 1750282

GMID: 357707  
Material: Diesel, EURO-6 Cert Fuel B7  
172 KG LINED STEEL DRUM 1A1  
Cust. Mat.:  
Batch: EJ0603T477  
Orig. Batch: 37  
Sample No.: 30030144  
Analyzed: 13.10.2017  
Divy. Qty: 172,0 KG

Vehicle: M-DH 6087  
Ship from: Shipping Point Hamburg Hamburg 02 Germany Page: 1 / 2

Feature	Units	Results	Limits Minimum	Maximum	Method
Cetane Number (CFR)	(*)	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	360,3	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 12918
Sulfur	mg/kg	< 3,0	-	10,0	EN ISO 20846
Corrosion - Copper		1A	-	-	EN ISO 2160
Carbon Residue - 1	% w	max. 1	-	0,26	-
Ash Content (*)	% w	< 0,10	-	0,010	EN ISO 10370
Water	mg/kg	48	-	200	EN ISO 12937
Particulate Matter	mg/kg	16,6	-	24,0	EN 12662
Strong Acid Number	mg	< 0,02	-	0,10	ASTM D974
Oxidation Stabilit	Hour	KOH/g 66,7	20,0	-	EN 15751

Bitte der Geschäftsstelle Haltermann Carless Deutschland Hamburg • HMB 11859 • UMLERNAUT-ID: DE91626666 •  
Oberschlesische Oel- und Gaswerke (Völkse) Peter Stubbe, Hertha Köhler  
Commerzbank AG • Konto 6102128 • Bankleitzahl 25040000 • IBAN DE20 2004 0030 0015 2128 00 • SWIFT Code COBADE33XXX



HORIBA EUROPE GMBH  
HANS-MESS-STRASSE 6  
61440 OBERURSEL

Delivery item/date  
80101799 000010 / 09.11.2017

Page  
2 / 2

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	(*) % w	0,86	-	-	EN 14078
Hydrogen	(*) % w	13,45	-	-	RWL-HM-28
Carbon	(*) % w	85,69	-	-	RWL-HM-28
C:H Ratio (H=1)	(*)	6,37	-	-	RWL-HM-28
H:C Ratio (C=1)	(*)	0,157	-	-	RWL-HM-28
Net Heating Value	(*) MJ/kg	42,587	-	-	RWL-HM-27
Net Heating Value	(*) Btu/lb	18436	-	-	RWL-HM-27

(\*) : tested by subcontractor  
(\*) : not accredited  
(\*) : 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

Bitte der Geschäftsstelle Haltermann Carless Deutschland Hamburg • HMB 11859 • UMLERNAUT-ID: DE91626666 •  
Oberschlesische Oel- und Gaswerke (Völkse) Peter Stubbe, Hertha Köhler  
Commerzbank AG • Konto 6102128 • Bankleitzahl 25040000 • IBAN DE20 2004 0030 0015 2128 00 • SWIFT Code COBADE33XXX

## B Results of dynamometer emission testing

Overview Chassis Dynamometer tests Suzuki Vitara motorkalibratie 1															
Test type	Road Load	Calibration	Phase	HC	CO	CO2	NOx	NO	NMHC	CH4	NMDOG	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]
15-8-2018	UDC cold	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	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+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	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	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+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	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	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+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	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	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+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	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	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+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	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	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+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	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	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+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	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	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+2	49.3	318.0	151.9	167.6	110.7	31.9	20.0	45.2	216.9	5.79	0.20	1.17E+11

Overview Chassis Dynamometer tests Suzuki Vftara motorkalibratie 1															
Test type	Road Load	Calibration	Phase	HC [mg/km]	CO [mg/km]	CO2 [g/km]	NOx [mg/km]	NO [mg/km]	NMHC [mg/km]	CH4 [mg/km]	NMOG [mg/km]	HC+NOx [mg/km]	FC [l/100km]	Particle Grav. [mg/km]	counts [1/km]
14-8-2018	UDC cold	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	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	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	4												
14-8-2018	4* UDC cold	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	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	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	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	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	1-4	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	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	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	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	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	1-4	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 Vitarra motorkalibratie 2															
Test type	Road Load	Calibration	Phase	HC [mg/km]	CO [mg/km]	CO2 [g/km]	NOx [mg/km]	NO [mg/km]	NMHC [mg/km]	CH4 [mg/km]	NMOG [mg/km]	HC+NOx [mg/km]	FC [l/100km]	Particle Grav. [mg/km]	counts [1/km]
10-12-2018	UDC cold	1	2	1	98.2	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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 m<sup>3</sup>/h  
fresh air 2,000 m<sup>3</sup>/h  
CVS dilution air 1,200 m<sup>3</sup>/h  
waste air 2,000 – 4,000 m<sup>3</sup>/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<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub>/NO, THC and CH<sub>4</sub>,  
separate EGR analyser

**MEXA ONE 2-OV**

Exhaust gas analyser,  
dilute bag & continuous measurement  
for: O<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub>/NO, THC, CH<sub>4</sub>.

**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<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub>/NO, THC, CH<sub>4</sub> and separate EGR analyser.
- o **Horiba MEXA ONE 2-OV**, Exhaust Gas Analysing System for dilute bag & continuous measurement with the following analysers: O<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub>/NO, THC, CH<sub>4</sub>.
- o **Horiba MEXA 2100 SPCS**, Solid Particle Counting System.
- o **Horiba MEXA ONE CVS**, Constant Volume Sampler System, 6 m<sup>3</sup>/min to 18 m<sup>3</sup>/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.