Translation

Kraftfahrt-
Bundesamt

Effectiveness of Software Updates for the Reduction of Nitrogen Oxides in Diesel Engines

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Contents

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Glossary

ABE	Allgemeine Betriebserlaubnis (National type approval)
CF	Conformity Factor
CO_2	Carbon dioxide
CO	Carbon monoxide
DEF	Diesel Exhaust Fluid
DPF	Diesel particulate filter
ECU	Engine control unit
EGR	Exhaust gas recirculation
EUDC	Extra Urban Driving Cycle
HC	Hydrocarbons
H_2O	Water /water vapour
HW	Hardware
K	Kelvin
KBA	Kraftfahrt-Bundesamt (Federal Motor Transport Authority)
N_2	Nitrogen
NEDC	New European Driving Cycle
NH_3	Ammonia
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
NSC	NO_x storage catalyst
OH^-	Hydroxide ion
PEMS	Portable Emissions Measurement System
RDE	Real Driving Emissions
SCR	Selective Catalytic Reduction
SW	Software
TD	Technical Service
UDC	Urban Driving Cycle
WLTC	Worldwide harmonized Light vehicles Test Cycle
WLTP	Worldwide harmonized Light vehicles Test Procedure

A. Introduction

On the basis of the events in connection with Volkswagen (VW) and the detection that prohibited defeat devices had been used in diesel engines of type EA 189, the effectiveness of software updates to restore compliance was tested by the Kraftfahrt-Bundesamt (Federal Motor Transport Authority, KBA). In October 2015, the KBA had ordered a mandatory recall to remove the prohibited defeat devices from the engine software.

Moreover, the KBA had been asked by the Federal Ministry of Transport and Digital Infrastructure (BMVI), within the context of the “Volkswagen Commission of Inquiry”, to also to test further diesel-powered motor vehicles of other German and foreign automotive manufacturers. It was found out that many manufacturers adapt the effectiveness of their emission control system to the driving and environmental conditions, e.g. the ambient temperatures, substantiating this in many cases with the exemption clauses in Article 5(2) of Regulation (EC) 715/2007, i.e. the need of protecting the engine or for the safe operation of the vehicle. In cases where irregularities were detected during the inspections, the KBA ordered further recalls. A compilation of the vehicles for which a mandatory recall has been initiated up to now can be found on the website of the KBA (www.KBA.de).

Irrespective of the difficult appraisal of the admissibility of the engine protection functionalities used, the BMVI encouraged several manufacturers in April 2016 to introduce improvements to their ongoing production and in some cases also to in-service vehicles within the framework of voluntary service measures.

Since the air pollutant levels continued to be excessively high, thus affecting air quality in many German cities which could lead to possible driving bans for diesel-powered passenger cars, the “National Forum Diesel” adopted on 2 August 2017 further measures for the reduction of the nitrogen oxide emissions (NO_x). The automotive industry has agreed to reduce the NO_X emissions from around 5.3 million diesel-powered passenger cars of Euro 5 and 6 pollutant emission categories which are registered in Germany by an average of 25-30%. In the meantime, the industry has increased this number by a further approximately 1 million vehicles.

A software update is a measure which can relatively quickly and easily be implemented in order to significantly reduce the NO_x emissions from diesel-powered passenger cars.

The automotive manufacturers develop these software updates, taking account of the latest findings and experience obtained from the evolution of diesel technology, in order to optimize the emission reduction and engine control strategies with regard to the NO_X emissions which are already in place. An example here is the extension of the operating limits of the exhaust gas recirculation with regard to the ambient temperature and pressure, thus improving the use of the exhaust gas recirculation and the nitrogen oxide emissions.

Within the context of the approval process of a software update, the KBA checks the reduction of the NO_X emissions achieved; it also has to check that the CO_2 emissions do not increase and other relevant parameters from the type-approval do not deteriorate. Aditionally, during the approval process the software update is examined as to the absence of prohibited defeat devices; this is done by means of software analysis and, if necessary, specific verification measurements.

The implementation of the software updates by the automotive manufacturers is supervised and documented by the KBA; this applies to the mandatory updates as well as to those provided as a voluntary service measure.

This report explains the implementation and possibilities of the software updates, describing the measures performed and of the verification measurements which document the reduction of the NO_X emissions in consideration of the 25-30% target.

In section B of the report (“Fundamentals”), first of all the fundamentals for the generation and reduction of NO_x emissions from motor vehicles are set forth in more detail.

Then, in section C of the report (“Investigations”), the measurements performed are presented and assessed. These measurements are subdivided into those performed on vehicles which were updated within the framework of mandatory as well as voluntary measures.

This report only focusses on measurements of vehicles which were completed by September 2019.

In total, the software updates of 46 different vehicle groups were checked. 21 vehicles were analysed for the measurements within the context of voluntary service measures by the manufacturers (general type approval of the software). 16 vehicle clusters were checked in the course of the verification measurements of the mandatory recalls by VW concerning engine type EA 189. In addition, nine vehicles of several manufacturers which were subject to mandatory recalls were tested.

Finally, in section D of the report (“Summary”), the proof of the effectiveness of software updates is summed up, based on the results of the comparative measurements performed by the KBA.

B. Fundamentals

I. Generation and reduction of NOx emissions

1. Generation of pollutant emissions / limit values

Apart from the main exhaust components, i.e. water vapour (H_2O) and carbon dioxide (CO_2), the combustion of diesel fuel also produces pollutants such as unburned hydrocarbons (HC), carbon monoxide (CO), carbon particles and also nitrogen oxides (NO_X).

The European emission legislation especially provided for the reduction of the limit value for NO_X as from the Euro 3 level. The applicable limit value for NO_X was defined as follows:

Pollutant emission category	NO_x limit value [mg/km]
Euro 3	500
Euro 4	250
Euro 5	180
Euro 6	80
Euro 6d-Temp	
WLTC:	80
RDE:	168

Table 1: Limit values for NOx (M1)

The limit values up to Euro 6 apply exclusively to the type approval testing cycle (NEDC) on the chassis dynamometer under laboratory conditions. Regulation (EC) 715/2007 reduced the related limit value in the NEDC and entrusted the European Commission, in the so-called regulatory procedure with Parliamentary scrutiny, with the task of defining the individual requirements, among other things, also at low ambient temperature. These requirements were laid down in the Implementing Regulation (EC) 692/2008. While a special test was introduced for petrol engines at cold ambient temperatures, the regulatory body did, for the time being, not establish defined tests for diesel engines. It was a known fact, that the exhaust gas recirculation used by diesel engines is a technologically sophisticated system at cold ambient temperatures, so that specific requirements were only laid down for the exhaust after treatment and limit values for cold ambient temperatures were to be established only at a later date, after gaining further experience.

This was done with the RDE provisions which were applied to vehicles with new type approvals for the purpose of monitoring as from 1 September 2017 at the earliest. Since 1 September 2019, the limit values of pollutant emission category Euro 6d-Temp have been applying to all newly registered passenger cars. They include for the first time a limit value for on-road tests in accordance with the RDE provisions, which is 168 mg/km.

Owing to the ever tightening limit values, it became more and more necessary to evolve engine internal measures in order to reduce NO_x emissions (exhaust gas recirculation) as well as effective exhaust after treatment systems in the exhaust branch which are placed downstream of the engine.

The pollutants HC and CO are effectively reduced with an oxidation catalyst which is also placed downstream of the engine; carbon black emissions are minimized by using particulate traps (diesel particulate filter).

But for the reduction of NO_x, different steps have to be taken. In order to understand the mechanisms of the different measures, it is necessary to explain the generation of NO_X in the course of diesel combustion.

The term NO_X covers all nitrogen oxide compounds (NO, NO_2, NO_3, N_2O, N_2O_3, N_2O_5). In the case of diesel combustion, however, only substantial quantities of NO and NO_2 are recorded which are added up under the above-mentioned generic term of nitrogen oxides (NO_X).

The generation process of NO presupposes high peak temperatures above 2,200k and local excess air. These are the conditions for the formation of thermal NO which accounts for a major share of the NO_X emissions from the engine. For the reduction of the thermal NO, the combustion temperature can be lowered by a high exhaust gas recirculation and charge air cooling and the injection characteristics for fuel injection can be modulated. The adaptation of the injection characteristics can lead to a more homogeneous combustion with lower peak pressures coupled with lower temperatures.

A further component of the NO_X emissions is nitrogen dioxide (NO_2) which accounts for only a small share of the overall NO_X emissions. In the course of the diesel engine combustion, NO_2 is generated mainly from the reaction of NO with HO_2 and OH radicals. In the ambient air, NO in turn reacts with ozone to form NO_2 through the incidence of light. Nitrogen dioxide has properties which may irritate the respiratory tract and by further chemical reactions in the atmosphere it can result in acid rain (www.hlnug.de).

2. Possibilities of reducing NO_x emissions

There are several concepts to lower the NO_x emissions from engines. In this context, a distinction is made between engine internal measures such as EGR, adaptation of the fuel injection, adaptation of the engine timing and external measures such as the use of a SCR catalytic converter or of a NOx storage catalyst. Modern diesel concepts normally include several of the measures mentioned for the reduction of pollutants so that NO_X can be reduced considerably in all driving situations if the existing hardware is fully exploited.

In the following, the usual measures for the reduction of NO_X emissions are explained.

a. Exhaust gas recirculation

The objective of exhaust gas recirculation is the lowering of the combustion temperature, in order to prevent the formation of thermal NO.

Here, use is made of two effects: Depletion of oxygen in the aspirated fresh air and higher specific heat capacity of the exhaust components recirculated.

The EGR rate is limited by the NO_X-carbon particles conflict of goals. The rising share of exhaust gas recirculated leads to an increasing formation of particles. This causes a more frequent regeneration of the diesel particulate filter (DPF) and thus to a higher fuel consumption.

Further limits for the recirculated exhaust gas quantities are set by the effects of the sooting and varnishing of components as well as by the dilution of engine oil which are described below.

b. NO_x storage catalyst

A further method for the reduction of the NO_x emissions from the engine is the use of an exhaust after treatment system such as the NO_X storage catalyst (NSC). An NSC has a special catalytic coating (mostly barium compounds) which absorbs nitrogen oxides from the exhaust gas in order to convert them to nitrogen (N_2) and CO_2 after saturation.

The engine is operated for a short period of time (approx. 2 to 10 seconds) with a rich air-fuel mixture ($\lambda<1$) in order to convert the previously stored NO_X (purge). The CO which is now contained in the exhaust gas reacts with the stored NO_X to form N_2 and CO_2. During this procedure, the catalytic coating is restored by oxidation and can subsequently again absorb NO_x.

c. Selective catalytic reduction

A further effective measure to reduce nitrogen oxide emissions from the engine is the use of a SCR system. This exhaust after treatment system consists of a SCR catalytic converter installed in the exhaust branch, a tank for diesel exhaust fluid (DEF) and a dosing unit.

The aqueous DEF is sprayed into the hot exhaust system via the dosing unit. Thermolysis and hydrolysis induce the urea solution to react, forming NH_3 (ammonia) and CO_2. The NH_3 thus obtained is now stored in the coating of the SCR catalytic converter ("storage mode") and can convert the NO_X

contained in the exhaust gas into N_2 and H_2O.

SCR systems have two different operating strategies for the conversion of NO_X. In the storage mode, priority is given to a sufficient storage filling level of NH_3. This operating strategy enables an optimally high NO_X conversion, even with transient engine operations. The SCR catalytic converter has, up to a certain temperature range, a good storage capacity and can absorb surplus NH_3 so that a release of the ammonia into the ambient air (so-called NH_3 slip) is prevented. The stored NH_3 is degraded with an erratic emergence of NO_X.

In the case of high temperatures in the SCR catalytic converter, the storage capacity decreases and there is the risk of a NH_3 slip. In such a case, there will be a change-over to a so-called online mode. If this strategy is applied the storage level will be minimized to such an extent that no NH_3 slip occurs. The NO_X conversion is achieved consistent with demand through the directly converted NH_3. Experience has shown that this operating mode achieves in most cases lower NO_x conversion rates as compared with the storage mode.

3. Effectiveness and limitations of software updates for the reduction of NO_X

In order to quickly reduce the NO_X emissions from in-service vehicles, application/calibration adaptations were made to the emission reduction systems. On the basis of these software adaptations, updates can be implemented in a relatively short period of time, which results in a direct improvement of the NO_X emissions. But these system extensions must be carefully developed and tested so as to prevent the risk of causing damage to the engine.

a. Update of the EGR control

Exhaust gas recirculation belongs to the engine internal measures and can, for example, also be subject to limitations depending on ambient temperature, which may cause substantial deposits (“sooting”) in the system, likely to lead to a reduction of the maximum possible exhaust gas recirculation owing to reductions in the cross section as well as to a system failure. Components such as the EGR cooler, directly belong to the engine in accordance with the approval regulations. Excessive sooting damages these components irreparably which means that they have to be replaced. Moreover, components such as the EGR valve can clog due to varnishing and thus ultimately break down. Among other things, the ambient temperature and the ambient air pressure are typical environmental conditions with limiting effect.

Another effect is the excessive saturation of the diesel particulate filter caused by an excessive EGR rate and the resulting in a more frequent regeneration. This regeneration is usually performed in such a way that the partial injection of fuel occurs at a very late stage. The soot particles collected will be combusted in the filter. If the late stage partial injection of fuel more often takes place, this will lead to a dilution of engine oil. This results in a decreased lubricating effect or in the formation of oil foam as a consequence of an excessively high fill level of the oil sump. Both can lead to engine damage.

Within the context of the software updates, among other things, the control strategy of the EGR is adapted. In order to enable an EGR to function correctly and durably in all operating points, several parameters in the engine control unit are adjusted in such a way that varying EGR rates are obtained in the case of high quantities of injected fuel and/or high engine speeds as well as specific temperature ranges (coolant temperature, ambient air temperature etc.). In the past, it was found in numerous cases that these parameters had been applied in such a way that the vehicle shows a considerable NO_X reduction by means of EGR only within the marginal conditions of the NEDC test (air temperature, injected fuel quantity, maximum engine speed).

The adaptation of the software which also means the update of the engine control unit cancels, among others, the correction of the EGR, depending on the ambient air and intake-air temperature, which was the reason for the cutting back of the exhaust emissions aftertreatment. This correction can be extended to cover low as well as high temperature ranges. Especially the lower temperature range was adapted, so that the EGR is also effective at low ambient air temperatures. This is of special relevance in view of the temperatures prevailing in Germany (annual average in 2018: 10.5°C) [Federal Environment Agency: www.uba.de], since a high EGR rate is also required here.

The application of a correction of the EGR, i.e. a reduction depending on the ambient temperature, is from the legal point of view only admissible if it is necessary for the protection of the engine against damage or accidents or if the limit value is complied with in the test cycle despite correction.

In addition, further parameters affecting the EGR, such as the maximum engine speed and the injected fuel quantity, were adapted so that the EGR in its updated form is essentially more effectively used in real road operation than with the older series dataset.

b. Update of the NSC control

Owing to its operating principle, the NSC is subject to a regular regeneration, the so-called purge. This purge is initiated by the engine control. By means of the software updates the purge behavior of the engine aftertreatment system can be adapted. There are two different options of detecting the fill level of NSC-NO_x - either model-based or sensor-based.

In contrast to sensor-based systems, model-based systems cannot detect a NH_3 slip and are, therefore, as a rule applied more conservatively. If the dataset has been updated, models and, if necessary, strategies are adapted, thus enabling higher NO_x conversion rates by an improved purge characteristic.

c. Update of the SCR control

Within the context of the software updates, among other things, the changeover conditions of the two operating strategies (storage and/or online mode) were adapted so that the vehicle remains in the storage mode for a longer period (with a higher NO_X conversion rate). In addition, the intended maximum NO_x conversion rate (1 = all NO_X are converted) can be adapted which is associated with an increase of the dosed DEF. In this connection, it is necessary to continuously prevent the NH_3 slip at high SCR temperatures, which in real world operations leads to conversion rates of < 1.

Similar to the temperature-based correction for exhaust gas recirculation, corrections are also applied to SCR systems, which can reduce the effectiveness of the system with a declining system temperature. By means of the software updates, the technically feasible NO_X conversion at lower catalyst temperatures is increased.

Moreover, inadmissible functions have been removed within the context of the mandatory updates. This includes, inter alia, a reduced DEF dosing in the case of certain DEF remaining distances (inducement) as well as heating-up strategies of the exhaust after treatment, which were only active on the chassis dyno or in the test cycle.

C. Investigations

I. Measurements

1. Background of the tests and fundamentals

In the following, the comparative measurements performed by the KBA with software updates of the engine control are presented. The comparative measurements described are performed for two variants of software updates. These updates were either implemented as a consequence of:

a) a voluntary service measure or

b) a mandatory recall.

Voluntary service measures are initiated by automotive manufacturers on an optional basis and are not officially imposed. Within the framework of the activities undertaken by the National Forum Diesel, the KBA checks these measures. Experience has shown that the percentage of updates performed in the course of voluntary service actions ranges between 80 and 90% of the vehicles registered in Germany. In the case of recalls ordered by the authorities, the target rate to be achieved in Germany is 100% of the vehicle registered.

If recalls are ordered by the authorities, vehicle holders are obliged to have software updates implemented. Vehicles not taking part in a mandatory recall cannot be granted a sticker when undergoing the main inspection, due to the considerable deficiency which is the object of the recall. Therefore, the KBA always orders recalls once proof is furnished of an inadmissible condition of the emission control system, even if the manufacturer has previously initiated a voluntary service action.

Under the current regulations, defeat devices are not admissible. However, in accordance with a derogation in Regulation (EC) 715/2007, a defeat device is admissible if, for example, the need for the device is justified in terms of protecting the engine against damage or accident and for safe operation of the vehicle as well as for compliance with the limit value.

Especially with regard to the reduction of the EGR rate, for instance, at lower or higher ambient temperatures, manufacturers justify this measure often with engine damage, proven by measurements or damage statistics. If it can be supposed that this evidence is not correct, the burden of proof lies with the KBA which has to carry out field tests. Sometimes it is difficult for the KBA to furnish such proof, since this requires complex software analyses and lengthy emission measurements.

In some cases, software analyses are not possible because some manufacturers do not hand over the necessary software to the KBA, citing confidential business and commercial secrets. But the software cannot simply be read from the vehicle since it is stored as an encrypted dataset in the ECU. If the manufacturer holds a type approval granted by the KBA the handing over of the software can, however, be enforced. In the current procedure, individual manufacturers have made the software available without a specific request. Only with the new Regulation (EU) 2018/858 will the KBA be able, as from 1 September 2020, to legally enforce the handing over of the software from all manufacturers, even that of vehicle types not approved by the KBA.

Even after a software analysis it is in some cases difficult to classify with sufficient certainty suspicious algorithms which have been detected as prohibited defeat devices. An evaluation is made in accordance with Regulations (EC) 715/2007 and 692/2008. A defeat device will be considered to be prohibited only if the measured emissions of the vehicle also deteriorate. If in a vehicle with exhaust gas recirculation and exhaust after treatment, as is the case for Euro 6 vehicles, for example the EGR rate is adjusted downwards with decreasing ambient temperatures, higher emissions of raw NO_X are generally produced inside the engine. However, this can, for instance, still be fully compensated by a SCR system which normally functions effectively even at low outside temperatures. In the case of increasing exhaust emissions, it must also be checked whether the limit value is still complied with under the conditions prevailing for the regular type approval with lower EGR rates. For such a measurement under conditions prevailing for type approval tests, complex adaptations or the support of the manufacturer for the adaptation of the engine software are necessary. Accordingly, the KBA still today approves software updates with lower EGR rates for colder ambient temperatures in compliance with the legislative requirements.

As long as no inadmissible applications are detected with regard to the exhaust gas and emission strategies used and the proof furnished by the manufacturer is still valid, there are no objections to the voluntary service measures for software updates. The KBA supports the voluntary service actions in order to improve emission values in real driving conditions as soon as possible. In principle, the KBA performs further in-depth inspections if this is necessary. If irregularities are detected in this connection, the KBA orders a recall in order to actually reach all vehicles.

a. Voluntary service measures

In this case, no prohibited defeat device in accordance with Regulation (EC) 715/2007 on the type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles was found in the software structure of the dataset which was on the market at the time when approval was granted. In such cases, the manufacturer has, in coordination with the KBA, adapted the possible technical limits on the basis of the experience gained in the meantime, in such a way that the efficiency of the exhaust after treatment system is enhanced even in realistic ambient conditions (e.g. low temperature, low air pressure).

Proof of the efficiency of a voluntary software update is provided on the basis of a defined procedure. Measurements are made on the chassis dynamometer according to the New European Driving Cycle (NEDC) to furnish proof of the CO_2 neutrality of the update. If this test is satisfactory, measurements according to the new Worldwide Harmonized Light Vehicle Test Procedure (WLTP) are carried out. The relevant driving cycle (WLTC) is performed in its first three phases (WLTC123) on the chassis dynamometer at ambient temperatures of 5°C, 10°C and 15°C, in order to show the influence of the measure in urban traffic as well as interurban traffic at low temperatures. Finally, the vehicle is operated in real world driving (Real Driving Emissions, RDE) pursuant to Regulation (EU) 2016/427, including a cold start, where the effectiveness of the update is tested under real ambient conditions (e.g. slow-moving traffic in cities, changing ambient conditions, influence of the driver etc.). After completion of the analysis of the software update without detecting any illegal defeat devices, the KBA grants a ABE, in the following designated as software-ABE. After approval by the KBA, the manufacturer can introduce the software update for field use.

b. Mandatory recall

If, in accordance with Regulation (EC) 715/2007, the use of a illegal defeat device was detected which reduces the effectiveness of the emission control system, the KBA issues a notice to have this non-compliant device removed within the framework of an official recall. Other European type approval authorities can also enact recall actions vis-á-vis manufacturers. In Germany, the KBA must than enforce this measure by also initiating a mandatory recall. Currently, the European type approval authorities do not apply uniform procedures in the case of recalls for safety or environmental reasons. The new Regulation (EU) 2018/858 harmonizes the procedure which means that recalls will in the future be performed on a uniform basis in all Member States.

In this case, the manufacturer must provide software from which the prohibited defeat device has been removed.

In order to prove the effectiveness of such mandatory updates, measurements are carried out comparing the original series dataset with the dataset of the update which was newly developed by the manufacturer.

For this purpose, an individual test programme is normally applied. Since it is possible in such cases to selectively test the condition which is to be corrected, a software analysis in combination with a comparative measurement by means of an RDE on-road test is in most cases sufficient. In principle, vehicles which were type approved according to the NEDC must only comply with NEDC requirements. It is not necessary to comply with the new requirements under RDE. The KBA, nevertheless, performs RDE measurements in order to assess the improved emissions performance of vehicles in real world traffic after a software update.

The following section explains the bases of the different test cycles.

c. Quality of software updates and corrective action

Approval of the software update is granted by the KBA on the basis of the applicable rules and regulations. Within the context of this approval process, the KBA examines by means of software analysis and specific verification measurements, whether the detected illegal defeat device was removed and the provisions with regard to pollutant, noise and CO_2 emissions as well as fuel consumption are complied with. The neutrality of fuel consumption was tested and proven on the basis of the rules and regulations applicable in this respect, even with the involvement of technical services.

The software update must not lead to an increase in CO_2 emissions or to a deterioration of other relevant parameters from the type approval.

If there are no objections to the software update, the KBA will grant approval and initiate the recall.

If the software update is implemented in a vehicle the holder will receive a confirmation of this measure.

In 2016, the KBA became aware of a few individual cases where some vehicle dealers had issued the certificate without having implemented the software update in the vehicle. Consequently, the KBA requested the affected automotive manufacturers to immediately improve the vehicles and retrofit them with the software updates. In the meantime, all the vehicles affected have been retrofitted.

2. Test cycles

In order to obtain comparable measurement results, defined test cycles are carried out on the chassis dynamometer under repeatable marginal conditions (e. g air pressure, air temperature, driving profile). Vehicles covered by the scope of application of Regulation (EC) 715/2007 (“Euro 5 and 6 for light passenger and commercial vehicles”) were, within the context of the type approval with regard to their exhaust emissions, tested either in accordance with the requirements of Regulation (EC) 692/2009 in the NEDC or in accordance with Regulation (EC) 2017/1151 in the WLTC.

Apart from measurements on the chassis dynamometer, the KBA also carried out test in road traffic, using Portable Emissions Measurement Systems (PEMS) in order to assess the emissions performance of the vehicles in real driving conditions (RDE).

a. New European Driving Cycle (NEDC)

A driving cycle is defined by a time-speed-profile. During the test, the vehicle must be driven on this driving curve, including a small tolerance range, on a chassis dynamometer. Apart from the speed, the shifting points (Non-Autogearboxes) are also given. The speed-time profile of the NEDC which is to be applied in the European type approval procedure is shown in the following.

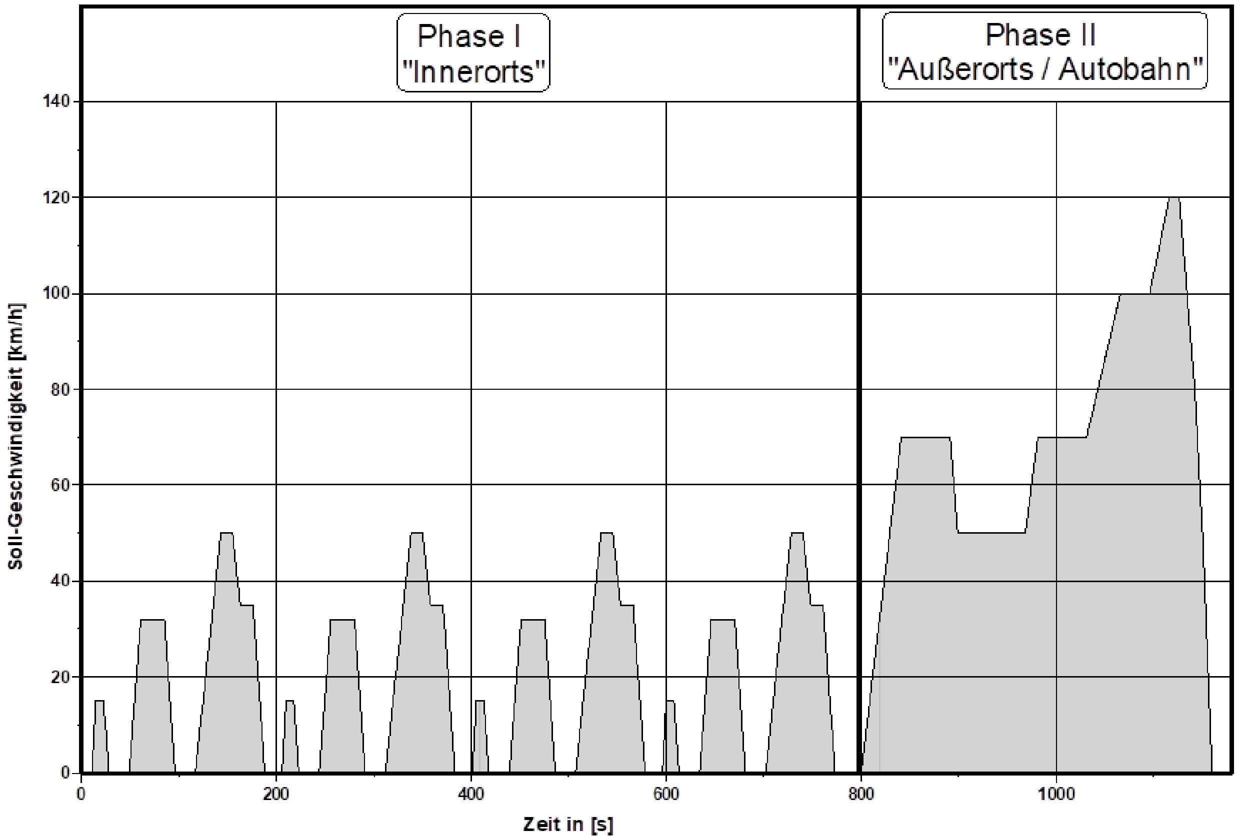

Figure 1: NEDC driving profile

Figure 1 shows the driving profile of the NEDC. The NEDC extends over a total of about 20 minutes (1180s) with two different parts. Part 1 is performed in the speed range of an urban journey (maximum speed 50 km/h, frequent stops) and is designated as **U**rban **D**riving **C**ycle (UDC). The following part 2 is to cover the speed range of an inter-urban journey with a short stretch of motorway and is designated as **E**xtra **U**rban **D**riving **C**ycle (EUDC).

The NEDC on the chassis dynamometer simulates straight-ahead driving on a level section of about 11 km with moderate acceleration (a_{max} = 0.8 - 1 m/s²), an average speed of $v_{Ø}$ = 33.6 km/h and a short-time maximum speed of v_{max} = 120 km/h.

The standard temperature for the measurement on the chassis dynamometer in the NEDC is 20-30°C in accordance with the EC Regulation.

b. Worldwide harmonized light vehicle test cycle (WLTC)

The WLTC is divided into four speed ranges (1=low, 2=medium, 3=high, 4=extra high) and is designated according to the shares used.

The first part (low) represents a journey in urban traffic with a maximum speed of up to 56.5 km/h.

Parts 2 (medium) and 3 (high) represent a journey on inter-urban roads and express roads. In part 2, the maximum speed is 76.6 km/h, in part 3 it is 97.4 km/h. In part 4, a journey on a motorway with a maximum speed of up to 131.3 km/h is simulated.

The following figure shows the driving profile of parts 1 to 3 of the WLTC.

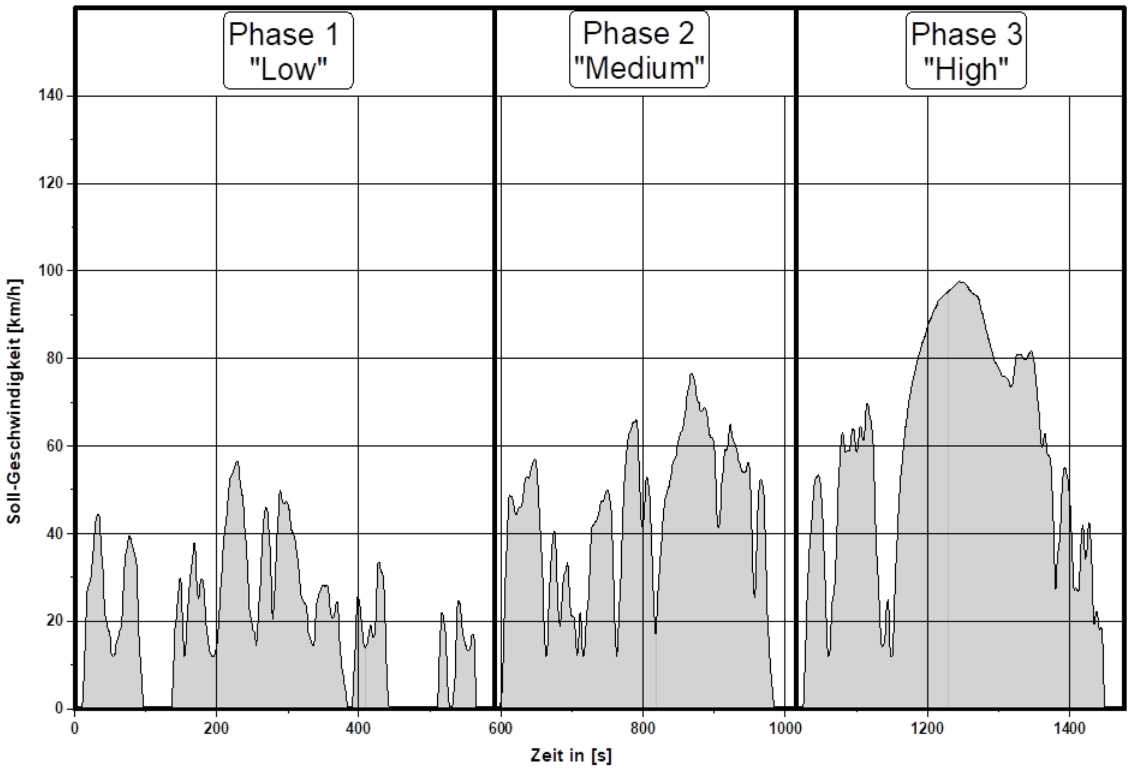

Figure 2: WLTC123 driving profile

The WLTC123 extends over a total of about 25 minutes (1477s), divided into three parts. Thus, with a maximum speed of 97.4 km/, the WLTC123 reflects driving situations prevailing in urban and inter-urban traffic.

For the WLTC123, a section of about 15 km is driven using a dynamic driving profile on the chassis dynamometer at a moderate acceleration (a_{max} = 1.6 m/s²) which is usual in real world traffic and an average speed of $v_{Ø}$ = 36.58 km/h.

With regard to the software updates which were granted the ABE by the KBA, the WLTC123 was used to show the improvement of the pollutant emissions in urban and inter-urban traffic.

The standard temperature for a measurement on the chassis dynamometer in the WLTC is 23°C ± 2°C in accordance with the EU Regulation. The KBA used lower ambient temperatures for its measurement series in order to assess the exhaust emission behaviour at low outside temperatures. The ambient temperatures for these measurements were 5°C, 10°C and 15°C.

c. RDE

The RDE test procedure using PEMS is provided for in Regulation (EU) 2016/427 and was further specified with regard to certain marginal conditions for the measurement by Regulations (EU) 2016/646 and 2017/1154.

Since the RDE test is carried out in road operation and not on the chassis dynamometer, several determinants such as the ambient conditions (air temperature, altitude, air pressure etc.) as well as the driving conditions (high/low traffic volume), driving dynamics (acceleration, deceleration), but also the vehicle conditions (vehicle mass or additional load etc.) affect the measurements. The EU Regulations specify these marginal conditions in such a way that they cover the range of normal operating conditions including cold start to a large extent. The essential ambient marginal conditions which ensure the validity of an RDE test are for example temperatures in the range between -7°C and 35°C and altitudes of up to 1300 m above sea level. The ambient temperatures are subject to seasonal and weather-related variations. When carrying out comparative measurements, it is endeavoured to have, if possible, a comparable ambient temperature.

An RDE test run must take between 90 and 120 minutes and consist of operation in urban traffic conditions (approx. 34%), rural traffic conditions (approx. 33%) and motorway conditions (approx. 33%). These driving conditions are characterized by different speed ranges. The following applies to passenger cars: Urban operation up to 60 km/h, rural operation between 60 km/h and 90 km/h, motorway operation from more than 90 km/h up to 145 km/h or partly even up to 160 km/h.

In view of these marginal conditions, a speed profile can for example look like the one shown in figure 3.

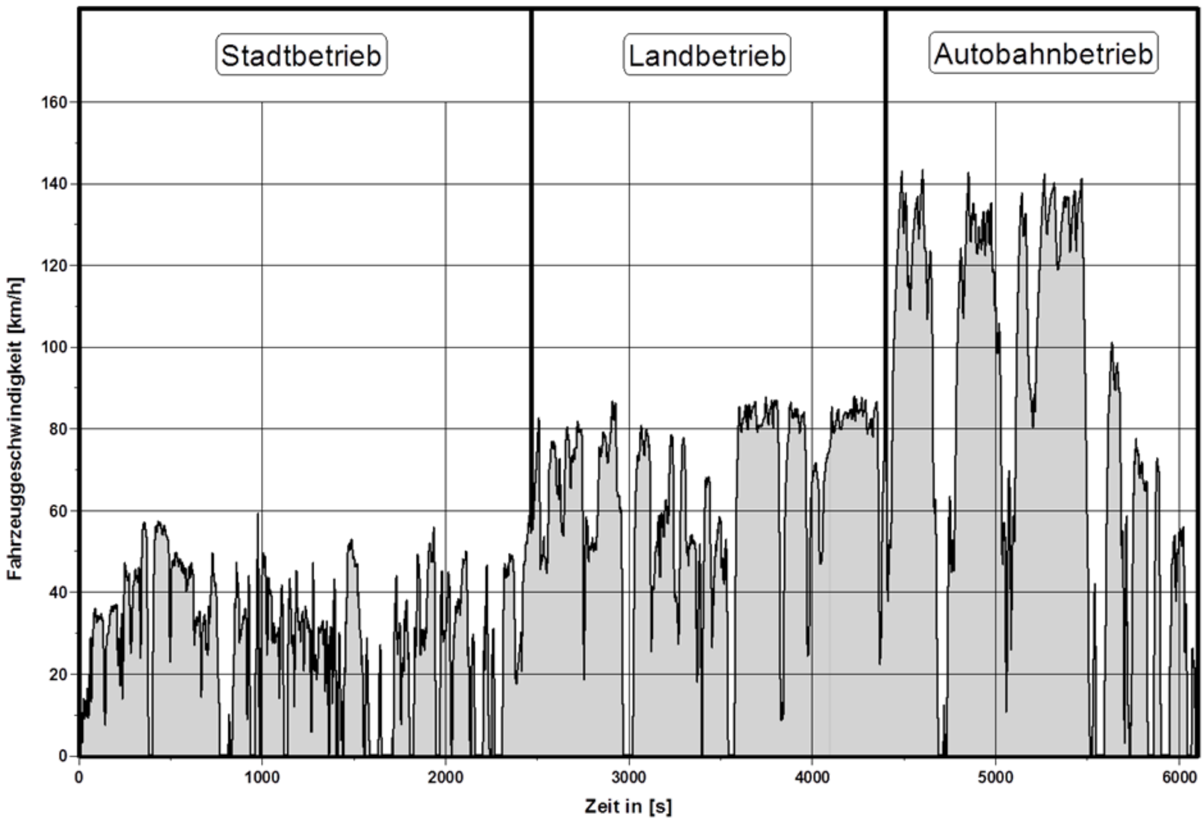

Figure 3: Example of an RDE driving profile

II. Measured vehicles

The following section sets forth the measurements carried out by the KBA to verify voluntary and mandatory software updates.

1. General Part

On 2 August 2017, the automotive manufacturers promised within the framework of the National Forum Diesel, to optimize the pollutant emissions of about 5.3 million of diesel-powered passenger cars of pollutant emission categories Euro 5 and 6 which are currently registered in Germany. This optimization includes vehicles covered by a mandatory recall action as well as vehicles for which the manufacturers offer a voluntary service measure. Software updates are to ensure a reduction of the NO_X emissions by an average of 25% to 30%. This was usually performed by adaptations to the calibration and application of the AGR system, the injection of DEF (if a SCR system is installed) as well as by the modification of the NSC purging behaviour (see also I.3). The manufacturers had to submit their applications for software updates to the KBA by 1 September 2018 at the latest. In the course of this process the number of vehicles reported increased to 6.3 million passenger cars. The measurements carried out by the KBA can be subdivided into two fields.

For voluntary software updates provided by the manufacturers in order to optimize the exhaust strategies, the effectiveness of the software update is assessed by means of measurements according to the NEDC as well as the WLTP and RDE, before a ABE for the software update is granted.

In the case of a mandatory recall, the KBA examines the software provided by the manufacturer for the removal of the prohibited defeat device. For this purpose, a software analysis is performed. In addition, measurements are carried out in real world traffic to verify the software update and the software analysis. If appropriate, further tests are carried out by a technical service.

Here it should be noted that vehicles which were type approved according to the NEDC must only comply with the requirements on the basis of which the type approval was granted. The removal of the illegal defeat device or a voluntary optimization of the emission strategies does not formally require that the vehicle complies with the relevant limit value in the more realistic WLTP and RDE.

2. Mandatory recall Volkswagen EA189

The following section presents the test results of the vehicle models where the KBA detected a illegal defeat device and for which it ordered a mandatory recall. In the first part, the vehicles of the manufacturer Volkswagen with the engine type EA189 are presented. The verification measurements of the VW EA189 engine generation are performed in so-called clusters. Every cluster comprises several vehicles having the same power of the engine and similar identification features. Combining several vehicles with similar engine features to a cluster reduces the inspection efforts. To take account of the diversification of the models, several vehicles of a cluster are tested.

The series of measurements focussing on the EA189 engine included measurements according to the NEDC driving profile on the road in real ambient conditions (air temperature, pressure, humidity) in order to represent the effectiveness of the software update.

The emission results have been measured with a PEMS. It can thus be determined how the software update functions in real ambient conditions outside the chassis dynamometer; then it can be assessed accordingly.

A technical service carried out tests on the chassis dynamometer to test the parameters which were relevant to the type approval. The technical service directly transmitted the results to the KBA.

Moreover, variations of the NEDC have been performed.

The “NEDC back” first completes the rural part of the cycle and subsequently the urban part.

In the case of the “NEDC +/-10%”, the speed driven is either increased by 10 % (e.g.: 120 km/h → 132 km/h and/or reduced by 10% (e.g.: 120 km/h → 108 km/h).

Thus, it is possible to also detect prohibited cycle recognitions/cycle beating of the vehicle.

The following table shows an overview of the verification vehicles including their breakdown into the individual clusters.

Cluster	Vehicle type	Engine power [kW]	Emission standard
#1	A4 2.0 TDI saloon	88	EU 5
	A4 2.0 TDI	88	EU 5
	A4 2.0 TDI Avant	88	EU 5
# 2	A4 2.0 TDI Avant	110	EU 5
	A4 2.0 TDI Avant	110	EU 5
	A4 2.0 TDI saloon	105	EU 5
#3	A4 Avant 2.0 TDI	130	EU 5
	A6 Avant 2.0 TDI	130	EU 5
	A4 Avant 2.0 TDI	130	EU 5
#4	A5 2.0 TDI Sportback	130	EU 5
	A4 allroad quattro	130	EU 5
#5	Golf 2.0 TDI	103	EU 5
	Golf Plus 2.0 TDI	103	EU 5
	Golf 2.0 TDI	103	EU 5
#6	CADDY 2.0 TDI	103	EU 5
	Tiguan 2.0 TDI	103	EU 5
#7	CADDY Maxi 2.0 TDI	125	EU 5
	Passat 2.0 TDI	125	EU 5
	Touran 2.0 TDI	125	EU 5
#8a	Q5 2.0 TDI	125	EU 6
	Passat 2.0 TDI	103	EU 6
#8b	Alhambra 2.0 TDI	130	EU 5
	Sharan 2.0 TDI	103	EU 5
	Q5 2.0 TDI	130	EU 5
#9a	Caddy 1.6 TDI	55	EU 5
	Caddy 1.6 TDI	75	EU 5
#9b	Polo 1.6 TDI	66	EU 5
	Golf 1.6 TDI	77	EU 5
	Polo 1.6 TDI	66	EU 5
#10	Golf Plus 1.6 TDI	77	EU 5
	Ibiza 1.6 TDI	66	EU 5
	Golf Variant 1.6 TDI	77	EU 5
#11	Ibiza 1.2 TDI	55	EU 5
	Polo 1.2 TDI	55	EU 5
	Polo 1.2 TDI	55	EU 5
#12	Amarok 2.0 TDI	120	EU 5
#13	Superb 2.0 TDI	103	EU 5
	Passat 2.0 TDI	103	EU 5
#14	A5 Sportback 2.0 TDI	105	EU 5
	A4 Avant 2.0 TDI	88	EU 5

Table 2: Overview of the vehicles tested of the individual EA189 clusters

a. VW EA189 Cluster #1

The following Table 3 represents the vehicle models of cluster #1 which have been tested by the KBA. Cluster #1 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 4: Test vehicle cluster #1

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Audi	Audi	Audi
Trade name	A4 2.0 TDI saloon	A4 2.0 TDI	A4 2.0 TDI Avant
Type approval	e1*2001/116*0430*17	e1*2001/116*0430*19	e1*2001/116*0430*18
Type / model / version	B8 / LCAGCF1 / FM6B1005R8K607MGEM1	B8 / ACAGCF1 / FM6B1005R8K607MGEM1	B8
Mileage [km]	69,951	39,292	89,800
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]	88	88	88

Table 3: Vehicles cluster #1

For the vehicle models of cluster #1, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 4.

Vehicle	Cycle	T SSW[1] [°C]	T USW[2] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	17	18	445	262	183	41
2		20	17	471	443	28	6
3		23	26	603	473	130	22
1	NEDC back	18	19	433	226	207	48
2		19	18	462	271	192	41
3		22	24	566	394	171	30
1	NEDC + 10 %	18	20	551	309	242	44
2		20	18	551	358	193	35
3		22	23	634	471	163	26
1	NEDC -10 %	17	19	402	218	184	46
2		19	17	413	249	164	40
3		23	25	518	373	145	28

[1] SSW: Series software
[2] USW: Update software

Table 4: Overview of the tests cluster #1 NO_X reduction

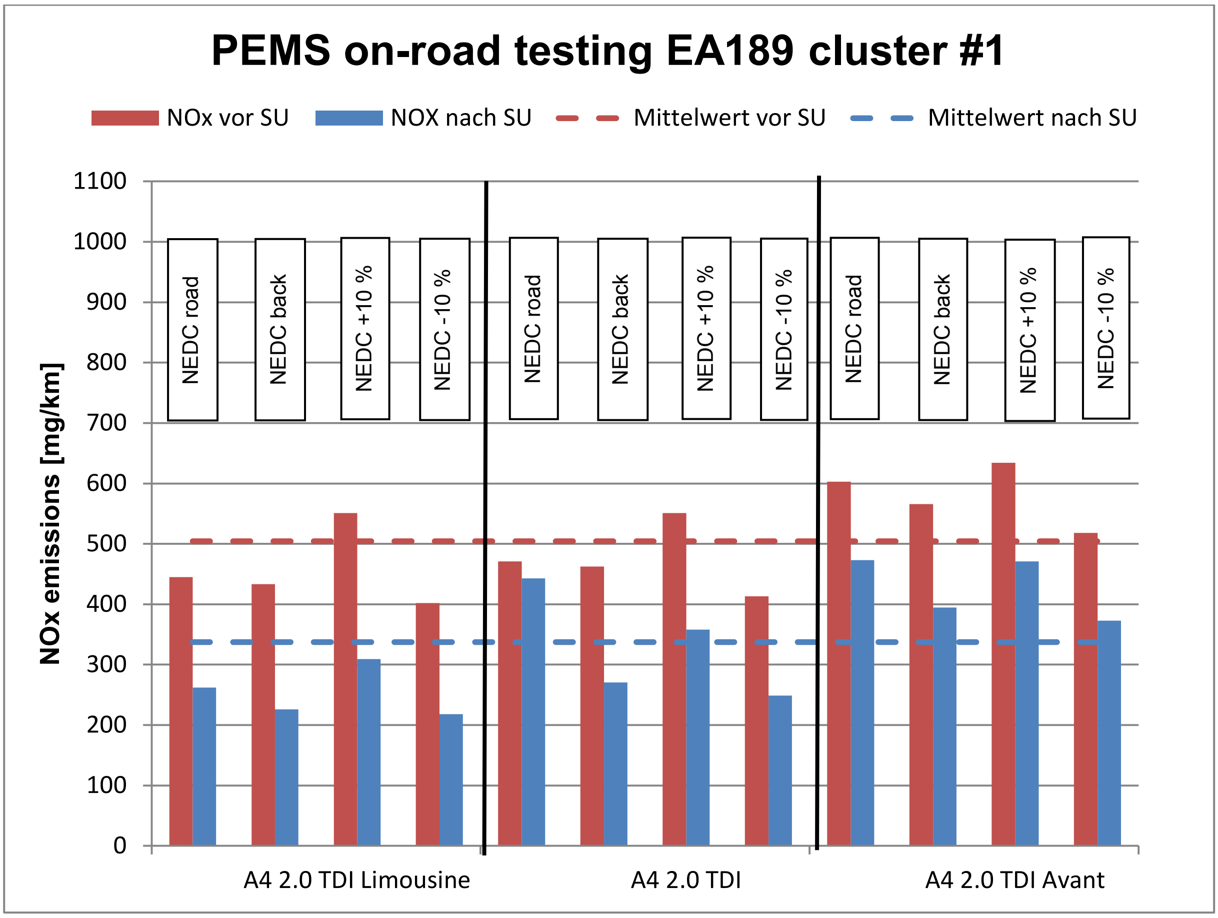

Figure 5: Bar chart cluster #1 NO_X reduction

b. VW EA189 cluster #2

The following Table 5 represents the vehicle models of cluster #2 which have been tested by the KBA. Cluster #2 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 6: Test vehicle cluster #2

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Audi	Audi	Audi
Trade name	A4 2.0 TDI Avant	A4 2.0 TDI Avant	A4 2.0 TDI saloon
Type approval	e1*2001/116*0430*33	e1*2001/116*0430*29	e1*2001/116*0430*25
Type / model / version	B8 / ACJCDF1 / FAVAW011RB8K1S57MJEM1	B8	B8
Mileage [km]	28,222	37,000	98,100
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]		110	105

Table 5: Vehicles cluster #2

For the vehicle models of cluster #2, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 6.

Vehicle	Cycle	T SSW[3] [°C]	T USW[4] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	22	29	556	549	7	1
2		22	21	559	455	104	19
3		22	20	460	486	-26	-6
1	NEDC back	21	26	533	512	20	4
2		22	20	521	431	90	17
3		19	20	467	396	71	15
1	NEDC + 10 %	22	26	722	702	20	3
2		22	21	698	671	27	4
3		21	19	617	575	42	7
1	NEDC -10 %	23	28	435	492	-57	-13
2		23	21	464	441	22	5
3		20	18	406	333	73	18

Table 6: Overview of the tests cluster #2 NO_X reduction

[3] SSW: Series software
[4] USW: Update software

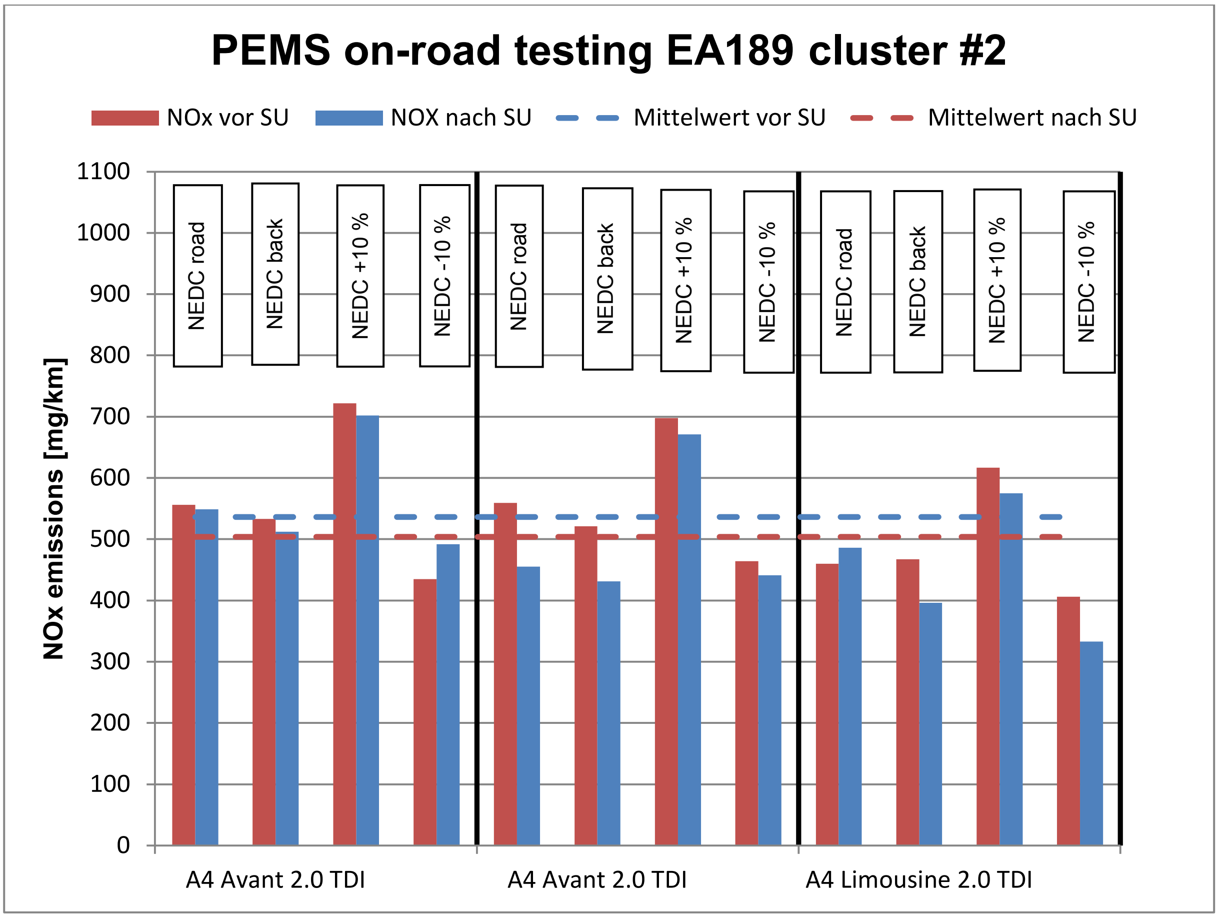

Figure 7: Bar chart cluster #2 NO_X reduction

c. VW EA189 cluster #3

The following Table 7 represents the vehicle models of cluster #3 which have been tested by the KBA. Cluster #3 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 8: Test vehicle cluster #3

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Audi	Audi	Audi
Trade name	A4 Avant 2.0 TDI	A6 Avant 2.0 TDI	A4 Avant 2.0 TDI
Type approval	e1*2001/116*0430*27	e1*2007/46*0436*06	e1*2001/116*0430*33
Type / model / ver-sion	B8	4G	B8
Mileage [km]	42,700	111,900	38,900
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]	130	130	130

Table 7: Vehicles cluster #3

For the vehicle models of cluster #3, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 8.

Vehicle	Cycle	T SSW[5] [°C]	T USW[6] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	17	14	261	270	-8	-3
2		21	19	318	208	109	34
3		20	13	288	305	-17	-6
1	NEDC back	16	13	266	255	11	4
2		20	19	298	183	115	39
3		19	12	283	240	43	15
1	NEDC + 10 %	15	13	284	274	11	-12
2		20	19	382	211	171	35
3		20	13	345	311	56	19
1	NEDC -10 %	16	14	255	285	-29	4
2		20	20	278	180	98	45
3		20	13	291	236	34	10

Table 8: Overview of the tests cluster #3 NO_X reduction

[5] SSW: Series software
[6] USW: Update software

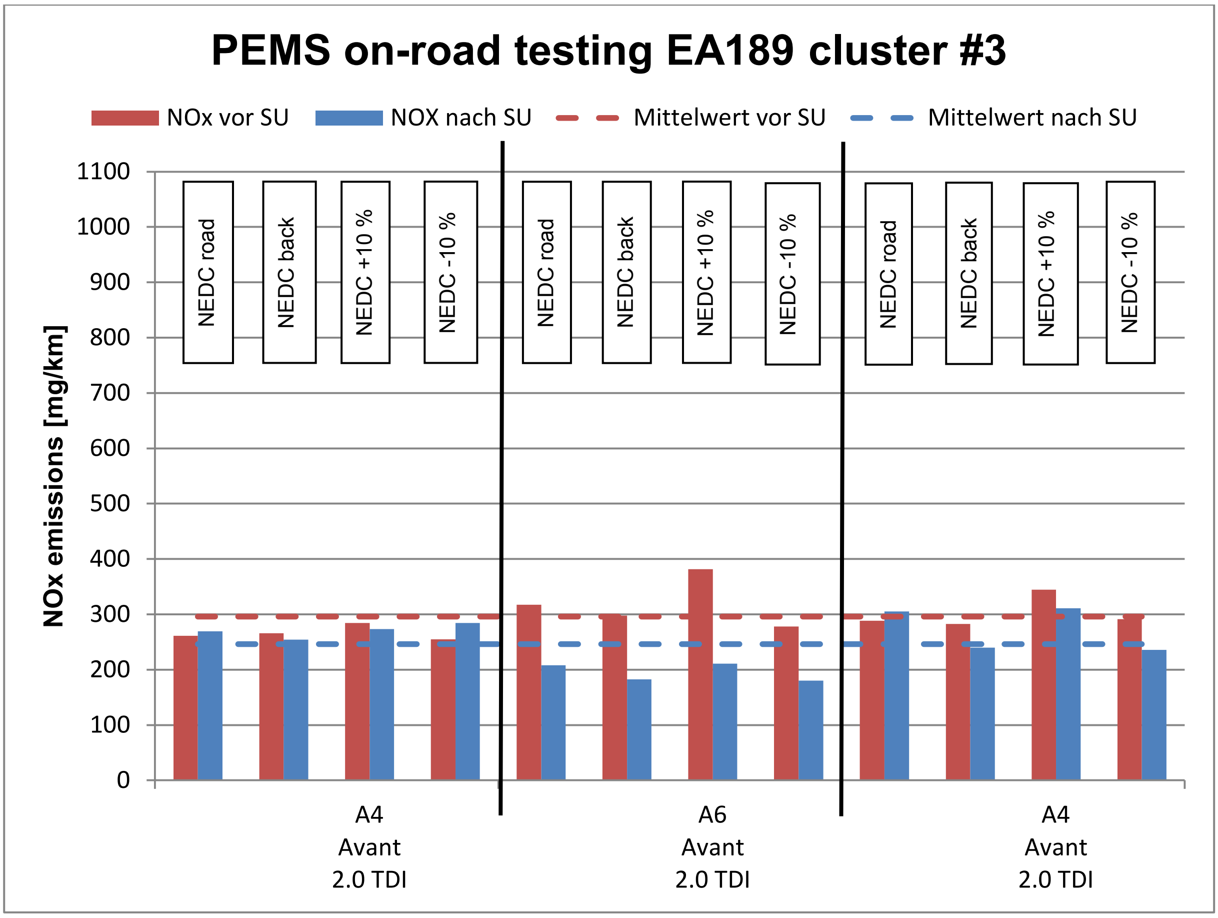

Figure 9: Bar chart cluster #3 NO_X reduction

d. VW EA189 cluster #4

The following Table 9 represents the vehicle models of cluster #4 which have been tested by the KBA. Cluster # 4 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 10: Test vehicle cluster #4

	Vehicle 1	Vehicle 2
Manufacturer	Audi	Audi
Trade name	A5 2.0 TDI Sportback	A4 allroad quattro
Type approval	e1*2001/116*0430*32	e1*2001/116*0430*33
Type / model / version	B8 / SCGLCQ1 / QD7B5027RB8T1S47MJEM1	B8
Mileage [km]	17,195	19,000
Emission standard	EU5	EU5
Engine capacity [ccm]	1,968	1,968
Engine power [kW]	130	130

Table 9: Vehicles cluster #4

For the vehicle models of cluster #4, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 10.

Vehicle	Cycle	T SSW[7] [°C]	T USW[8] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	16	17	856	548	309	36
2		27	29	791	716	75	9
1	NEDC back	16	13	740	354	386	52
2		27	27	767	638	130	17
1	NEDC + 10 %	17	16	1,088	762	326	30
2		27	28	874	863	11	1
1	NEDC -10 %	17	19	646	423	224	35
2		27	28	635	592	43	7

Table 10: Overview of the tests cluster #4 NO_X reduction

[7] SSW: Series software
[8] USW: Update software

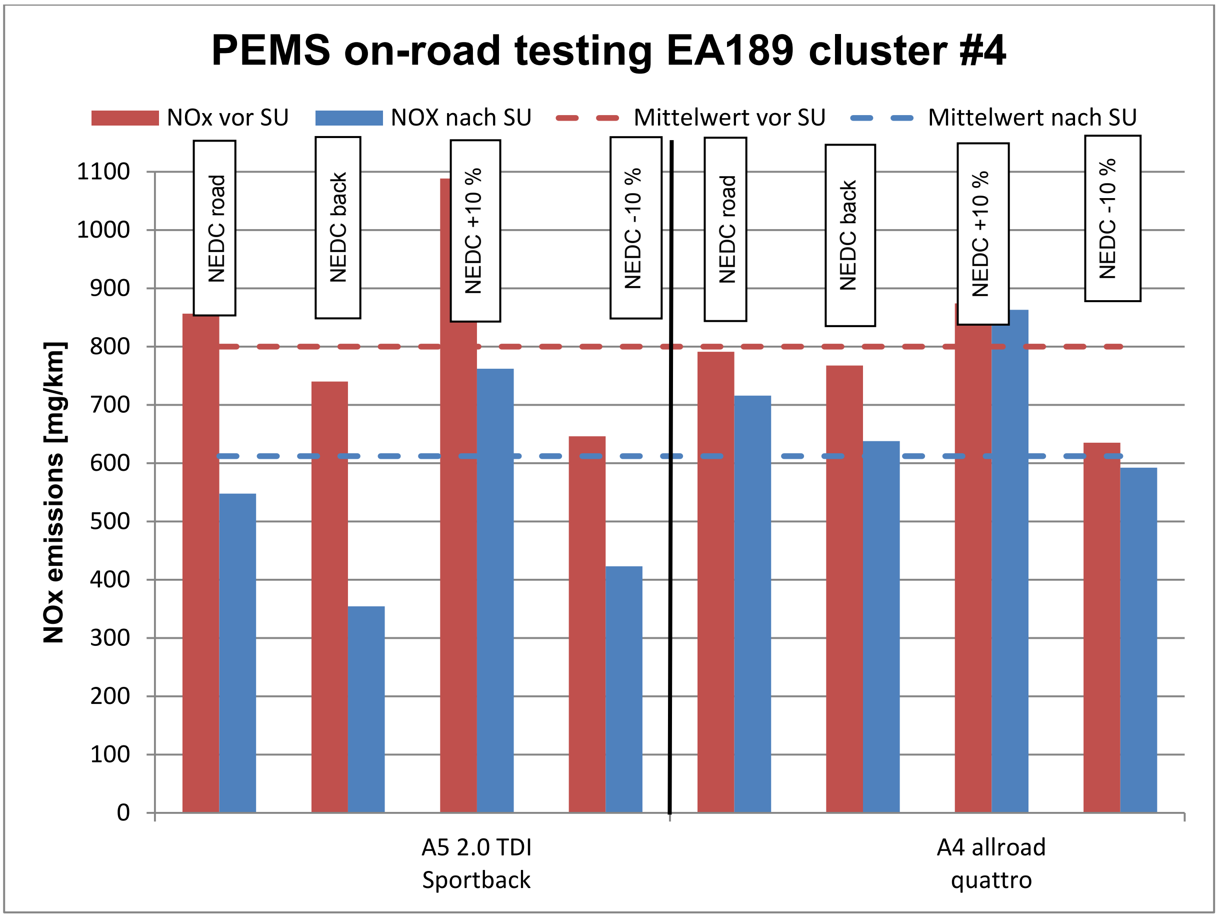

Figure 11: Bar chart cluster #4 NO_X reduction

e. VW EA189 cluster #5

The following Table 11 represents the vehicle models of cluster #5 which have been tested by the KBA. Cluster #5 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 12: Test vehicle cluster #5

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	VW	VW	VW
Trade name	Golf 2.0 TDI	Golf Plus 2.0 TDI	Golf 2.0 TDI
Type approval	e1*2001/116*0242*44	e1*2001/116*0304*29	e1*2001/116*0242*43
Type / model / version	1K/ ACCFFBX0 / FM6FM62Q025N7MGN1	1KP / ACCFHCX0 / FM6FM62Q025N7MGN1	1K / ACCFFBX0 / FM6FM62Q025N7MGN1
Mileage [km]	27,242	15,404	33,098
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]	103	103	103

Table 11: Vehicles cluster #5

For the vehicle models of cluster #5, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 12.

Vehicle	Cycle	T SSW[9] [°C]	T USW[10] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	10	9	508	578	-70	-14
2		22	16	623	387	236	38
3		26	18	486	285	201	41
1	NEDC back	9	9	556	482	74	13
2		20	14	609	330	279	46
3		22	20	466	254	212	45
1	NEDC + 10 %	17	9	468	537	-69	-15
2		19	15	775	412	363	47
3		19	21	547	293	254	46
1	NEDC -10 %	18	9	408	453	-45	-11
2		21	18	528	371	157	30
3		26	18	521	295	226	43

Table 12: Overview of the tests cluster #5 NO_X reduction

[9] SSW: Series software
[10] USW: Update software

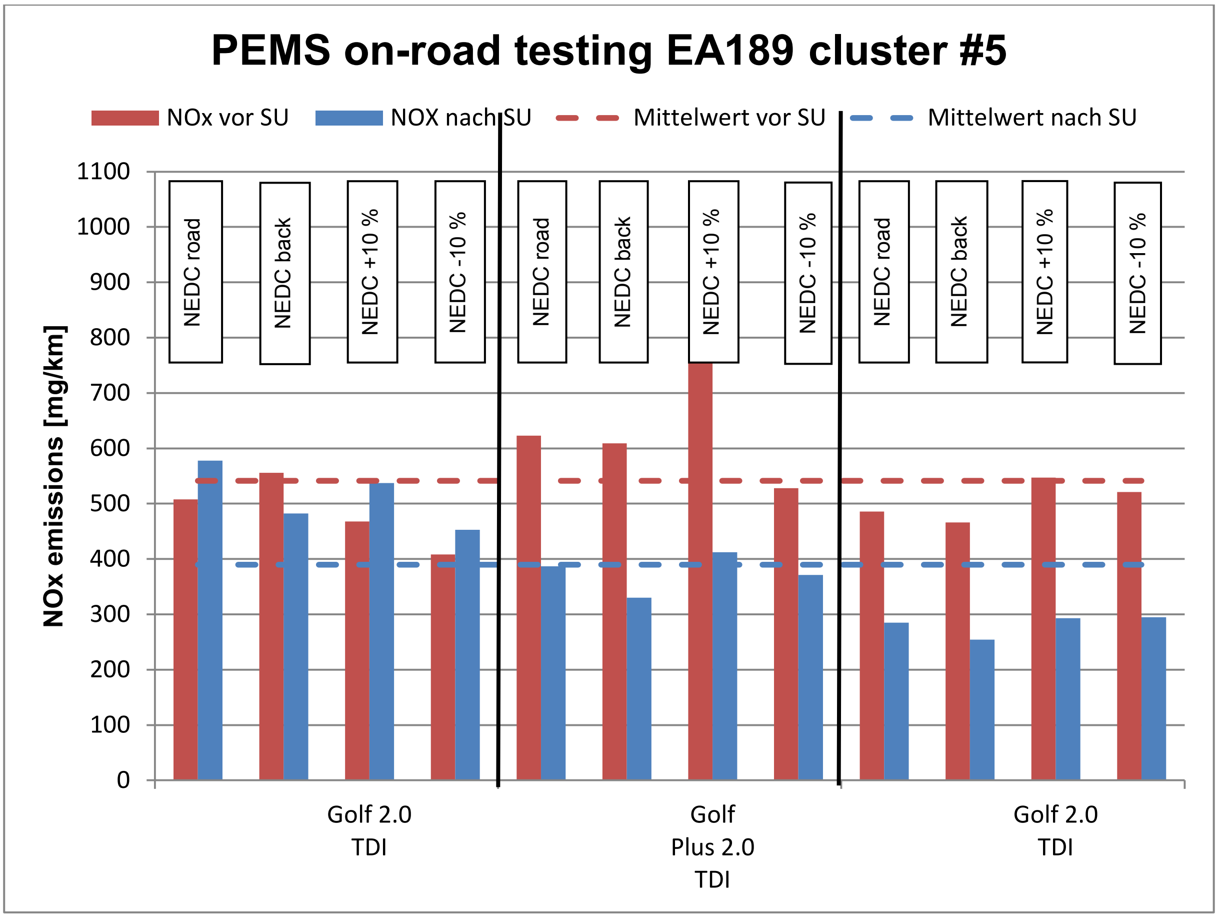

Figure 13: Bar chart cluster #5 NO_X reduction

f. VW EA189 cluster #6

The following Table 13 represents the vehicle models of cluster #6 which have been tested by the KBA. Cluster #6 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 14: Test vehicle cluster #6

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	VW	VW	VW
Trade name	Caddy 2.0 TDI	Caddy 2.0 TDI	Tiguan 2.0 TDI
Type approval	e1*2001/116 *0252*41	e1*2001/116 *0252*41	e1*2001/116 *0450*19
Type / model / version	2K / ACCFHCX01	2K / ACCFHCX01	5N / ACCFFBX1
Mileage [km]	8,214	17,441	10,306
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]	103	103	103

Table 13: Vehicles cluster #6

For the vehicle models of cluster #6, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 14.

Vehicle	Cycle	T SSW[11] [°C]	T USW[12] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	24	29	488	222	266	55
2		15	21	530	241	289	55
3		26	18	671	233	437	65
1	NEDC back	22	31	517	215	302	58
2		16	20	502	251	251	50
3		22	20	668	223	445	67
1	NEDC + 10 %	23	29	612	312	300	49
2		16	20	617	218	400	65
3		19	21	760	297	463	61
1	NEDC -10 %	24	30	438	187	251	57
2		16	21	462	334	127	28
3		26	18	589	188	401	68

Table 14: Overview of the tests cluster #6 NO_X reduction

[11] SSW: Series software
[12] USW: Update software

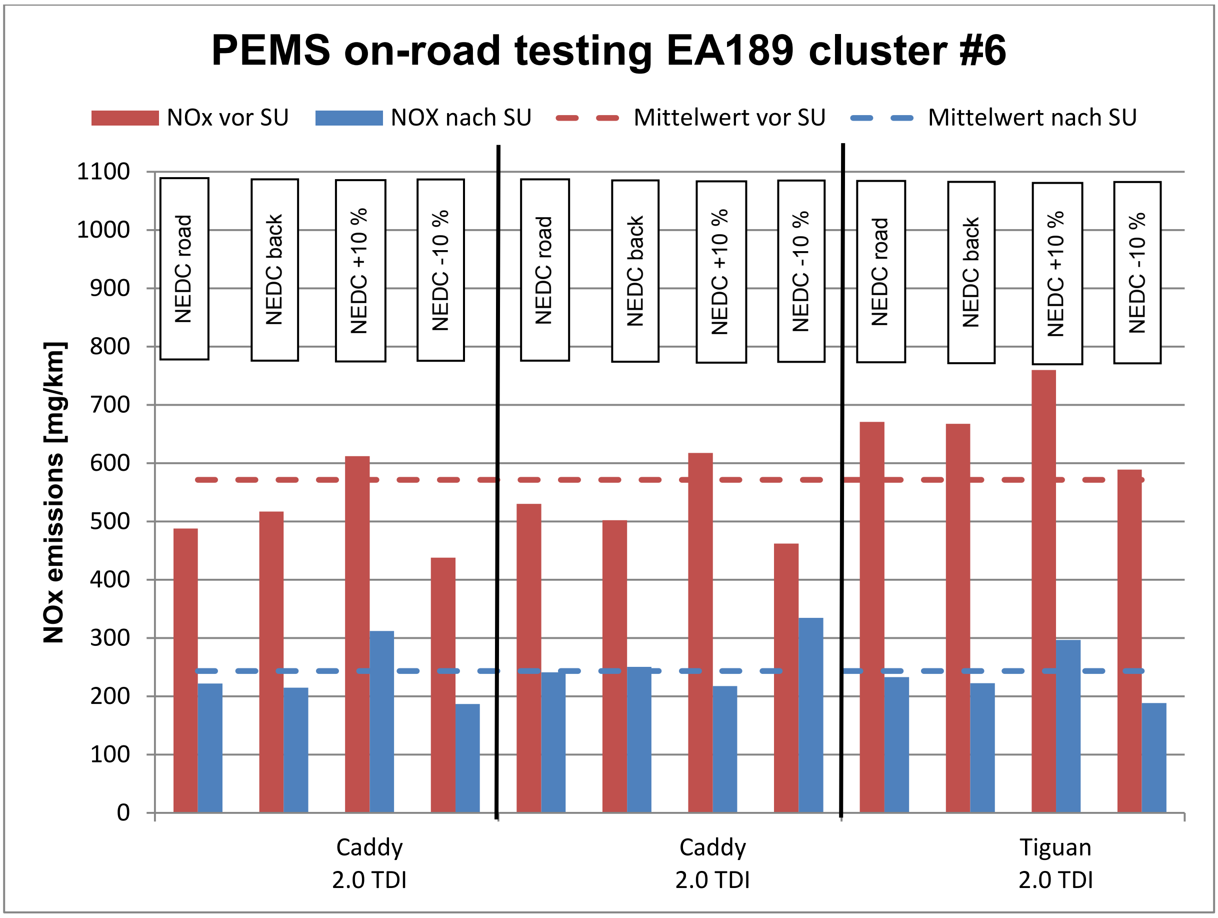

Figure 15: Bar chart cluster #6 NO_X reduction

g. VW EA189 cluster #7

The following Table 15 represents the vehicle models of cluster #7 which have been tested by the KBA. Cluster #7 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 16: Test vehicle cluster #7

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	VW	VW	VW
Trade name	CADDY Maxi 2.0 TDI	Passat 2.0 TDI	Touran 2.0 TDI
Type approval	e1*2001/116*0252*41	e1*2001/116*0307*33	e1*2001/116*0211*28
Type / model / version	2K / AFCFJAX01	3C / ACCFGBX0	1T / CFJAAF
Mileage [km]	18,542	114,037	29,574
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]	125	125	125

Table 15: Vehicles cluster #7

For the vehicle models of cluster #7, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 16.

Vehicle	Cycle	T SSW[13] [°C]	T USW[14] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	21	19	413	308	105	25
2		26	32	459	272	186	41
3		20	14	573	315	258	45
1	NEDC back	22	17	454	309	146	32
2		26	32	477	283	195	41
3		20	16	582	283	300	51
1	NEDC + 10 %	22	18	482	365	117	24
2		27	32	586	300	286	49
3		20	14	661	395	266	40
1	NEDC -10 %	22	17	374	261	114	30
2		26	30	494	297	197	40
3		20	15	519	268	251	48

Table 16: Overview of the tests cluster #7 NO_X reduction

[13] SSW: Series software
[14] USW: Update software

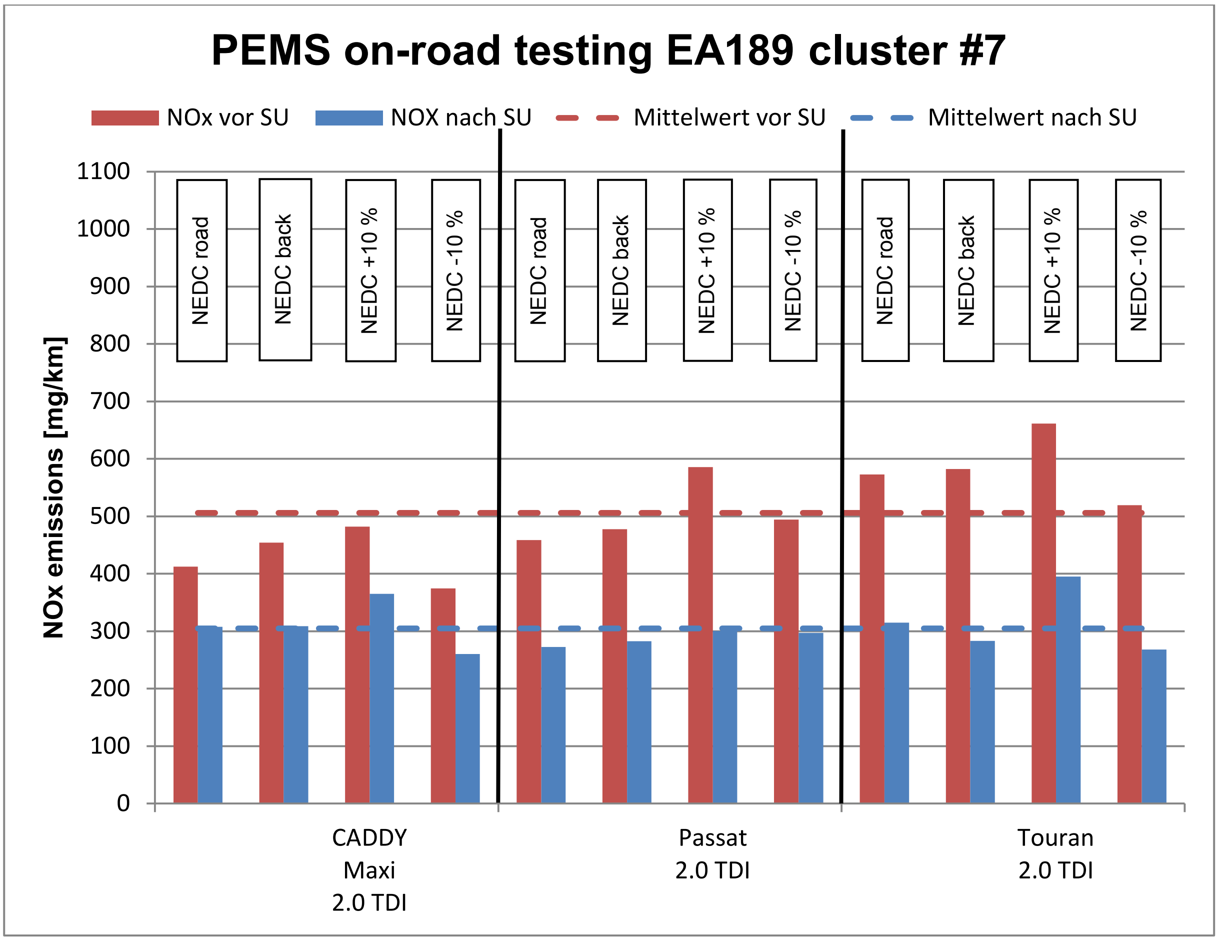

Figure 17: Bar chart cluster #7 NO_X reduction

h. VW EA189 cluster #8a

The following Table 17 represents the vehicle models of cluster #8a which have been tested by the KBA. Cluster #8a contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 18: Test vehicle cluster #8a

	Vehicle 1	Vehicle 2
Manufacturer	Audi	VW
Trade name	Q5 2.0 TDI	Passat 2.0 TDI
Type approval	e1*2001/116*0473*09	e1*2001/116*0307*36
Type / model / version	8R / XCGLBQ1 / QD7B5035R8R727MKEM0	3C / ACCFFBX0 / FD6FD62E018STP07MKSNVR2O
Mileage [km]	81,793	9,722
Emission standard	EU6	EU6
Engine capacity [ccm]	1,968	1,968
Engine power [kW]	125	103

Table 17: Vehicles cluster #8a

For the vehicle models of cluster #8a, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 18.

Vehicle	Cycle	T SSW[15] [°C]	T USW[16] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	**NEDC road**	9	12	536	112	424	79
2		17	11	444	31	413	93
1	**NEDC back**	8	11	450	91	359	80
2		14	11	160	16	144	90
1	**NEDC + 10 %**	7	11	607	198	409	67
2		19	20	308	142	166	54
1	**NEDC -10 %**	7	11	407	64	344	84
2		19	21	291	68	223	77

Table 18: Overview of the tests cluster #8a NO_X reduction

[15] SSW: Series software
[16] USW: Update software

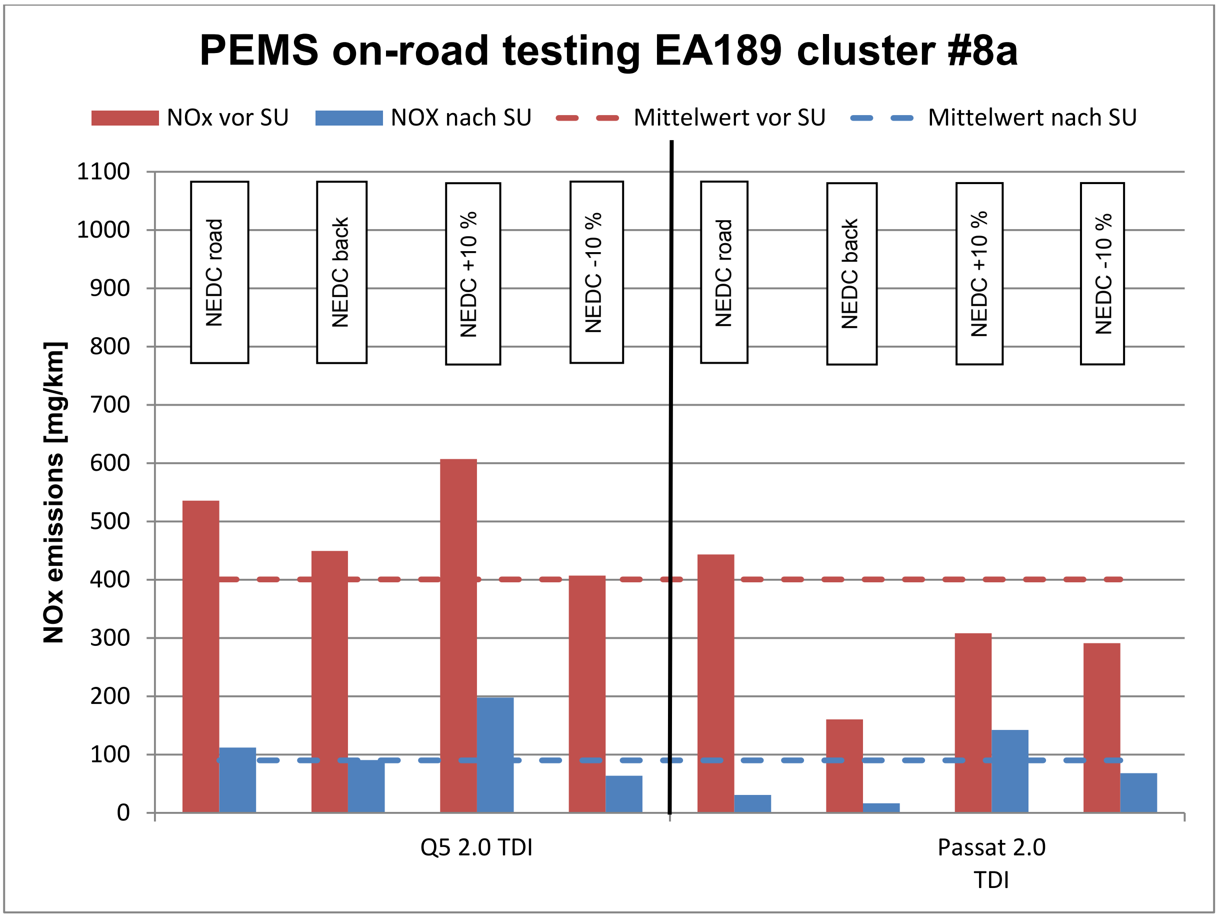

Figure 19: Bar chart cluster #8a NO_X reduction

i. VW EA189 cluster #8b

The following Table 19 represents the vehicle models of cluster #8b which have been tested by the KBA. Cluster #8b contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 20: Test vehicle cluster #8b

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Seat	VW	Audi
Trade name	Alhambra 2.0 TDI	Sharan 2.0 TDI	Q5 2.0 TDI
Type approval	e1*2007/46*0401*09	e1*2007/46*0401*09	e1*2001/116*0473*17
Type / model / version	7N / CFGCX0AF	7N / CFFBX0AF	8R / XCGLCQ1 / QD7B5035R8R727MJEM1G
Mileage [km]	37,758	50,233	52,432
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]	130	103	130

Table 19: Vehicles cluster #8b

For the vehicle models of cluster #8b, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 20.

Vehicle	Cycle	T SSW[17] [°C]	T USW[18] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	21	19	413	308	105	25
2		26	32	459	272	186	41
3		20	14	573	315	258	45
1	NEDC back	22	17	454	309	146	32
2		26	32	477	283	195	41
3		20	16	582	283	300	51
1	NEDC + 10 %	22	18	482	365	117	24
2		27	32	586	300	286	49
3		20	14	661	395	266	40
1	NEDC -10 %	22	17	374	261	114	30
2		26	30	494	297	197	40
3		20	15	519	268	251	48

Table 20: Overview of the tests cluster #8b NO_X reduction

[17] SSW: Series software
[18] USW: Update software

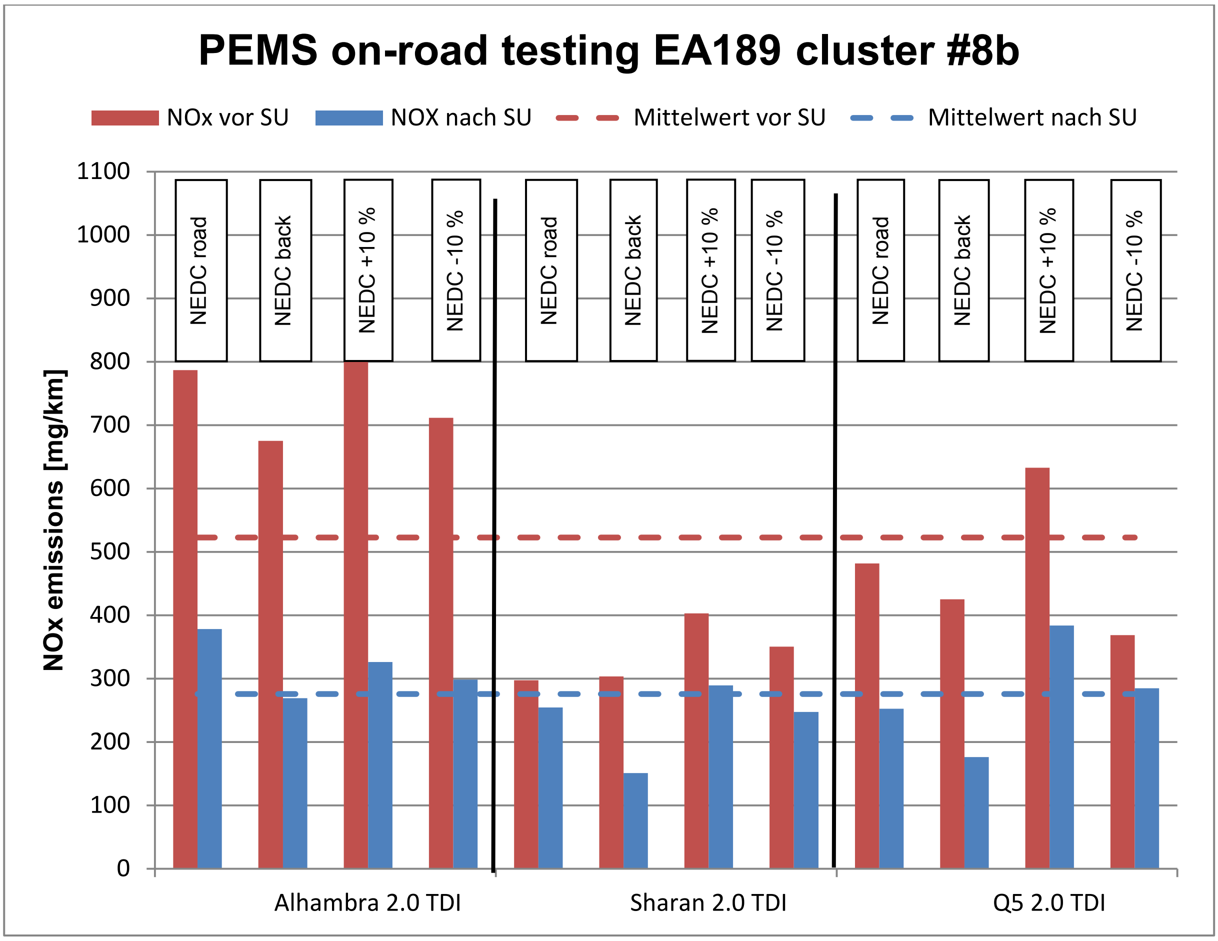

Figure 21: Bar chart cluster #8b NO_X reduction

j. VW EA189 cluster #9 a

The following Table 21 represents the vehicle models of cluster #9 a which have been tested by the KBA. Cluster #9 a contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 22: Test vehicle cluster #9a

	Vehicle 1	Vehicle 2
Manufacturer	VW	VW
Trade name	Caddy 1.6 TDI	Caddy 1.6 TDI
Type approval	e1*2007/46*0217* 21	e1*2007/46*0217* 21
Type / model / version	2KN / BBCAYEX0 / N0J2FM5FM5A4056N1-SN2VR07MJG2NLL060	2KN / BBCAYDX0 / N0J2FM5FM5A4056N1-SN2VR07MJG2OLL060
Mileage [km]	12,221	431
Emission standard	EU5	EU5
Engine capacity [ccm]	1,598	1,598
Engine power [kW]	55	75

Table 21: Vehicles cluster #9a

For the vehicle models of cluster #9a, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 22.

Vehicle	Cycle	T SSW[19] [°C]	T USW[20] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	19	10	568	280	306	52
2		9	13	803	324	479	60
1	NEDC back	18	9	566	284	282	50
2		11	12	777	286	491	63
1	NEDC + 10 %	19	11	410	361	49	12
2		13	12	593	413	180	30
1	NEDC -10 %	19	11	641	266	375	59
2		15	14	859	308	551	64

Table 22: Overview of the tests cluster #9a NO_X reduction

[19] SSW: Series software
[20] USW: Update software

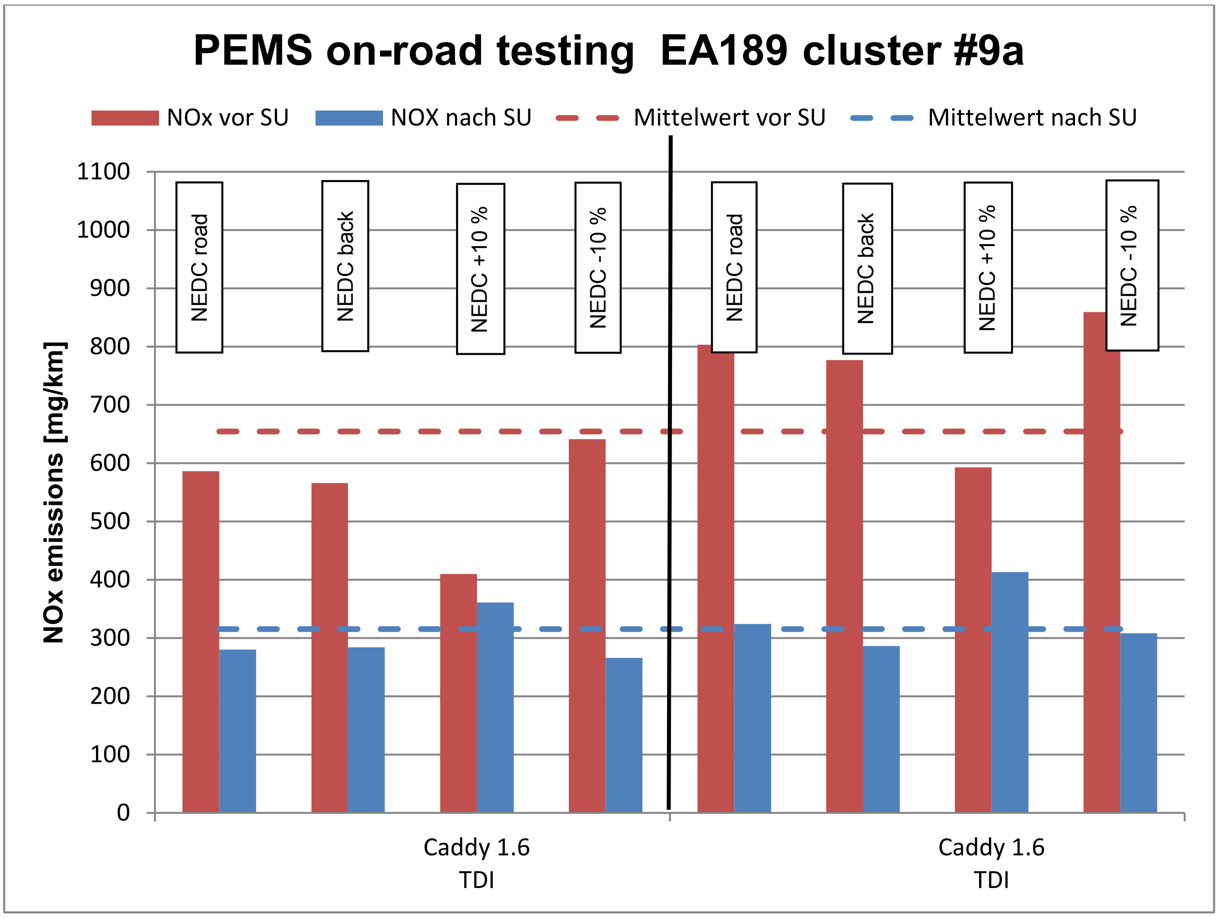

Figure 23: Bar chart cluster #9a NO_X reduction

k. VW EA189 cluster #9 b

The following Table 23 represents the vehicle models of cluster #9 b which have been tested by the KBA. Cluster #9 b contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 24: Test vehicle cluster #9b

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	VW	VW	VW
Trade name	Polo 1.6 TDI	Golf 1.6 TDI	Polo 1.6 TDI
Type approval	e1*2001/116* 0510*15	e1*2001/116* 0328*26	e1*2001/116* 0510*15
Type / model / version	6R	1KM	6R
Mileage [km]	79900	61200	79850
Emission standard	Euro 5	Euro 5	Euro 5
Engine capacity [ccm]	1598	1598	1598
Engine power [kW]	66	77	66

Table 23: Vehicles cluster #9b

For the vehicle models of cluster #9 b, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 24.

Vehicle	Cycle	T SSW[21] [°C]	T USW[22] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	9	11	620	366	255	41
2		13	12	981	419	499	54
3		13	9	672	410	263	39
1	NEDC back	7	8	618	418	200	32
2		12	9	934	562	372	40
3		12	7	637	459	178	28
1	NEDC + 10 %	8	10	607	471	135	22
2		13	11	894	480	415	46
3		13	7	656	509	146	22
1	NEDC -10 %	7	9	660	397	263	40
2		13	10	958	481	477	50
3		12	7	671	442	230	34

Table 24: Overview of the tests cluster #9b NO_X reduction

[21] SSW: Series software
[22] USW: Update software

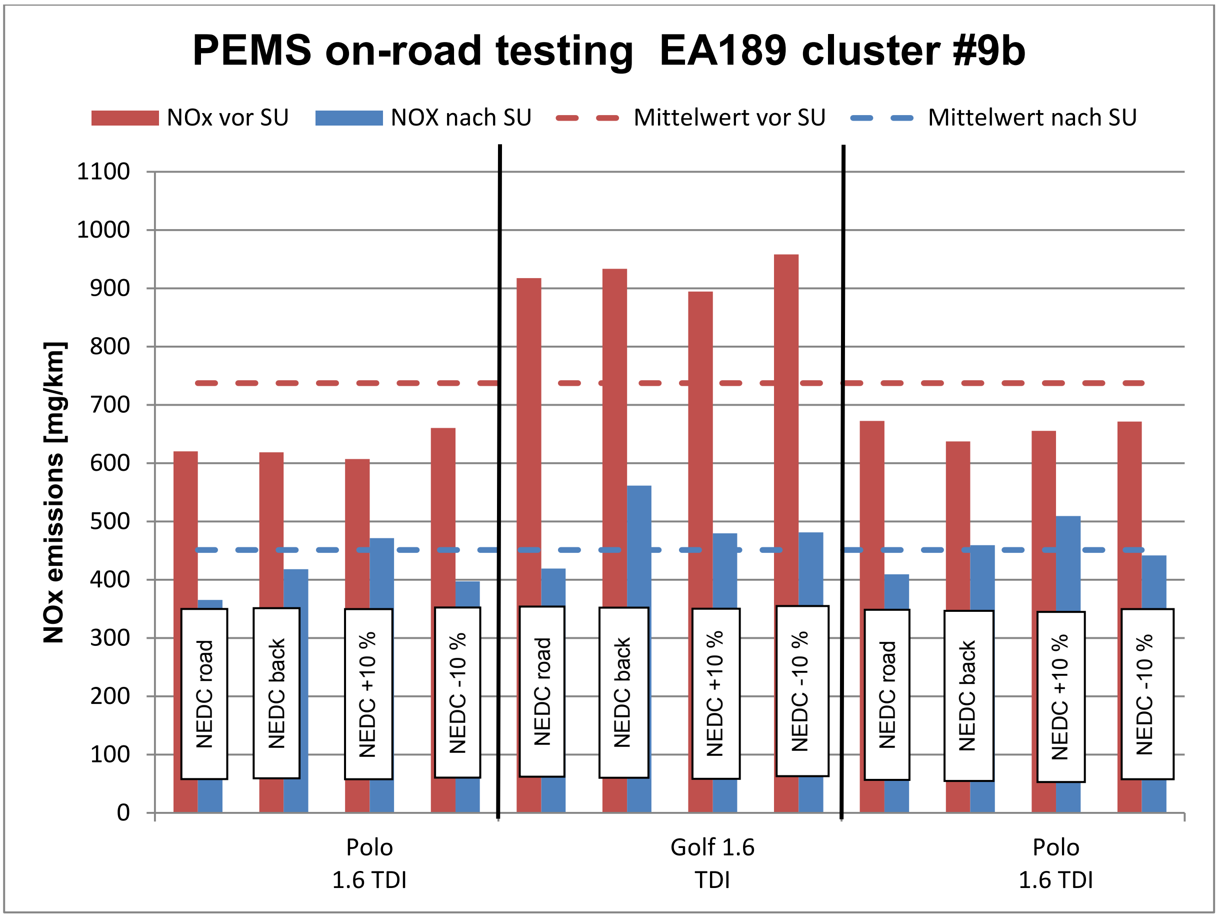

Figure 25: Bar chart cluster #9b NO_X reduction

I. VW EA189 cluster #10

The following Table 25 represents the vehicle models of cluster #10 which have been tested by the KBA. Cluster #10 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 26: Test vehicle cluster #10

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	VW	Seat	VW
Trade name	Golf Plus 1.6 TDI	Ibiza 1.6 TDI	Golf Variant 1.6 TDI
Type approval	e1*2001/116*0304*27	e9*2001/116*0067*29	e1*2001/116*0328*26
Type / model / version	1KP / ACCAYCX0 / FD7FD7AM014-E7MGN1	6J /SCCAYBX0 / AGNFD7AM00-77MJGI	1KM / ACCAYCX0 / FD7FD7AM014-N7MGN1
Mileage [km]	26,798	40,321	26,084
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,598	1,598	1,598
Engine power [kW]	77	66	77

Table 25: Vehicles cluster #10

For the vehicle models of cluster #10, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 26.

Vehicle	Cycle	T SSW[23] [°C]	T USW[24] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	12	8	956	587	369	39
2		7	7	745	422	323	43
3		17	12	979	381	598	61
1	NEDC back	12	8	1,001	564	437	44
2		6	7	702	416	286	41
3		16	12	960	375	586	61
1	NEDC + 10 %	12	8	849	615	234	28
2		6	7	726	451	275	38
3		16	11	858	379	479	56
1	NEDC -10 %	12	8	971	631	340	35
2		6	7	734	391	344	47
3		17	11	963	488	475	49

Table 26: Overview of the tests cluster #10 NO_X reduction

[23] SSW: Series software
[24] USW: Update software

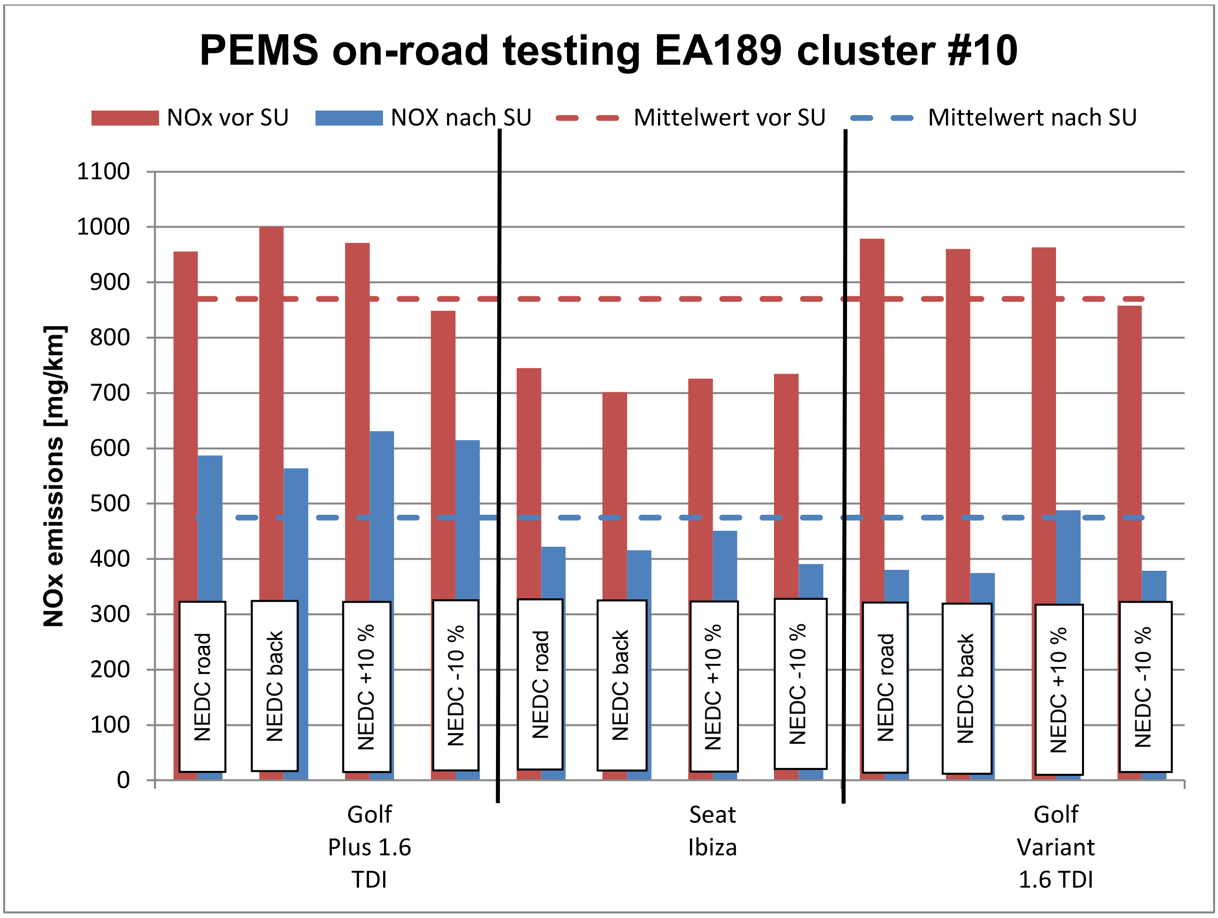

Figure 27: Bar chart cluster #10 NO_X reduction

m. VW EA189 cluster #11

The following Table 27 represents the vehicle models of cluster #11 which have been tested by the KBA. Cluster #11 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 28: Test vehicle cluster #11

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Seat	VW	VW
Trade name	Ibiza 1.2 TDI	Polo 1.2 TDI	Polo 1.2 TDI
Type approval	e9*2001/116*0067*26	e1*2001/116*0510*13	e1*2001/116*0510*10
Type / model / version	6J / SCCFWAX0 / SGNFM52R0317MJGI	6R / ABCFWA / FM5FM52R031LLEVR67MQ	6R / ABCFWA / FM5FM52R031LLEVR67MG
Mileage [km]	7,824	16,427	41,226
Emission standard	EU5	EU5	EU5
Engine capacity [ccm]	1,199	1,199	1,199
Engine power [kW]	55	55	55

Table 27: Vehicles cluster #11

For the vehicle models of cluster #11, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 28.

Vehicle	Cycle	T SSW[25] [°C]	T USW[26] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	17	16	571	489	82	14
2		29	27	346	275	70	20
3		19	32	380	338	42	11
1	NEDC back	18	16	513	378	136	26
2		30	27	334	280	54	16
3		20	29	374	353	21	6
1	NEDC + 10 %	19	17	663	558	106	16
2		31	29	414	372	42	10
3		19	31	446	438	7	2
1	NEDC -10 %	18	16	506	467	39	8
2		30	27	300	248	52	17
3		19	30	303	272	32	10

Table 28: Overview of the tests cluster #11 NO_X reduction

25 SSW: Series software
26 USW: Update software

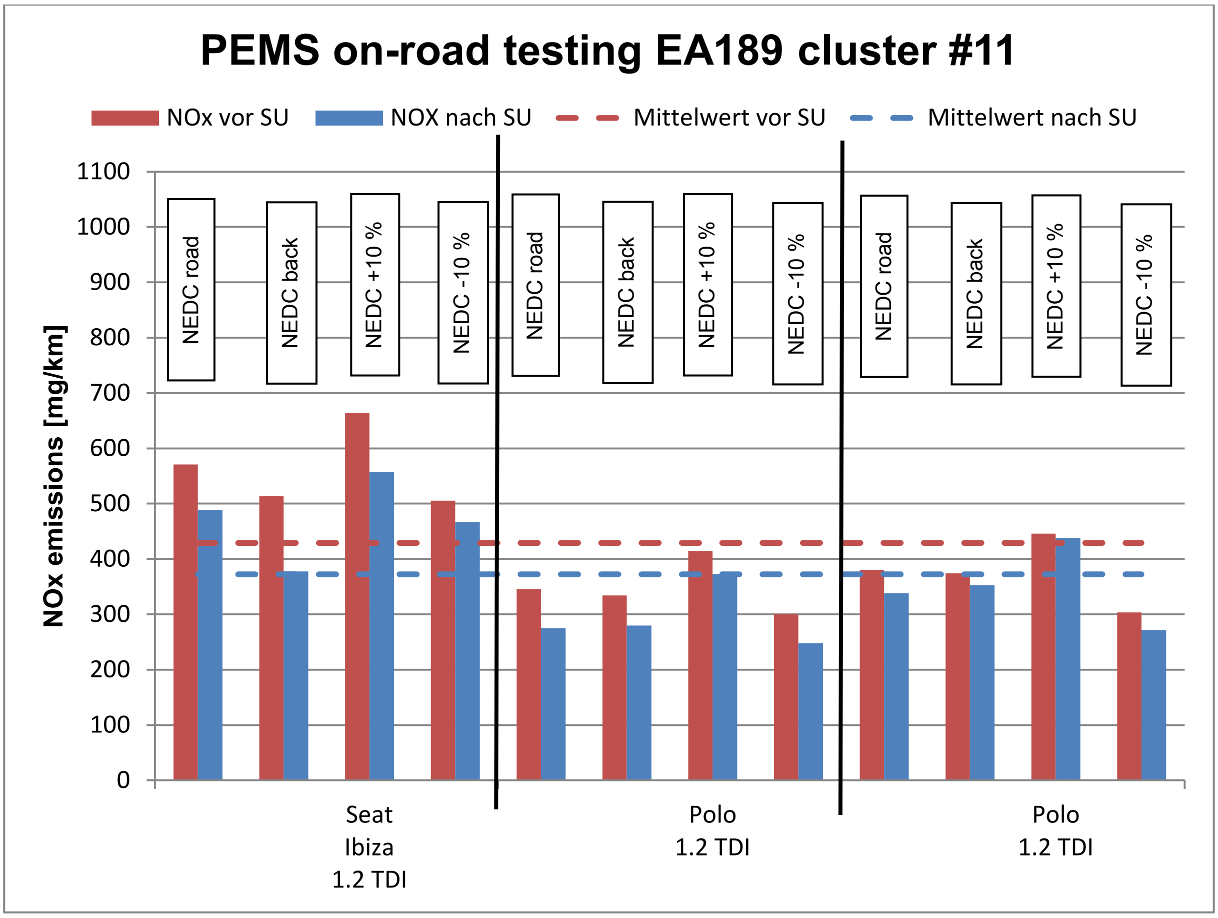

Figure 29: Bar chart cluster #11 NO_X reduction

n. VW EA189 cluster #12

The following Table 29 represents the vehicle models of cluster #12 which have been tested by the KBA. Cluster #12 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 30: Test vehicle cluster #12

	Vehicle 1
Manufacturer	VW
Trade name	Amarok 2.0 TDI
Type approval	e1*2007/46*0356*05
Type / model / version	2H
Mileage [km]	15,830
Emission standard	EU5
Engine capacity [ccm]	1,968
Engine power [kW]	120

Table 29: Vehicles cluster #12

For the vehicle models of cluster #12, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 30.

Vehicle	Cycle	T SSW[27] [°C]	T USW[28] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	25	23	645	581	64	10
1	NEDC back	23	21	640	610	31	5
1	NEDC + 10 %	24	24	653	595	57	9
1	NEDC -10 %	24	22	651	468	183	28

Table 30: Overview of the tests cluster #12 NO_X reduction

[27] SSW: Series software
[28] USW: Update software

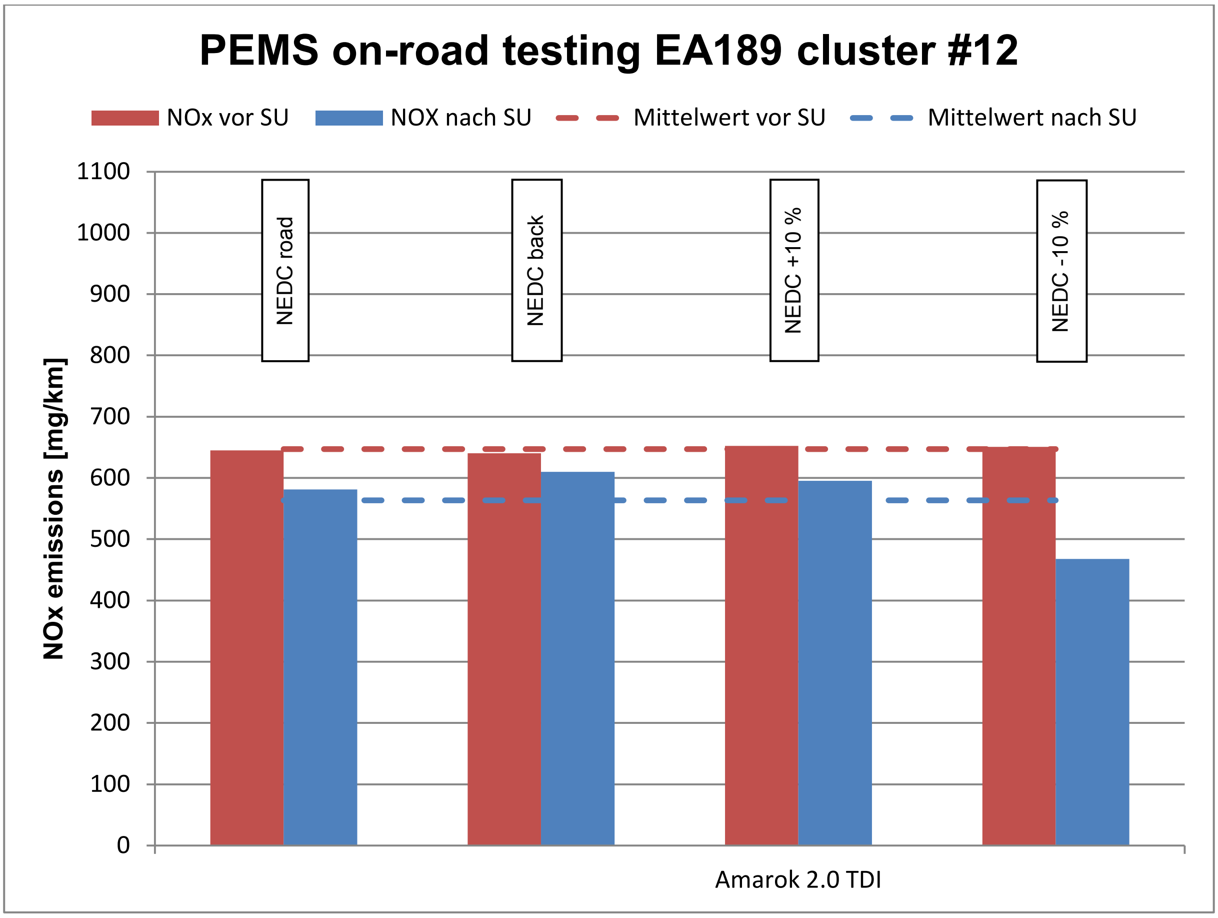

Figure 31: Bar chart cluster #12 NO_X reduction

o. VW EA189 cluster #13

The following Table 31 represents the vehicle models of cluster #13 which have been tested by the KBA. Cluster #13 contains further vehicle models with related engine/exhaust gas after treatment strategies.

Figure 32: Test vehicle cluster #13

	Vehicle 1	Vehicle 2
Manufacturer	Skoda	VW
Trade name	Superb 2.0 TDI	Passat 2.0 TDI
Type approval	e11*2001/116*0326*31	e1*2001/116*0307*26
Type / model / version	3T / ACCFFBX01 / NFM6FM62Q0257	3C / ACCFFBX0 / FM6FM62Q025STP07MGSNVR2O
Mileage [km]	33,130	59,367
Emission standard	EU5	EU5
Engine capacity [ccm]	1,968	1,968
Engine power [kW]	103	103

Table 31: Vehicles cluster #13

For the vehicle models of cluster #13, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices traffic. The measurement results can be seen from Table 32.

Vehicle	Cycle	T SSW[29] [°C]	T USW[30] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC road	17	20	914	471	443	49
2		19	14	592	391	202	34
1	NEDC back	16	21	720	375	345	48
2		16	13	539	308	230	43
1	NEDC + 10 %	17	23	891	478	414	46
2		18	13	607	417	190	31
1	NEDC -10 %	18	22	864	464	400	46
2		20	15	597	351	246	41

Table 32: Overview of the tests cluster #13 NO_X reduction

[29] SSW: Series software
[30] USW: Update software

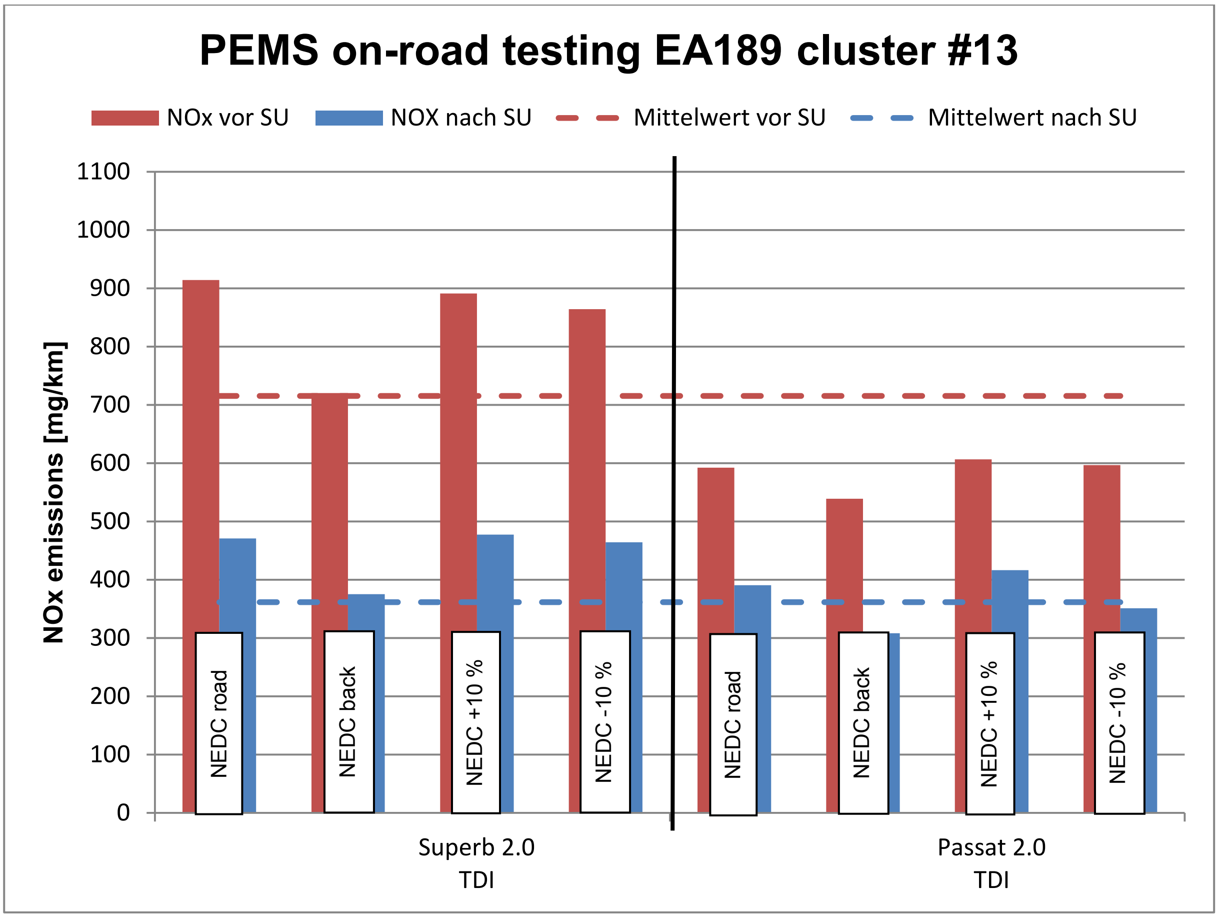

Figure 33: Bar chart cluster #13 NO_X reduction

p. VW EA189 cluster #14

The following Table 33 represents the vehicle models of cluster #14 which have been tested by the KBA. Cluster #14 contains further vehicle models with related engine/exhaust gas after treatment strategies.

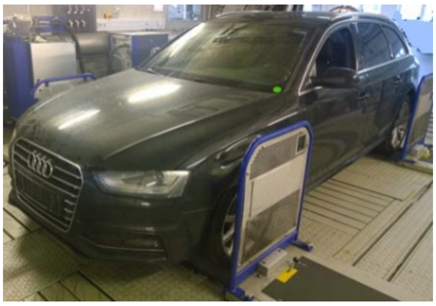

Figure 34: Test vehicle cluster #14

	Vehicle 1	Vehicle 2
Manufacturer	Audi	Audi
Trade name	A5 Sportback 2.0 TDI	A4 Avant 2.0 TDI
Type approval	e1*2001/116*0430*26	e1*2001/116*0430*33
Type / model / version	B8	B8
Mileage [km]	79,400	10,900
Emission standard	EU5	EU5
Engine capacity [ccm]	1,968	1,968
Engine power [kW]	105	88

Table 33: Vehicles cluster #14

For the vehicle models of cluster #14, the following reduction potentials by software updates were determined in the four NEDC measurements in road traffic which were carried out using PEMS devices. The measurement results can be seen from Table 34.

Vehicle	Cycle	T SSW[31] [°C]	T USW[32] [°C]	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	**NEDC road**	6	9	321	235	87	27
2		3	7	366	280	86	24
1	**NEDC back**	2	7	332	305	27	8
2		3	6	360	361	-1	0
1	**NEDC + 10 %**	2	8	359	237	121	34
2		3	7	410	335	75	18
1	**NEDC -10 %**	1	7	391	236	155	40
2		2	7	454	321	132	29

Table 34: Overview of the tests cluster #14 NO_X reduction

[31] SSW: Series software
[32] USW: Update software

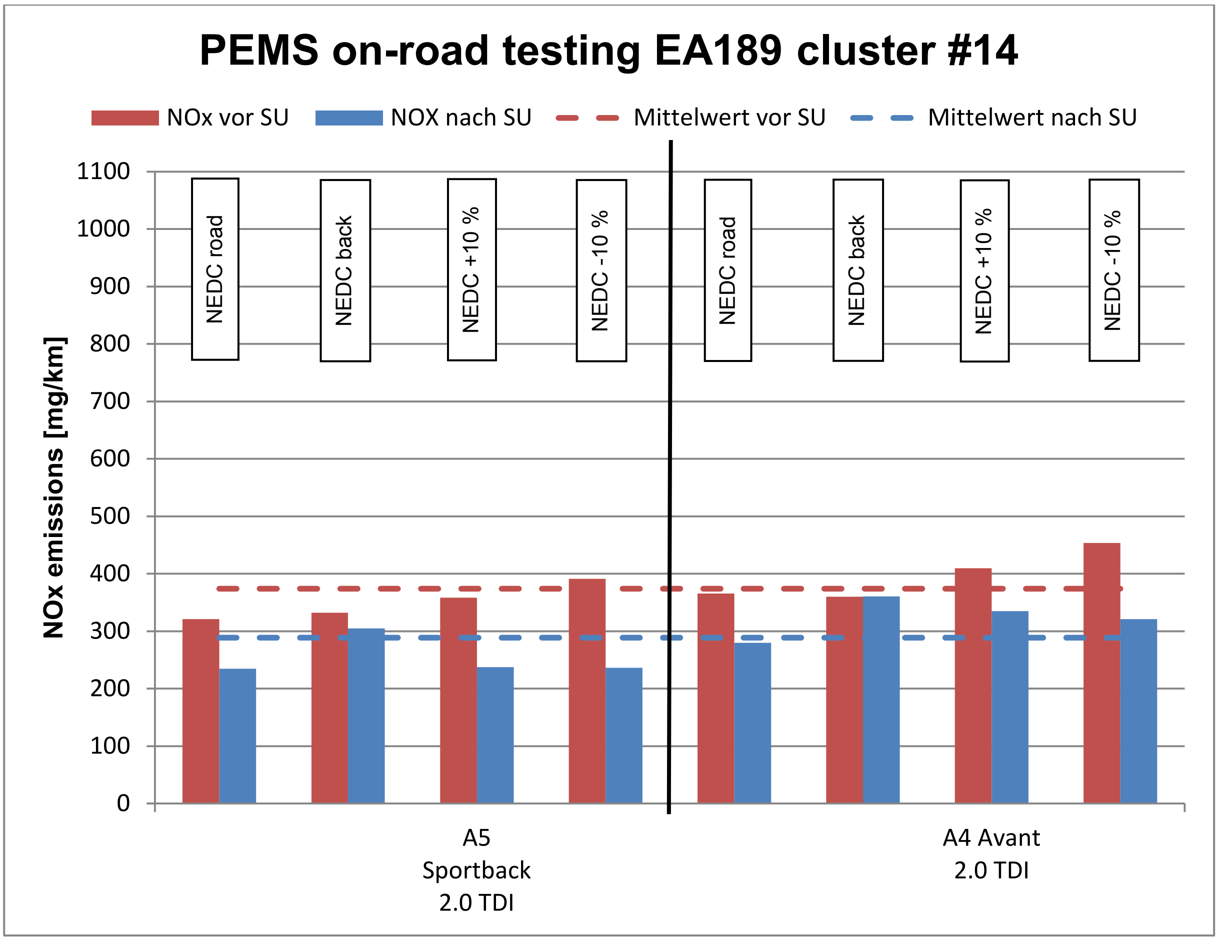

Figure 35: Bar chart cluster #14 NO_X reduction

3. Further mandatory recalls

Apart from the mandatory recall of Volkswagen vehicles of engine type EA189, the KBA detected prohibited defeat devices in further vehicle models of other manufacturers. Table 25 shows an overview of the vehicles affected. This involves exclusively vehicle models of emission standard Euro 6.

Vehicle type	Emission standard
Audi A6 3.0l TDI	EU 6
Audi A8 4.2l TDI	EU 6
BMW 750d xDrive	EU 6
Mercedes C 200 d	EU 6
Mercedes Vito 1.6l CDI	EU 6
Opel Zafira Tourer 1.6l CDTI	EU 6
Opel Insignia 2.0l CDTI	EU 6
Porsche Cayenne 3.0l Diesel	EU 6
Porsche Macan S 3.0l Diesel	EU 6

Table 35: Overview of the vehicles which were subject to further mandatory recalls

Within the context of the verification of software updates, the KBA has carried out tests on a representative vehicle. In this connection, an in-depth software analysis of the update software is performed by the software analysts of the KBA and RDE on-road tests are carried out by engineers of the KBA, using the series dataset and the dataset of the update. Moreover, the manufacturer furnishes proof on the basis of type approval testing with a recognized technical service that the software update complies with the legal requirements and that the vehicle complies with the threshold values of its emission category as regards consumption, emissions of pollutants and noise behaviour.

a. Audi A6 3.0l TDI (Euro 6)

The RDE tests were carried out at ambient temperatures of 19.8°C with series software and 22.3°C with update software.

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

Figure 36: Test vehicle Audi A6 3.0l TDI

Manufacturer:		Audi
Trade name:		A6 3.0l TDI
Vehicle category:		M1
Engine capacity (ccm):		2,967
Engine power (kW):		240
Odometer reading (km):		7,795
Approval number:		e1*2007/46*0436*28
Emissions approval number:		e13 715 2007 136 6588 03
Emission standard:		EU6
Type/model/version:		4G / ACVUBQ1 / QA8QA8BK021P4G13S57MMEM2K
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	x

Table 36: Vehicle data Audi A6 3.0 TDI 240kW

	Audi A6 3.0l TDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	510	239	272	53

Table 37: NO_X reduction Audi A6 3.0 TDI 240kW

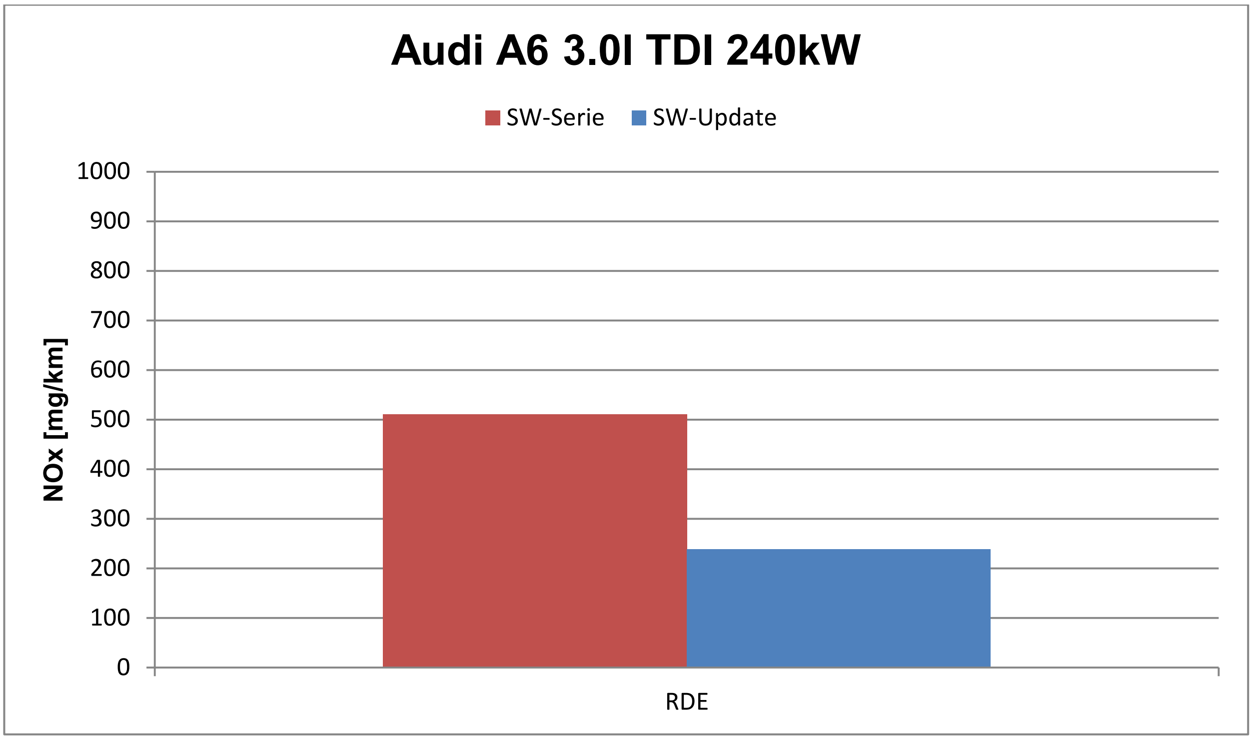

Figure 37: Bar chart NO_X reduction Audi A6 3.0 TDI 240kW

b. Audi A8 4.2l TDI (Euro 6)

The RDE tests were carried out at ambient temperatures of 25.8°C with series software and 21.8°C with update software.

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

Figure 38: Test vehicle Audi A8 4.2 l TDI

Manufacturer:		Audi
Trade name:		A8 4.2l TDI
Vehicle category:		M1
Engine capacity (ccm):		4,134
Engine power (kW):		283
Odometer reading (km):		9,749
Approval number:		e1*2007/46*0284*20
Emissions approval number:		e13*715/2007*136/2014W*6497*01
Emission standard:		EU6
Type/model/version:		4J / LCTECQ1 / QA8QA8BL002P4H08S57MMEM2K1
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	x

Table 38: Vehicle data Audi A8 4.2l TDI

	Audi A8 4.2l TDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measurement	849	288	561	66

Table 39: NO_X reduction Audi A8 4.2l TDI

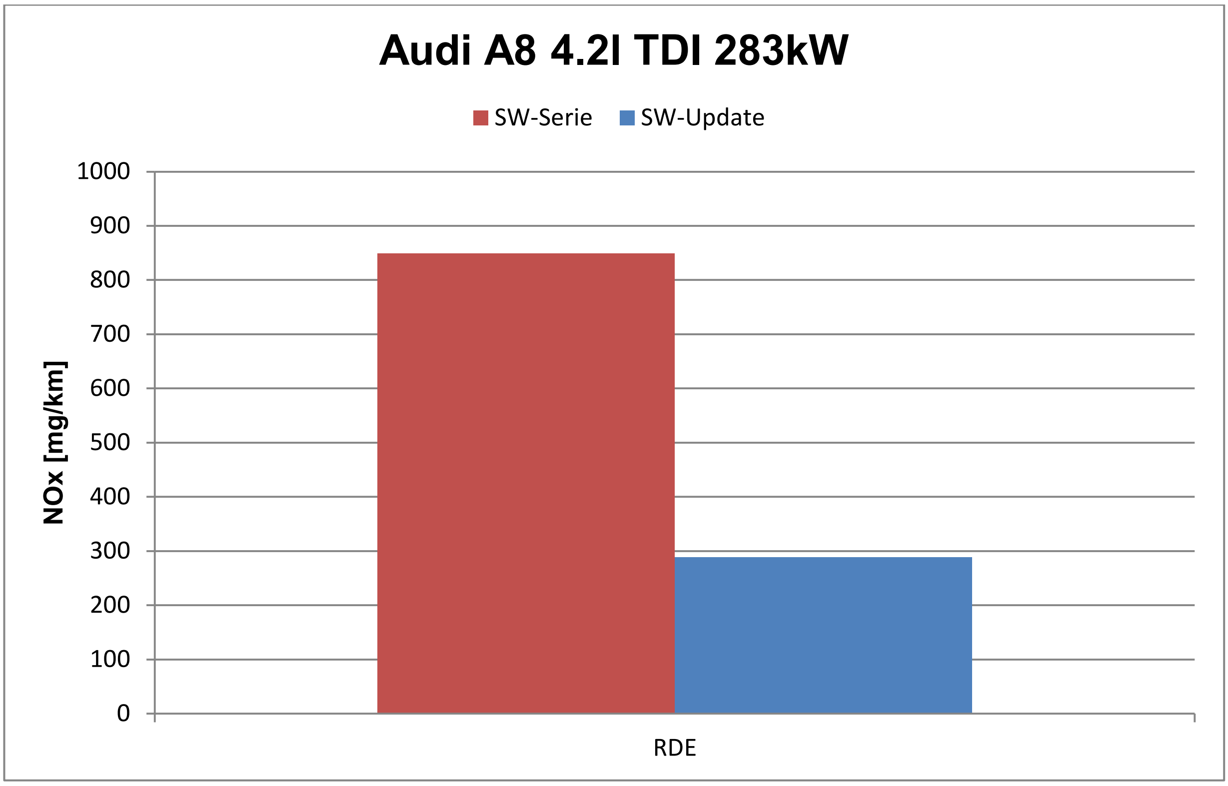

Figure 39: Bar chart NO_X reduction Audi A8 4.2l TDI

c. BMW 750d xDrive (Euro 6)

The RDE tests were carried out at ambient temperatures of 3°C with series software and 2°C with update software.

In order to optimize the NO_X emissions, the NO_X conversion rate of the NSC is raised.

Figure 40: Test vehicle BMW 750d xDrive

Manufacturer:		BMW
Trade name:		750d xDrive
Vehicle category:		M1
Engine capacity (ccm):		2,993
Engine power (kW):		280
Odometer reading (km):		80,630
Approval number:		e1*2007/46*0276*09
Emissions approval number:		e24*715/2007*566/2011T*0144*00
Emission standard:		EU6
Type/model/version:		7L / YB81 / 6A050000
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	x
	Particulate trap	x
	SCR cat	

Table 40: Vehicle data BMW 750d xDrive

	BMW 750d xDrive			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	608	564	44	7

Table 41: NO_X reduction BMW 750d xDrive

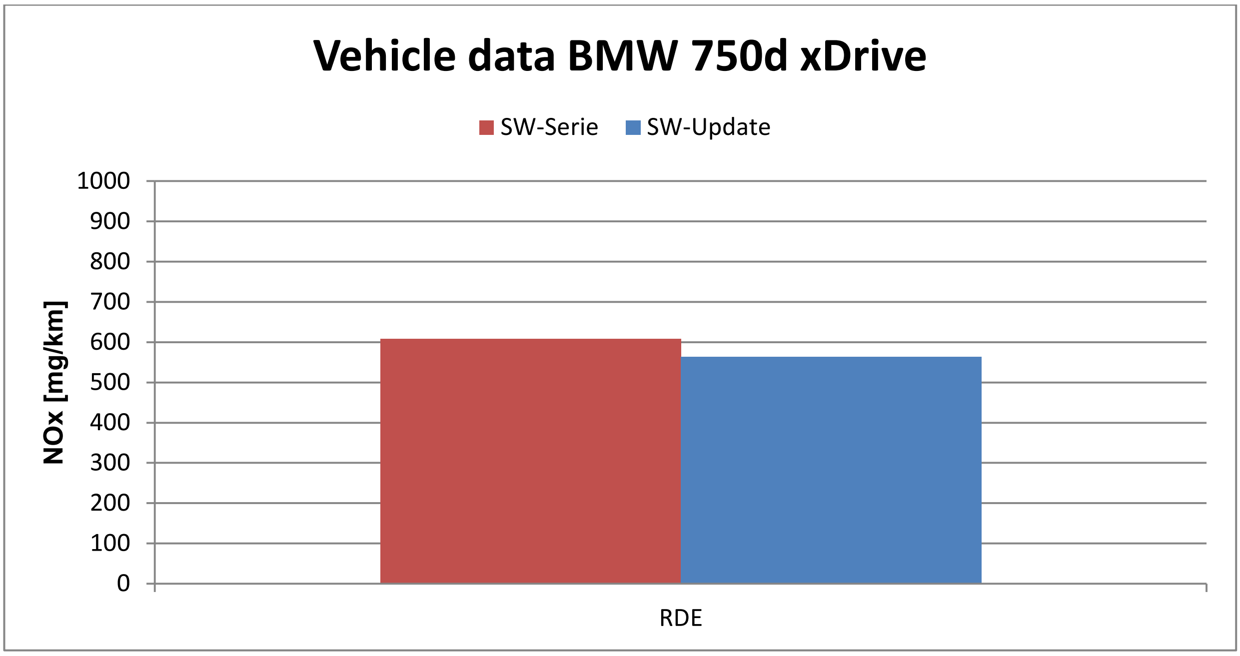

Figure 41: Bar chart NO_X reduction BMW 750d xDrive

d. Mercedes C 200 d (Euro 6)

The RDE tests were carried out at ambient temperatures of 7.8°C with series software and 4.6°C with update software.

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

Figure 42: Test vehicle Mercedes C 200 d

Manufacturer:		Mercedes
Trade name:		C 200 d
Vehicle category:		M1
Engine capacity (ccm):		1,598
Engine power (kW):		100
Odometer reading (km):		12,245
Approval number:		e1*2001/116*0457*32
Emissions approval number:		e1*715/2007*136/2014W*1078*03
Emission standard:		EU6
Type/model/version:		204 K / R237P0 / PZAA0521
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	x

Table 42: Vehicle data Mercedes C 200 d

	Mercedes C 200 d			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measurement	563	109	454	81

Table 43: NO_X reduction Mercedes C 200 d

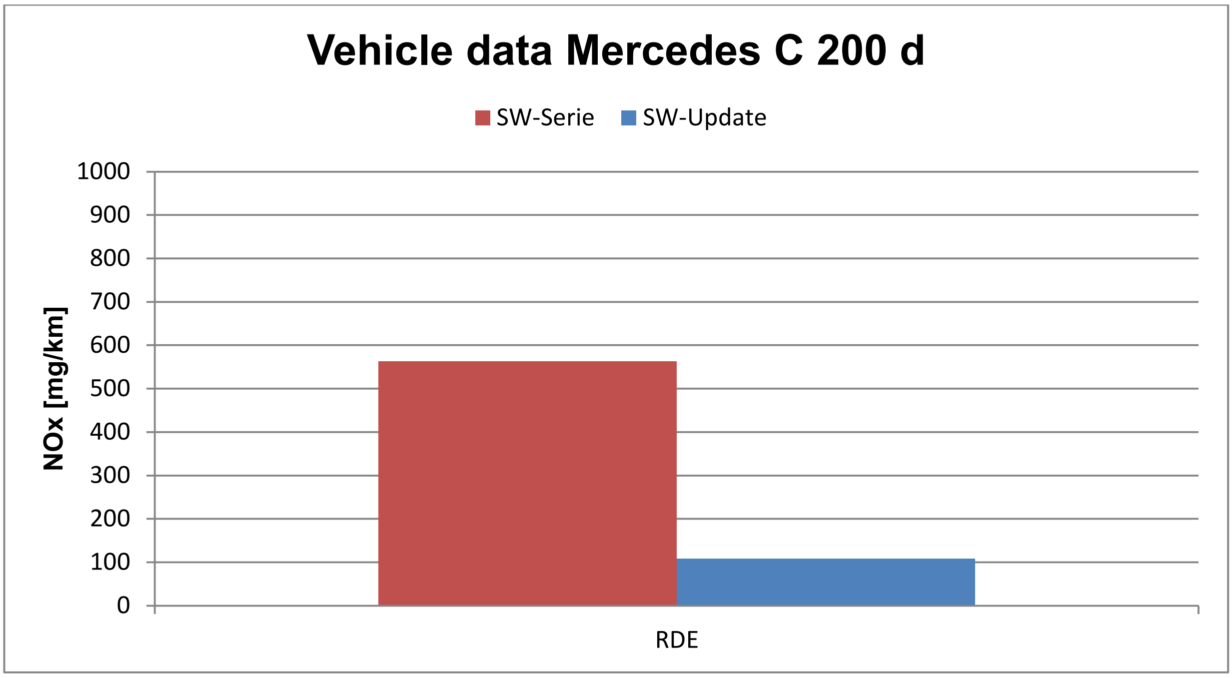

Figure 43: Bar chart NO_X reduction Mercedes C 200 d

e. Mercedes Vito 1.6l CDI (Euro 6)

The RDE tests were carried out at ambient temperatures of 22.3°C with series software and 15.0°C with update software.

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

Figure 44: Test vehicle Mercedes Vito 1.6l CDI

Manufacturer:		Mercedes
Trade name:		Vito 1.6l CDI
Vehicle category:		M1
Engine capacity (ccm):		1,598
Engine power (kW):		65
Odometer reading (km):		9,931
Approval number:		e1*2007/46*0457*15
Emissions approval number:		e1*715/2007*136/2014W*1209*00
Emission standard:		EU6
Type/model/version:		639/2 / KOR45305N / 2RNP7R79XX
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	x

Table 44: Vehicle data Mercedes Vito 1.6 CDI

	Mercedes Vito 1.6l CDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	57	32	25	44

Table 45: NO_X reduction Mercedes Vito 1.6 CDI

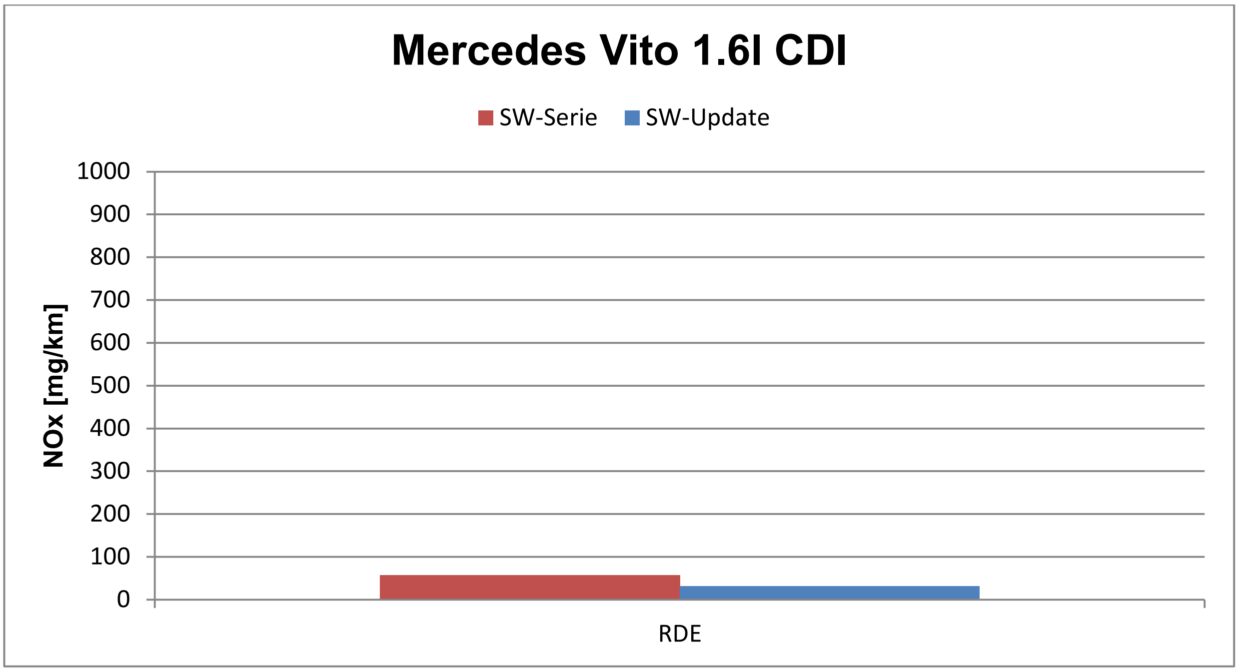

Figure 45: Bar chart NO_X reduction Mercedes Vito 1.6 CDI

f. Opel Zafira 1.6l CDTI (Euro 6)

Table 46 below shows the test results of the 1.6l Zafira. The vehicle has a SCR catalytic converter.

Figure 46: Test vehicle Opel Zafira Tourer 1.6l

	Vehicle 1	Vehicle 2
Manufacturer	Opel	Opel
Trade name	Zafira TOURER 1.6l CDTI	Zafira TOURER 1.6l CDTI
Type approval	e4*2007/46*0204*21	e4*2007/46*0204*22
Type / model / version	P-J/SW (BA2P3FPHJ5)	P-J/SW (EAEGC12)
Mileage [km]	13,743	7,524
Emission standard	EU6	EU6
Engine capacity [ccm]	1,598	1,598
Engine power [kW]	88	100

Table 46: Vehicle data Opel Zafira 1.6l CDTI

For the verification of the Zafira 1.6l CDTI, the measurements were performed according to the NEDC driving profile. In order to show the potential for improvement at low temperatures, the temperature of the test chamber was gradually reduced. The measurement results can be seen from Table 47

Vehicle	Cycle	NOX SSW [mg/km]	NOX USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	**NEDC cold**	47	53	-6	-13
2		38	44	-6	-16
1	**NEDC warm**	238	37	201	84
2		161	46	115	71
1	**NEDC back**	86	20	66	77
2		20	15	5	25
1	**NEDC + 10 %**	180	36	144	80
2		79	30	49	62
1	**NEDC 15°C**	578	29	549	95
2		453	55	398	88
1	**NEDC 10°C**	615	17	598	97
2		511	31	480	94
1	**NEDC 5°C**	426	71	355	83
2		396	72	324	82

Table 47: Overview of the tests Opel Zafira 1.6l CDTI NO_Xreduction

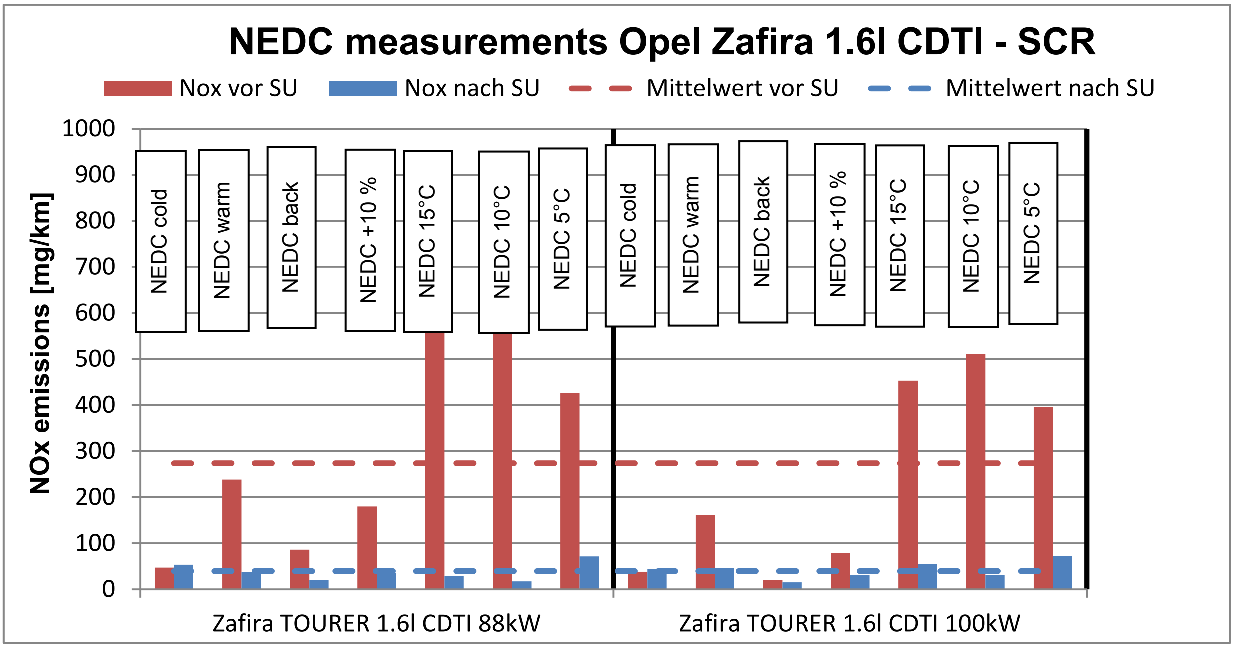

Figure 47: Bar chart Opel Zafira 1.6l CDTI NO_X reduction

g. Opel Insignia 2.0l CDTI (Euro 6)

Table 48 below shows the test results of the 2.0l Insignia. The vehicle has a SCR catalytic converter.

Figure 48: Test vehicle Opel Insignia 2.0l CDTI

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Opel	Opel	Opel
Trade name	Insignia Sports Tourer SW	Insignia Sports Tourer SW	Insignia 4x4
Type approval	e1*2007/46*0374*17	e1*2007/46*0374*16	
Type / model / version	0G-A / DAHMC12	0G-A / DAHMC12	3716-N094
Mileage [km]	7,229	1,733	28,702
Emission standard	EU6	EU6	EU6
Engine capacity [ccm]	1,956	1,956	1,956
Engine power [kW]	125	125	125

Table 48: Vehicle data Opel Insignia 2.0l CDTI

For the verification of the Insignia 2.0l CDTI, the measurements were performed according to the NEDC driving profile. In order to show the potential for improvement at low temperatures, the temperature of the test chamber was gradually reduced. The measurement results can be seen from Table 49.

Vehicle	Cycle	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC cold	46	57	-11	-24
2		56	70	-14	-25
3		80	58	22	28
1	NEDC warm	35	9	26	74
2		45	44	1	2
3		114	17	97	85
1	NEDC back	13	2	11	85
2		24	19	5	21
3		23	17	6	26
1	NEDC + 10 %	38	8	30	79
2		45	39	6	13
3		190	20	170	89
1	NEDC 15°C	156	16	140	90
2		73	37	36	49
3		249	30	219	88
1	NEDC 10°C	380	27	353	93
2		344	33	311	90
3		877	66	811	92
1	NEDC 5°C	317	31	286	90
2		405	58	347	86
3		949	52	897	95

Table 49: Overview of the tests Opel Insignia 2.0 l CDTI NO_X reduction

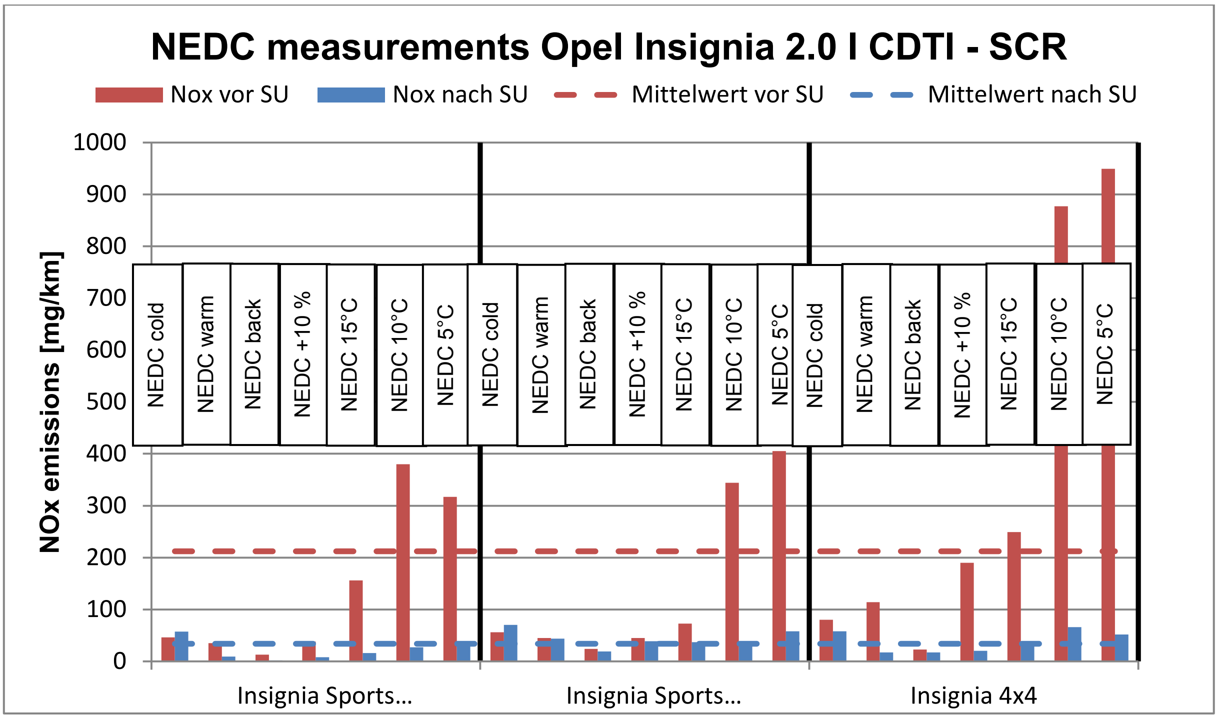

Figure 49: Bar chart Opel Insignia 2.0 l CDTI NO_X reduction

h. Porsche Cayenne 3.0l Diesel (Euro 6)

The RDE tests were carried out at ambient temperatures of 6.5°C with series software and 8.5° C with update software.

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

Figure 50: Test vehicle Porsche Cayenne 3.0l Diesel

Manufacturer:		Porsche
Trade name:		Cayenne 3.0l Diesel
Vehicle category:		M1G
Engine capacity (ccm):		2,967
Engine power (kW):		193
Odometer reading (km):		8,459
Approval number:		e13*2007/46*1085*16
Emissions approval number:		e1*715/2007*2015/45W*1112*01
Emission standard:		EU6
Type/model/version:		92A / EG22 / 01
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	x

Table 50: Vehicle data Porsche Cayenne 3.0 Diesel

	Porsche Cayenne 3.0l Diesel			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	190	83	107	56

Table 51: NO_X reduction Porsche Cayenne 3.0l Diesel

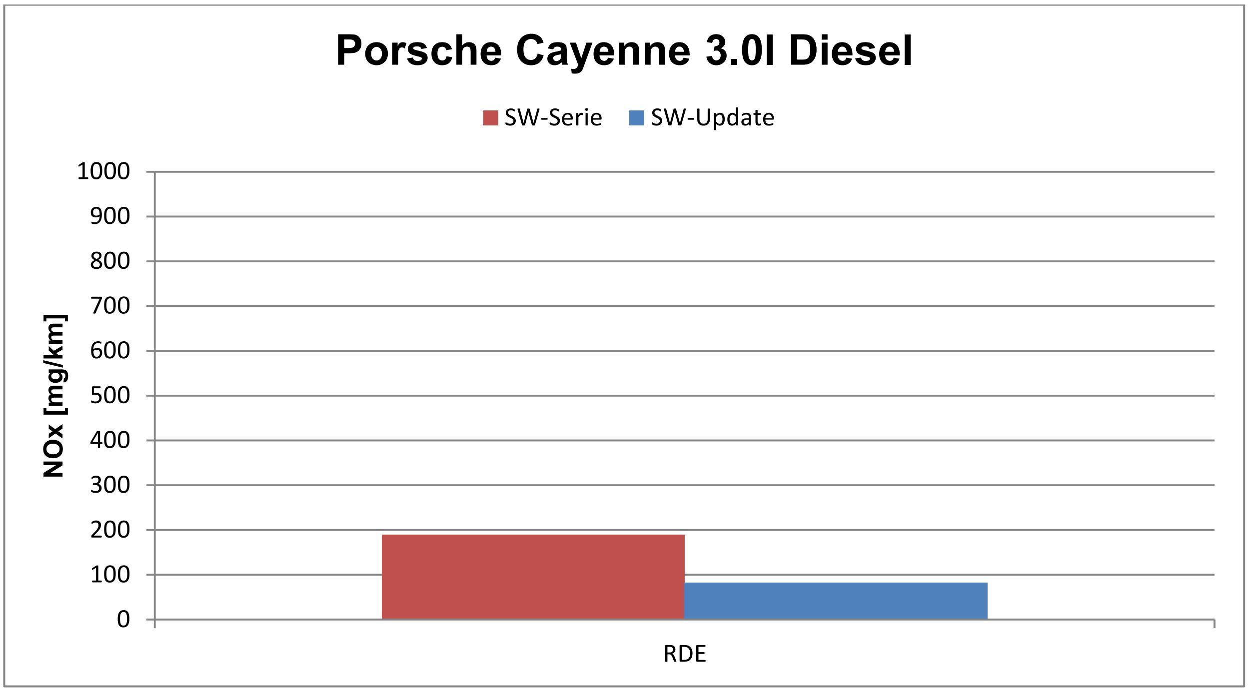

Figure 51: Bar chart NO_X reduction Porsche Cayenne 3.0l Diesel

i. Porsche Macan S 3.0l Diesel (Euro 6)

The RDE tests were carried out at ambient temperatures of 8.0°C with series software and 7.7°C with update software.

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

Figure 52: Test vehicle Porsche Macan S 3.0l Diesel

Manufacturer:		Porsche
Trade name:		Macan S 3.0 Diesel
Vehicle category:		M1
Engine capacity (ccm):		2,967
Engine power (kW):		190
Odometer reading (km):		4,000
Approval number:		e13 2007 0000 46 1165 07
Emissions approval number:		e1*715/2007*2015/45W*1034*01
Emission standard:		EU6
Type/model/version:		95B / JG22 / D2
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	x

Table 52: Vehicle data Porsche Macan S 3.0 Diesel

	Porsche Macan S 3.0l Diesel			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measurement	746	192	555	74

Table 53: NO_X reduction Porsche Macan S 3.0 Diesel

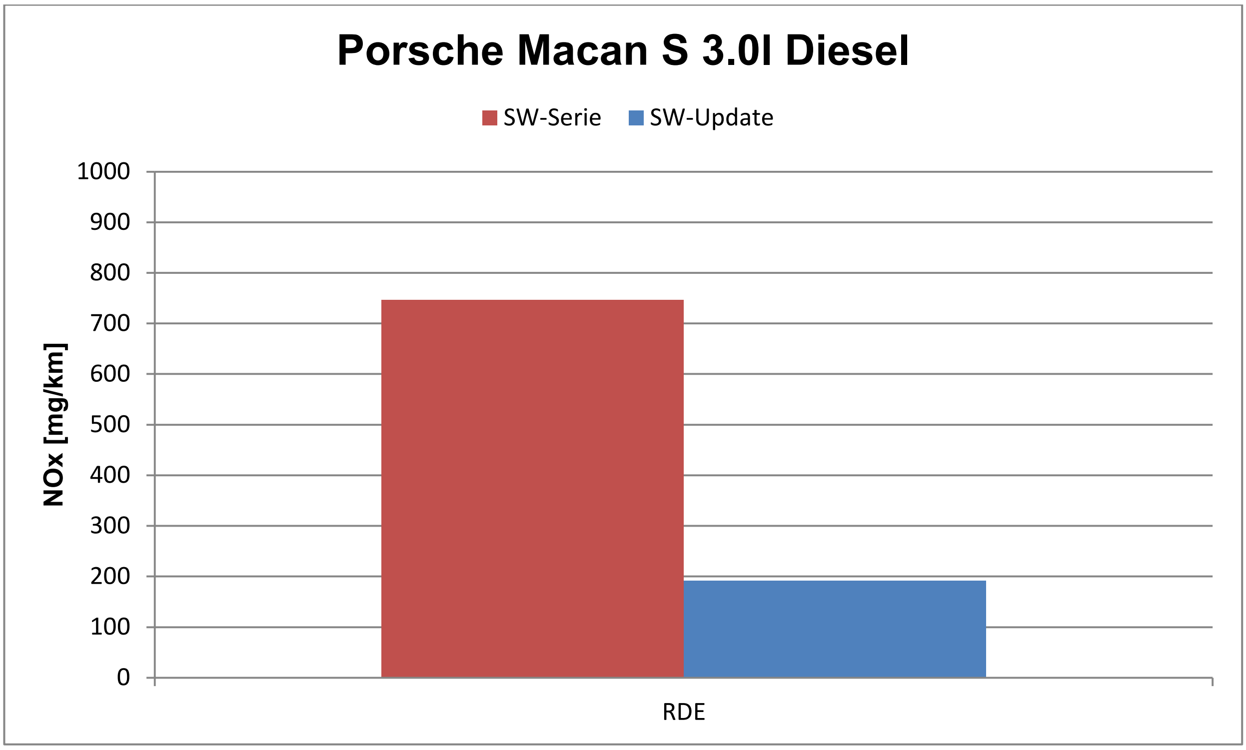

Figure 53: Bar chart NO_X reduction Porsche Macan S 3.0 Diesel

4. Voluntary software updates

In the following section, the measurements of the vehicles are presented for which the automotive manufacturers have agreed to optimize the pollutant emissions by implementing software updates on a voluntary basis within the framework of the National Forum Diesel.

Table 54 shows the vehicle models of emission standards 5 and 6 inspected after the implementation of software updates.

Vehicle type	Engine power [kW]	Emission standard
Test vehicle Audi A6 3.0l TDI	180	EU 5
BMW 320d	135	EU 5
BMW 520d	135	EU 5
Fiat 500X 2.0 MultiJet	103	EU 6
Mazda 6 2.2l SkyActive	129	EU 6
Mercedes A/B/GLA OM607	80/66	EU 5
Mercedes B 180 CDI	80	EU 5
Mercedes C 220 CDI	125	EU 5
Mercedes E 350 CDI	170	EU 5
Mercedes GLK 220 CDI 4MATIC	125	EU 5
Mercedes B 200 d	100	EU 6
Mercedes GLE350 d	190	EU 6
Mercedes C 220 d	125	EU 6
Mercedes GLC 220 d	125	EU 6
Mitsubishi Outlander 2.2l Di-D	110	EU 6
Opel Corsa 1.3 CDTi	70	EU 6
Opel Insignia 1.6 CDTi	100	EU 6
Subaru Outback 2.0 D	110	EU 6
VW Crafter / Amarok 2.0l TDI	100/103/132	EU 5
VW T6 2.0l TDI	75	EU 6
VW Touareg 3.0l TDI	180	EU 5

Table 54: Overview of the vehicles with voluntary software updates

For the verification of the software updates within the framework of the National Forum Diesel, the KBA has carried out tests on exhaust chassis dynamometers at different temperatures as well as RDE measurements. The tests on the exhaust chassis dynamometer were conducted according to the WLTC driving profile. The focus of the software updates is on the improvement of the emissions especially in urban and rural operations; therefore, the share of the WLTC on the motorway is not performed (WLTC123).

After successful verification of the emission improvement, the KBA granted a general type approval for the software update. The general type approval refers always to a group of model series which are comparable with regard to their engine and exhaust after treatment.

The testing of voluntary software updates which are not part of the National Forum Diesel is performed through an analysis of the software for engine control as well as comparative measurements according to RDE and/or special tests on a case-by-case basis (e.g. modifications of the NEDC).

a. Audi A6 3.0l TDI (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 14.4° C with series software and 14.5 °C with update software.

The test vehicle and the results for obtaining the general type approval No 91759 are presented in the following.

Figure 54: Test vehicle Audi A6 3.0l TDI

Manufacturer:		Audi
Trade name:		A6 Avant 3.0 TDI
Vehicle category:		M1
Engine capacity (ccm):		2,967
Engine power (kW):		180
Odometer reading (km):		113,310
Approval number:		e1*2007/46*0436*11
Emissions approval number:		e13*715/2007*566/2011F*0180*06
Emission standard:		EU5
Type/model/version:		4G / ACDUDQ1 / QD7B5027R4G71S57MGEM2
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 55: Vehicle data Audi A6 Avant 3.0 TDI

	Audi A6 3.0 TDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	1,013	204	809	80
WLTC123 10 °C	819	184	635	78
WLTC123 15 °C	675	167	509	75
RDE measure-ment	1,649	408	1,241	75

Table 56: NO_X reduction Audi A6 3.0 TDI

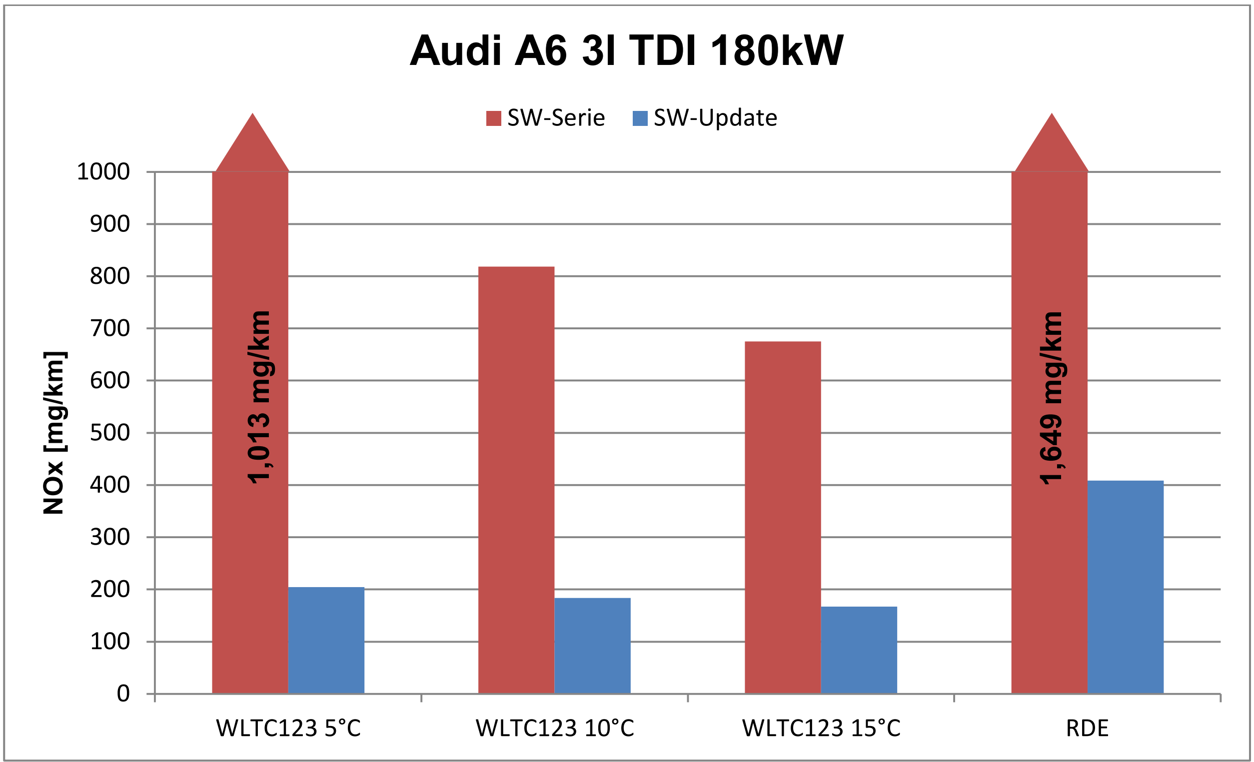

Figure 55: Bar chart NO_X reduction Audi A6 3.0 TDI

b. BMW 320d (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 21.9° C with series software and 22.8° C with update software.

The test vehicle and the results for obtaining the general type approval No 91717 are presented in the following.

Figure 56: Test vehicle BMW 320d

Manufacturer:		BMW
Trade name:		320d
Vehicle category:		M1
Engine capacity (ccm):		1,995
Engine power (kW):		135
Odometer reading (km):		134,000
Approval number:		e1*2007/46*0315*01
Emissions approval number:		e24*715/2007*692/2008A*0049*00
Emission standard:		EU5
Type/model/version:		3K / UY11 / 5A
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 57: Vehicle data BMW 320d

	BMW 320d			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	602	419	183	31
WLTC123 10 °C	468	333	136	29
WLTC123 15 °C	338	340	-2	-1
RDE measurement	526	451	75	14

Table 58: NO_X reduction BMW 320d

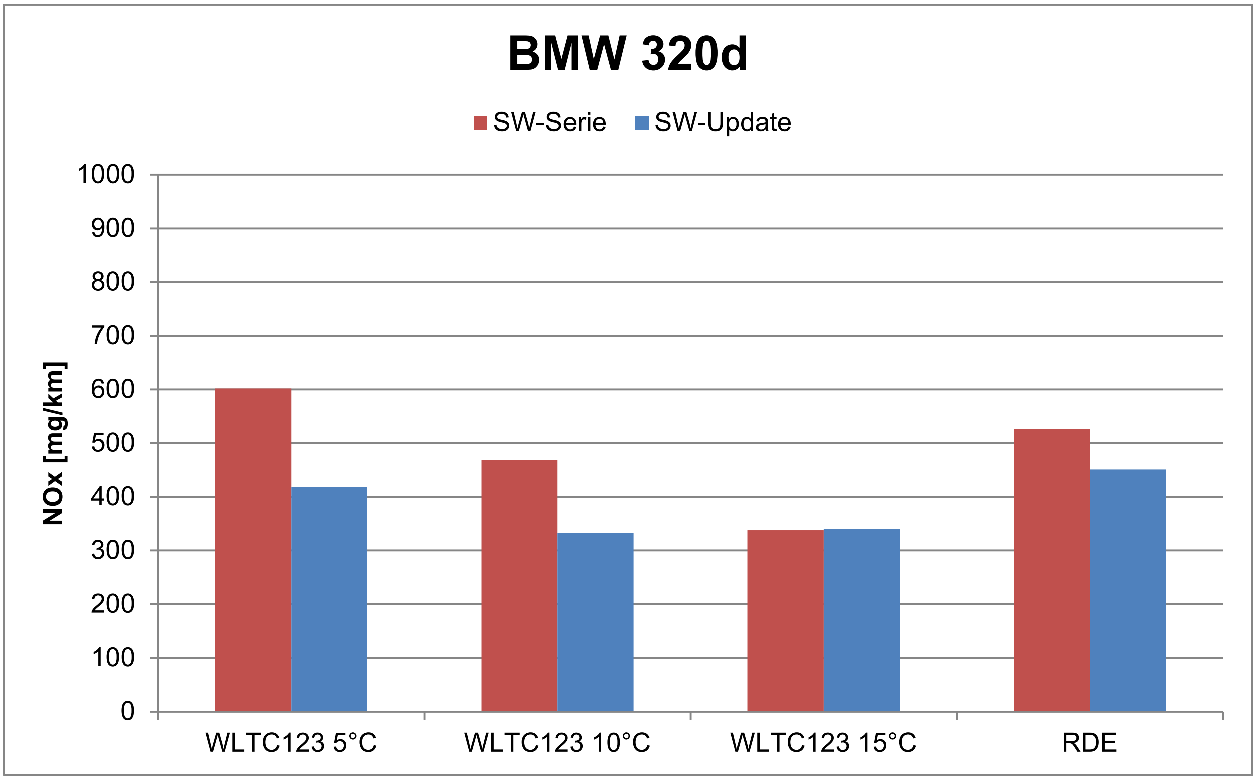

Figure 57: Bar chart NO_X reduction BMW 320d

c. BMW 520d (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 19° C with series software and 26° C with update software.

The test vehicle and the results for obtaining the general type approval No 91716 are presented in the following.

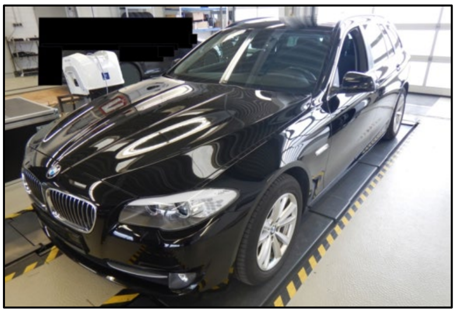

Figure 58: Test vehicle BMW 520d

Manufacturer:		BMW
Trade name:		520d
Vehicle category:		M1
Engine capacity (ccm):		1,995
Engine power (kW):		135
Odometer reading (km):		133,114
Approval number:		e1*2007/46*0455*08
Emissions approval number:		e24*715/2007*459/2012J
Emission standard:		EU5b
Type/model/version:		5K / MX11 / 5A100
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 59: Vehicle data BMW 520d

	BMW 520d			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	722	280	442	61
WLTC123 10 °C	326	320	6	2
WLTC123 15 °C	241	261	-21	-9
RDE measure-ment	342	306	37	11

Table 60: NO_X reduction BMW 520d

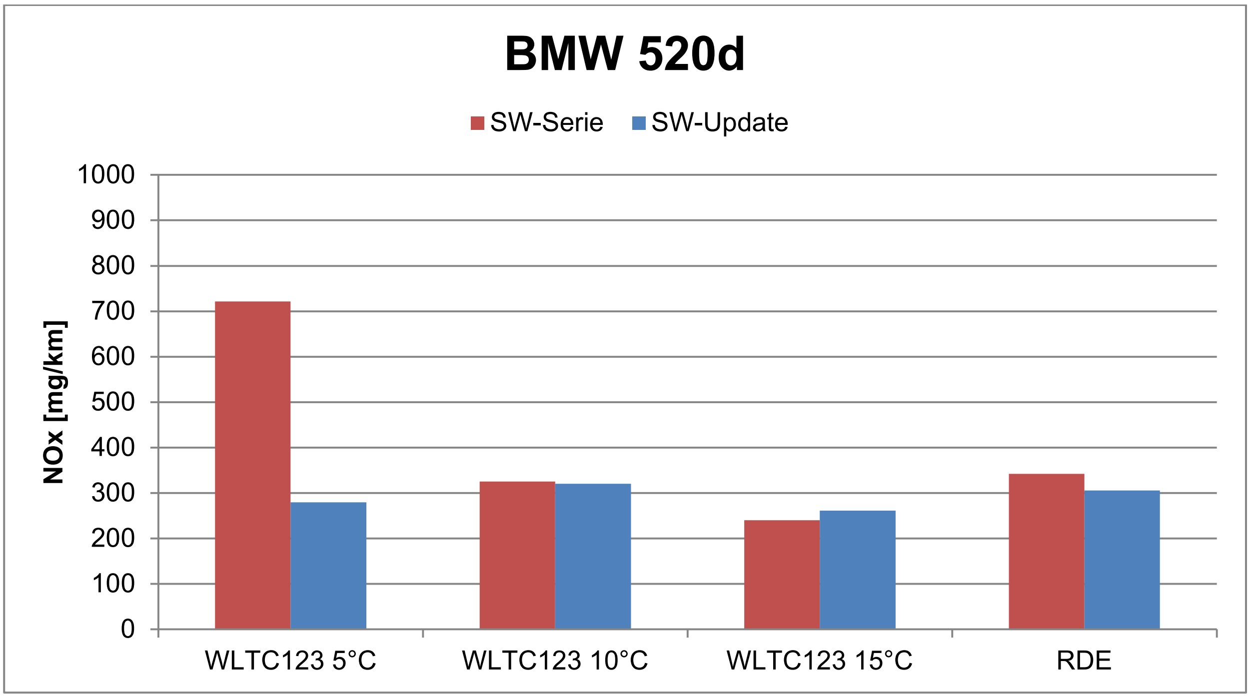

Figure 59: Bar chart NO_X reduction BMW 520d

d. Fiat 500X 2.0 MultiJet (Euro 6)

The KBA carried out comparative measurements on this vehicle with series software as well as update software. However, the responsibility for the recall does not lie with the KBA but with the Italian type approval authority.

The RDE tests were carried out at ambient temperatures of 11.2° C with series software and 13.3° C with update software. Vehicle A was used for the measurement of the RDE with series software. Vehicle B was used for the updated dataset (see table).

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures, as well as the operational range of the NSC.

Figure 60: Test vehicle Fiat 500X 2.0 MultiJet

Manufacturer:		Fiat
Trade name:		500X 2.0 MultiJet
Vehicle category:		M1
Engine capacity (ccm):		1,956
Engine power (kW):		103
Odometer reading (km):		Vehicle A: 16,994 Vehicle B: 0
Approval number:		Vehicle A: e3*2007/46*0318*00 Vehicle B e3 2007031802
Emissions approval number:		e3*715/2007*136/2014W*0443*00
Emission standard:		EU6
Type/model/version:		Vehicle A: 334 / AXB22 / 01A Vehicle B: 334 / AXB22 / 01E
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	x
	Particulate trap	x
	SCR cat	

Table 61: Vehicle data Fiat 500X 2.0 MultiJet

	Fiat 500X 2.0 MultiJet			
	NOx emissions [mg/km]		Reduction	
	Software Series (Vehicle A)	Software Update (Vehicle B)	Absolute [mg/km]	Relative [%]
RDE measurement	1,358	394	964	71

Table 62: NO_X reduction Fiat 500 X 2.0 MultiJet

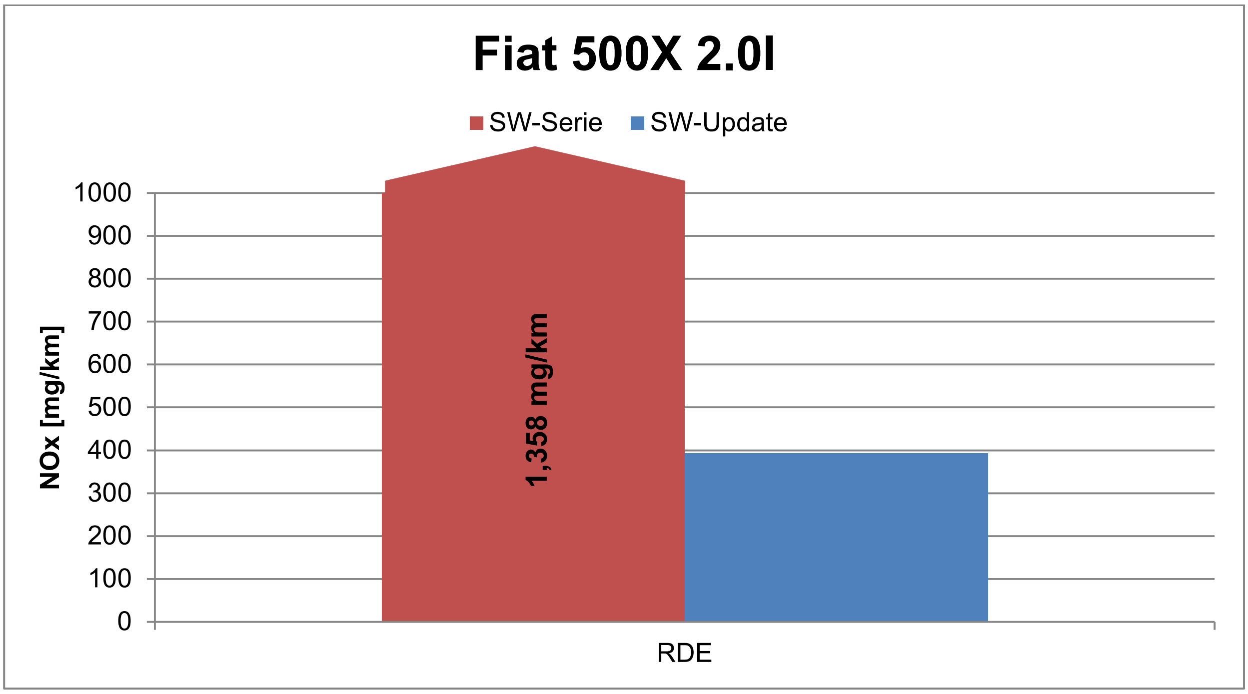

Figure 61: Bar chart NO_X reduction Fiat 500 X 2.0 MultiJet

e. Mazda 6 2.2l SkyActive (Euro 6)

The RDE tests were carried out at ambient temperatures of 2.0°°C with series software and 4.0°C with update software.

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures and with increased engine speeds.

Figure 62: Test vehicle Mazda 6 2.2l SkyActive

Manufacturer:		Mazda
Trade name:		6 2.2 SkyActive
Vehicle category:		M1
Engine capacity (ccm):		2,191
Engine power (kW):		129
Odometer reading (km):		19,865
Approval number:		e1*2001/116*0448*22
Emissions approval number:		e11*715/2007*136/3025W
Emission standard:		EU6
Type/model/version:		GH / 692 / 87WO
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	

Table 63: Vehicle data Mazda 6 2.2l SkyActive

	Mazda 6 2.2l SkyActive			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	275	257	18	7

Table 64: NO_X reduction Mazda 6 2.2l SkyActive

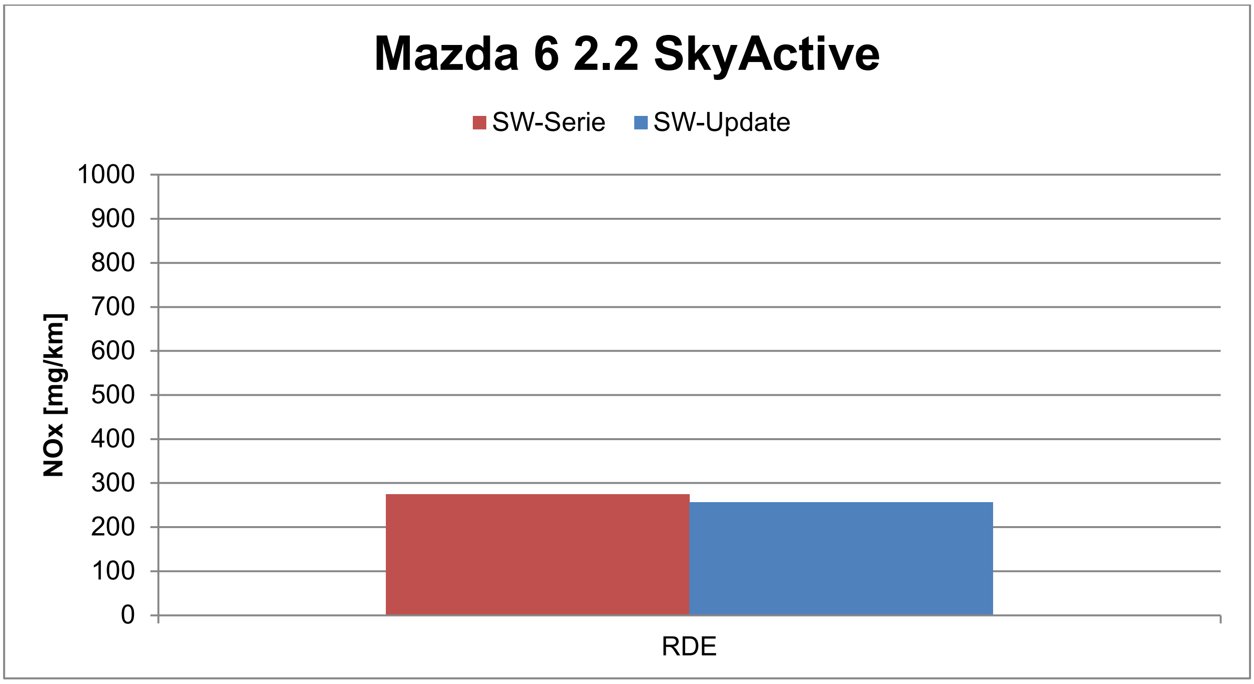

Figure 63: Bar chart NO_X reduction Mazda 6 2.2l SkyActive

f. Mercedes A/B/GLA OM607 (Euro 5)

Table 66 below shows the test results of the OM607 A/B/GLA category. Apart from the low-pressure and high-pressure EGR, the vehicles also have a NSC. A reduction of the NO_X emissions was realized by adapting the operating strategy of low-pressure and high-pressure EGR.

Figure 64: Test vehicle Mercedes GLA180 d

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	Mercedes	Mercedes	Mercedes
Trade name	A 180 d	GLA 180 d	B 160 d
Type approval	e1*2001/116*0470*16	e1*2001/116*0470*16	e1*2001/116*0470*16
Type / model / version	245 G	245 G	245 G
Odometer reading [km]	7,537	41,509	35,976
Emission standard	Euro 6	Euro 6	Euro 6
Engine capacity [ccm]	1,461	1,461	1,461
Engine power [kW]	80	80	66

Table 65: Vehicle data Mercedes OM607 A/B/GLA category

For the verification of the OM607 A/B/GLA category, the measurements were performed according to the NEDC driving profile. In order to show the potential for improvement at low temperatures, the temperature of the test chamber was gradually reduced. The measurement results can be seen from Table 66.

Vehicle	Cycle	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC cold	35	34	1	3
2		56	57	-1	-2
3		79	46	33	42
1	NEDC warm	158	89	69	44
2		176	160	16	9
3		223	129	94	42
1	NEDC back	83	35	48	58
2		108	108	0	0
3		99	60	39	39
1	NEDC + 10 %	97	88	9	9
2		147	148	-1	-1
3		149	106	43	29
1	NEDC 15°C	112	119	-7	-6
2		200	177	23	12
3		169	140	29	17
1	NEDC 10 C	148	80	68	46
2		311	186	125	40
3		206	151	55	27
1	NEDC 5 C	379	85	294	78
2		411	105	306	74
3		412	124	288	70

Table 66: Overview of the tests NO_X reduction Mercedes OM607 A/B/GLA category

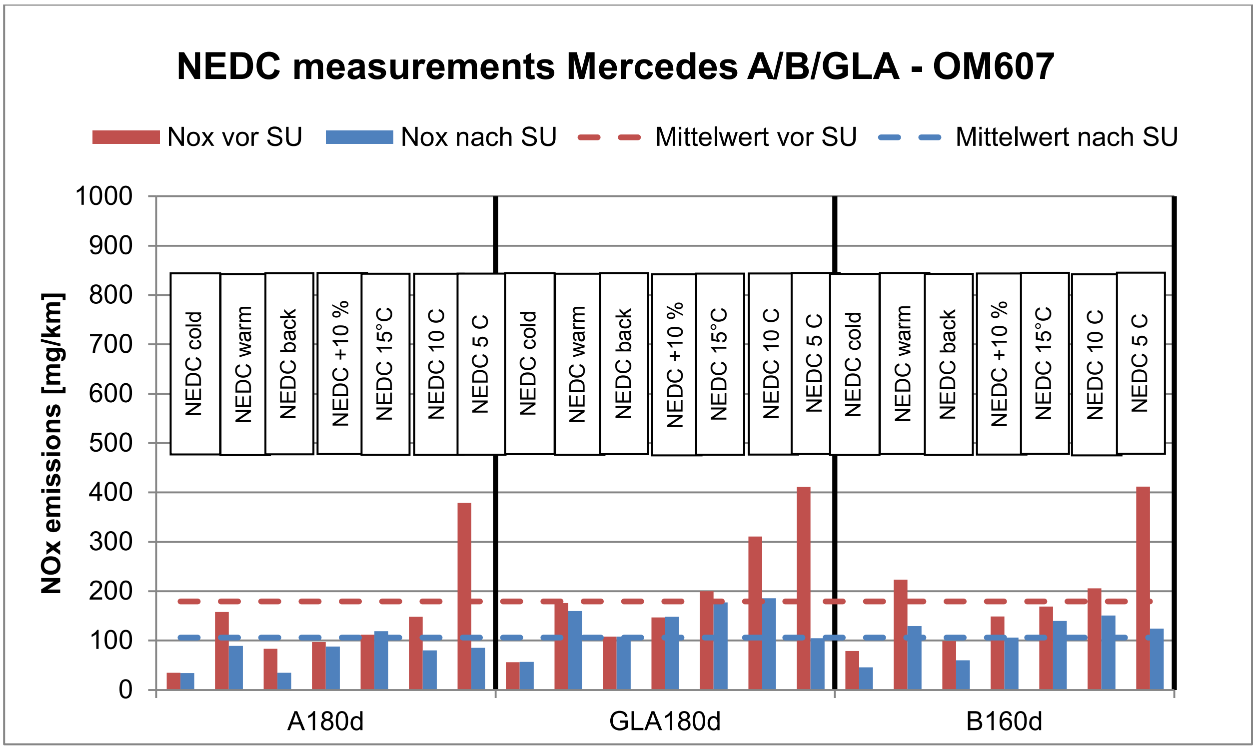

Figure 65: Bar chart NO_X reduction Mercedes OM607 A/B/GLA category

g. Mercedes B 180 CDI (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.
The RDE tests were carried out at ambient temperatures of 15°C with series software and 18°C with update software.
The test vehicle and the results for obtaining the general type approval No 91732 are presented in the following.

Figure 66: Test vehicle Mercedes B 180 CDI

Manufacturer:		Mercedes
Trade name:		B 180 CDI
Vehicle category:		M1
Engine capacity (ccm):		1,796
Engine power (kW):		80
Odometer reading (km):		64,939
Approval number:		e1*2007/46*0751*01
Emissions approval number:		e1*715/2007*566/2011J*0608*01
Emission standard:		EU5
Type/model/version:		246 / M2017M2 / UZAAA500
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR catalytic converter	-

Table 67: Vehicle data Mercedes B 180 CDI

	Mercedes B 180 CDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	334	235	99	30
WLTC123 10 °C	384	263	121	32
WLTC123 15 °C	342	249	93	27
RDE measure-ment	441	341	100	23

Table 68: NO_X reduction Mercedes B 180 CDI

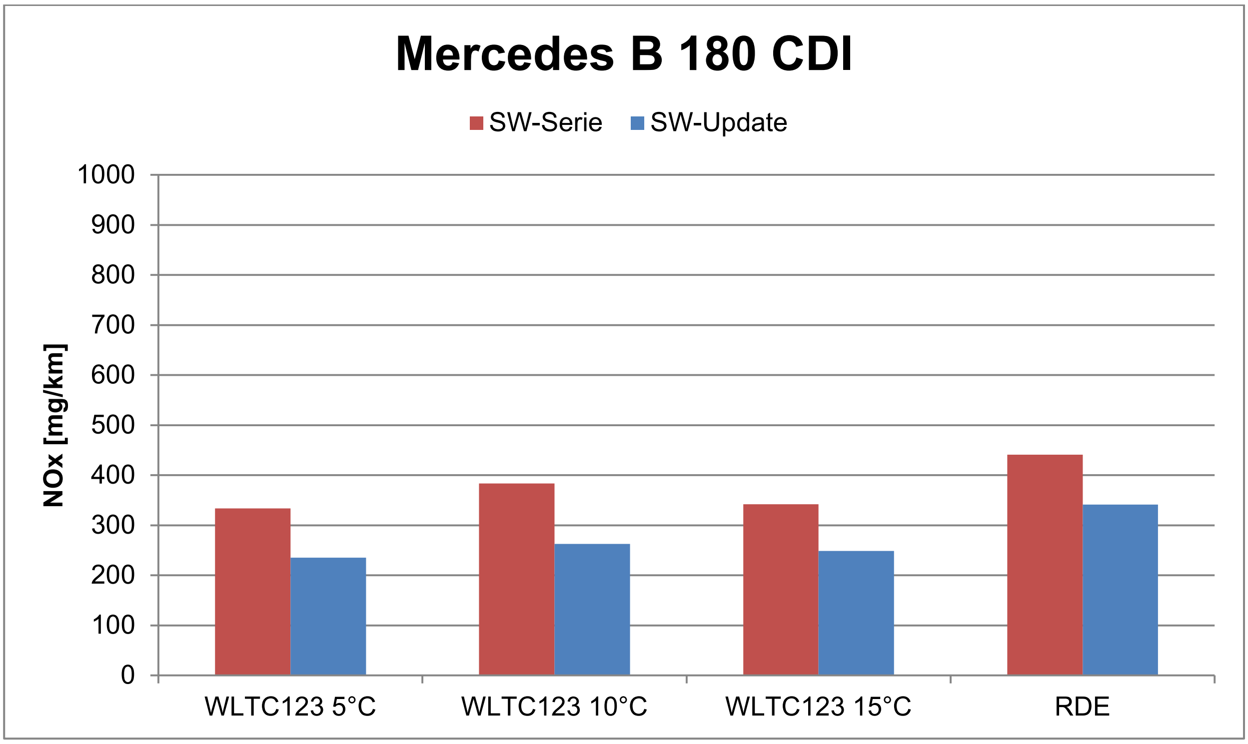

Figure 67: Bar chart NO_X reduction Mercedes B 180 CDI

h. Mercedes C 220 CDI (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 19°C with series software and 24°C with update software.

The test vehicle and the results for obtaining the general type approval No 91707 are presented in the following.

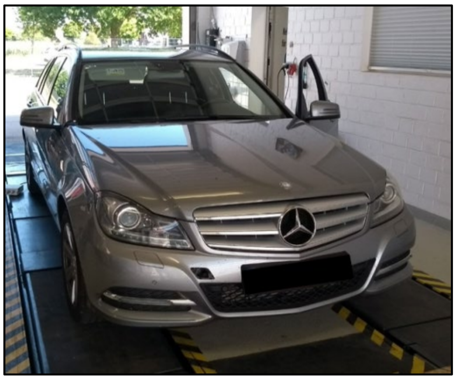

Figure 68: Test vehicle Mercedes C 220 CDI

Manufacturer:		Mercedes
Trade name:		C 220 CDI
Vehicle category:		M1
Engine capacity (ccm):		2,143
Engine power (kW):		125
Odometer reading (km):		150,769
Approval number:		e1*2001/116*0457*24
Emissions approval number:		e1*715/2007*1995/2013J*0777*03
Emission standard:		EU5
Type/model/version:		204K / H2S2M0 / NZAAA500
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 69: Vehicle data Mercedes C 220 CDI

	Mercedes C 220 CDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	287	149	139	48
WLTC123 10 °C	331	250	80	24
WLTC123 15 °C	291	218	73	25
RDE measure-ment	503	311	192	38

Table 70: NO_X reduction Mercedes C 220 CDI

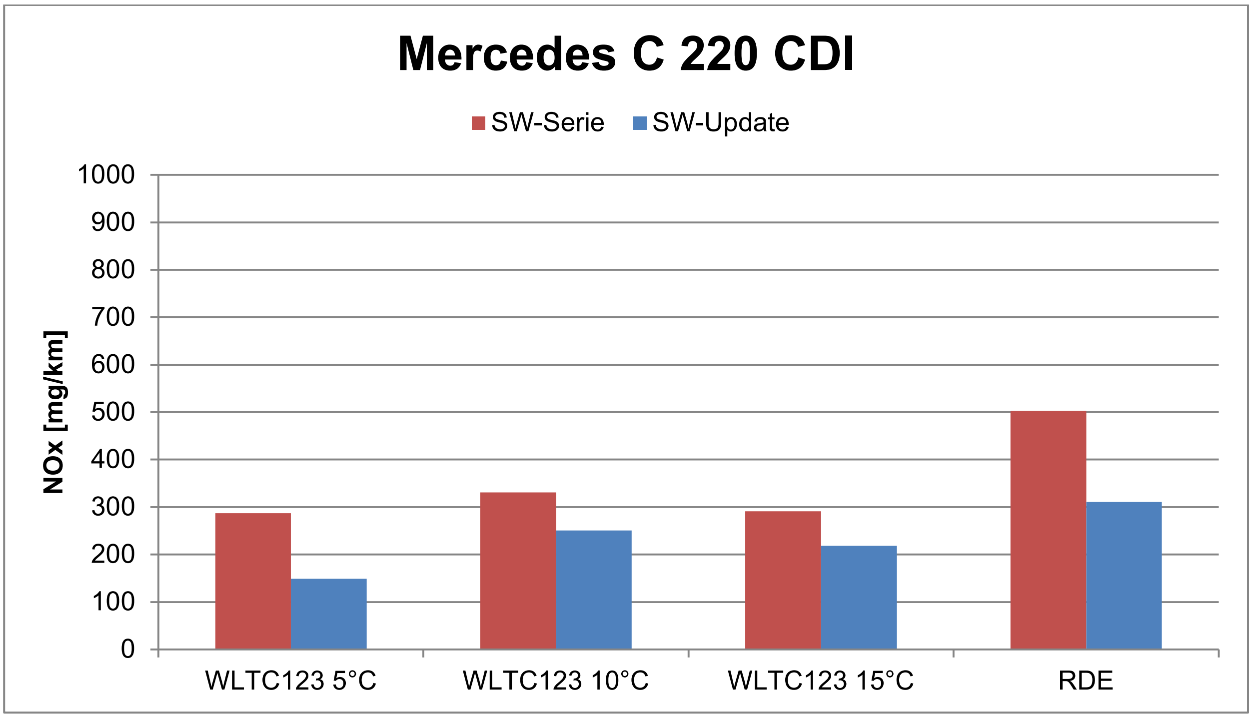

Figure 69: Bar chart NO_X reduction Mercedes C 220 CDI

i. Mercedes E 350 CDI (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 7.9° C with series software and 11.3° C with update software.

The test vehicle and the results for obtaining the general type approval No 91726 are presented in the following.

Figure 70: Test vehicle Mercedes E 350 CDI

Manufacturer:		Mercedes
Trade name:		E 350 CDI
Vehicle category:		M1
Engine capacity (ccm):		2,987
Engine power (kW):		170
Odometer reading (km):		87,229
Approval number:		e1*2007/46*0200*03
Emissions approval number:		e1*715/2007*692/2008A*0040*05
Emission standard:		EU5
Type/model/version:		212K / J225M0 / NZAAA500
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 71: Vehicle data Mercedes E 350 CDI

	Mercedes E 350 CDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	387	276	111	29
WLTC123 10 °C	320	259	61	19
WLTC123 15 °C	292	273	19	6
RDE measure-ment	723	489	234	32

Table 72: NO_X reduction Mercedes E 350 CDI

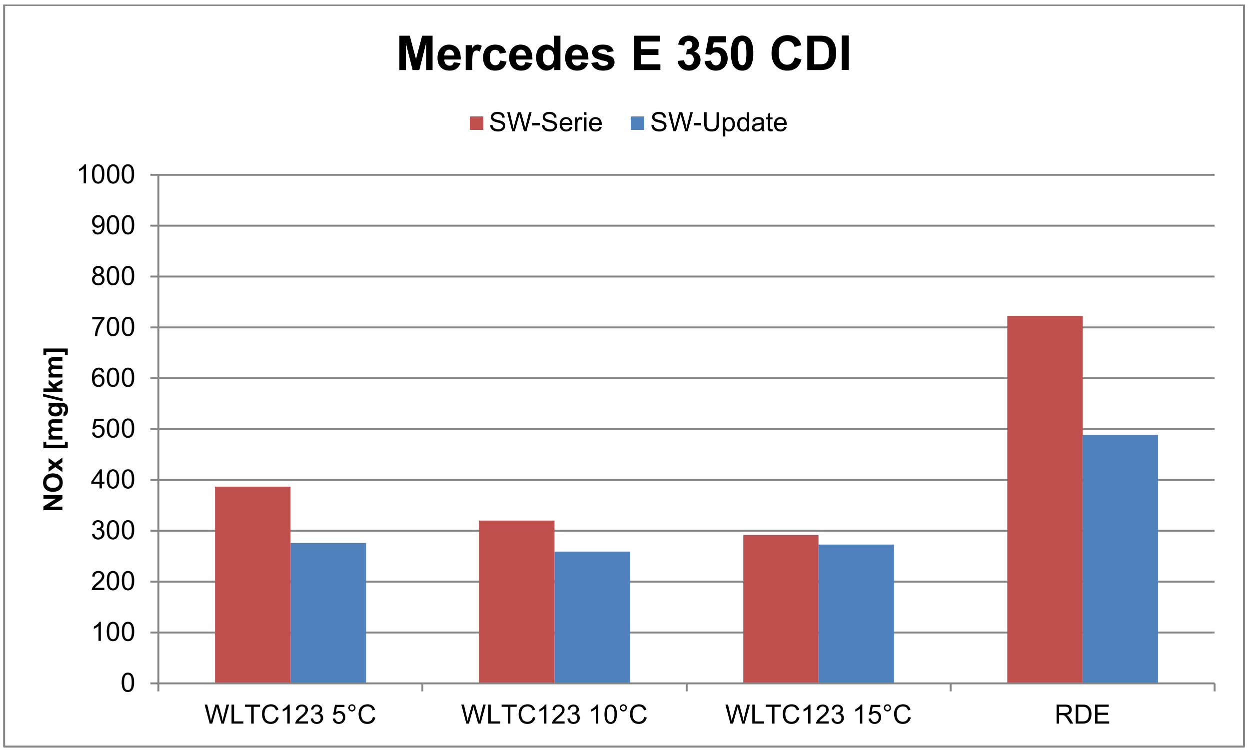

Figure 71: Bar chart NO_X reduction Mercedes E 350 CDI

j. Mercedes GLK 220 CDI 4MATIC (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 19°C with series software and 24°C with update software.

The test vehicle and the results for obtaining the general type approval No 91722 are presented in the following.

The approval numbers e1*2001/116*0480*11 to 15 form part of a mandatory recall.

Figure 72: Test vehicle Mercedes GLK 220 CDI 4Matic

Manufacturer:		Mercedes
Trade name:		GLK 220 CDI 4MATIC
Vehicle category:		M1
Engine capacity (ccm):		2,143
Engine power (kW):		125
Odometer reading (km):		90,225
Approval number:		e1*2001/116*0480*13
Emissions approval number:		e1*715/2007*630/2012J0777*01
Emission standard:		EU5
Type/model/version:		204X / H7S2M1 / NZCEA503
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 73: Vehicle data Mercedes GLK 220 CDI

	Mercedes GLK 220 CDI 4MATIC			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	492	200	292	59
WLTC123 10 °C	370	226	144	39
WLTC123 15 °C	289	264	26	9
RDE measurement	412	339	73	18

Table 74: NO_X reduction Mercedes GLK 220 CDI

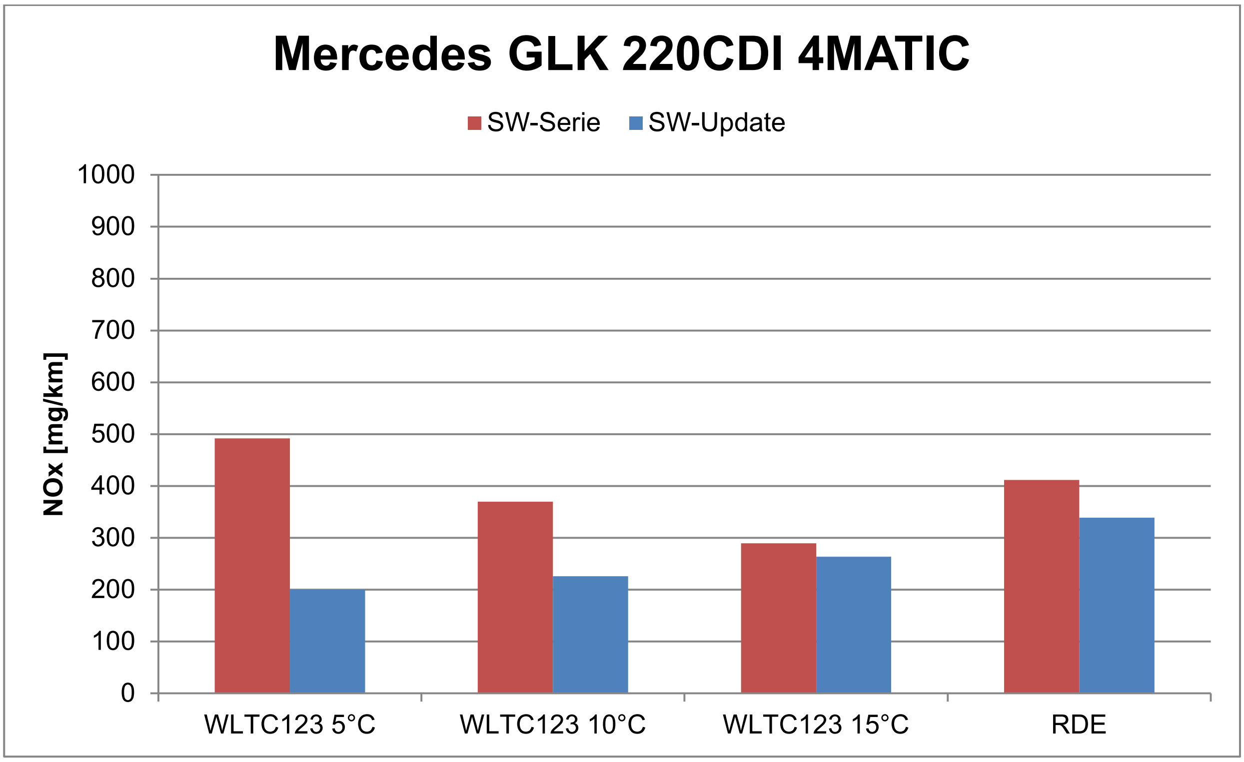

Figure 73: Bar chart NO_X reduction Mercedes GLK 220 CDI

k. Mercedes B 200 d (Euro 6)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 4.8° C with series software and 3.4° C with update software.

The test vehicle and the results for obtaining the general type approval No 91722 are presented in the following.

Figure 74: Test vehicle Mercedes B 200 d

Manufacturer:		Mercedes
Trade name:		B 200 d
Vehicle category:		M1
Engine capacity (ccm):		2,143
Engine power (kW):		100
Odometer reading (km):		17,919
Approval number:		e1*2001/116*0470*18
Emissions approval number:		e1*715/2007*136/2014W*1079*05
Emission standard:		EU6
Type/model/version:		245G / M2S1P2 / MZBA1502
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 75: Vehicle data Mercedes B 200 d

	Mercedes B 200 d			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	192	68	124	65
WLTC123 10 °C	162	80	82	50
WLTC123 15 °C	161	82	80	49
RDE measurement	502	186	316	63

Table 76: NO_X reduction Mercedes B 200 d

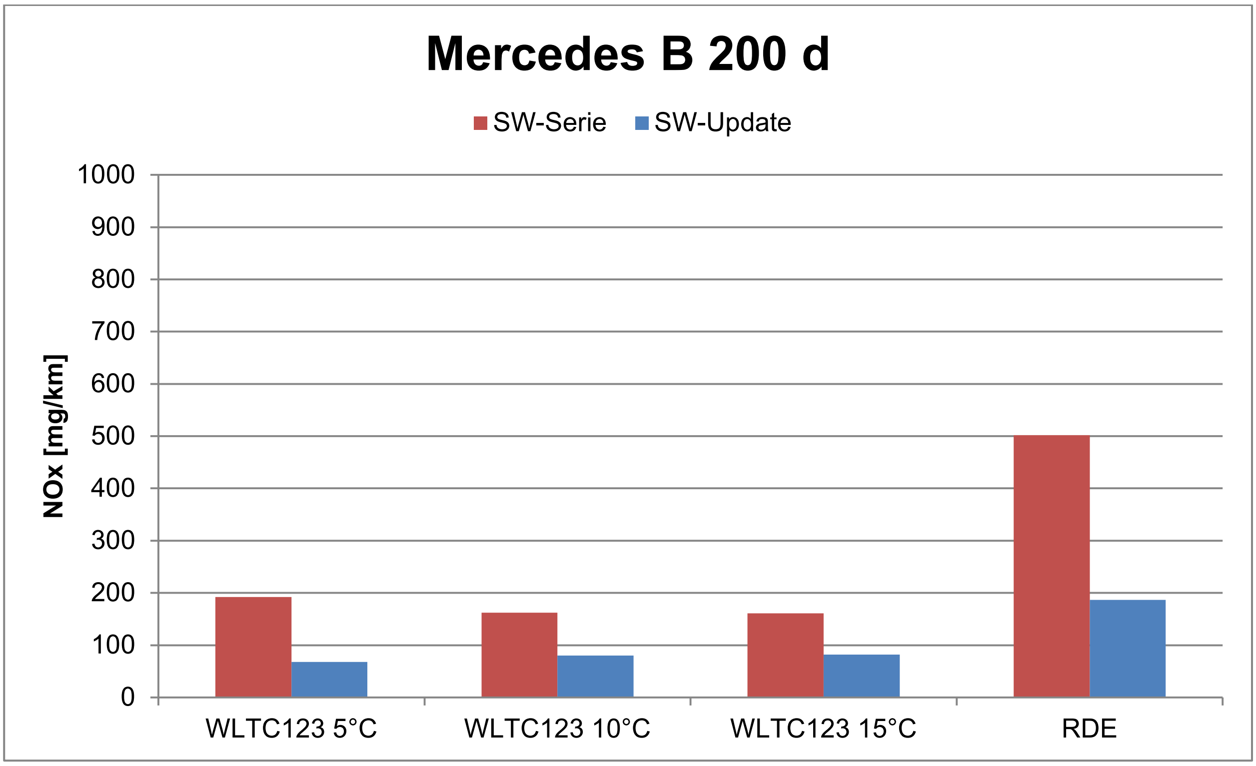

Figure 75: Bar chart NO_X reduction Mercedes B 200 d

I. Mercedes GLE 350 d (Euro 6)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 4.6 °C with series software and 4.5 °C with update software.

The test vehicle and the results for obtaining the general type approval No 91749 are presented in the following.

The approval numbers e1*2007/46*0598*17 to 22 form part of a mandatory recall.

Figure 76: Test vehicle Mercedes GLE 350 d

Manufacturer:		Mercedes
Trade name:		GLE 350 d
Vehicle category:		M1
Engine capacity (ccm):		2,987
Engine power (kW):		190
Odometer reading (km):		11,379
Approval number:		e1*2007/46*0598*22
Emissions approval number:		e1*715/2007*136/2014W*1186*05
Emission standard:		EU6
Type/model/version:		166 / A2BFP1 / CZCAA5F4
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 77: Vehicle data Mercedes GLE 350 d

	Mercedes GLE 350 d			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	29	11	17	61
WLTC123 10 °C	16	13	2	16
WLTC123 15 °C	18	15	3	17
RDE measurement	177	70	108	61

Table 78: NO_X reduction Mercedes GLE 350 d

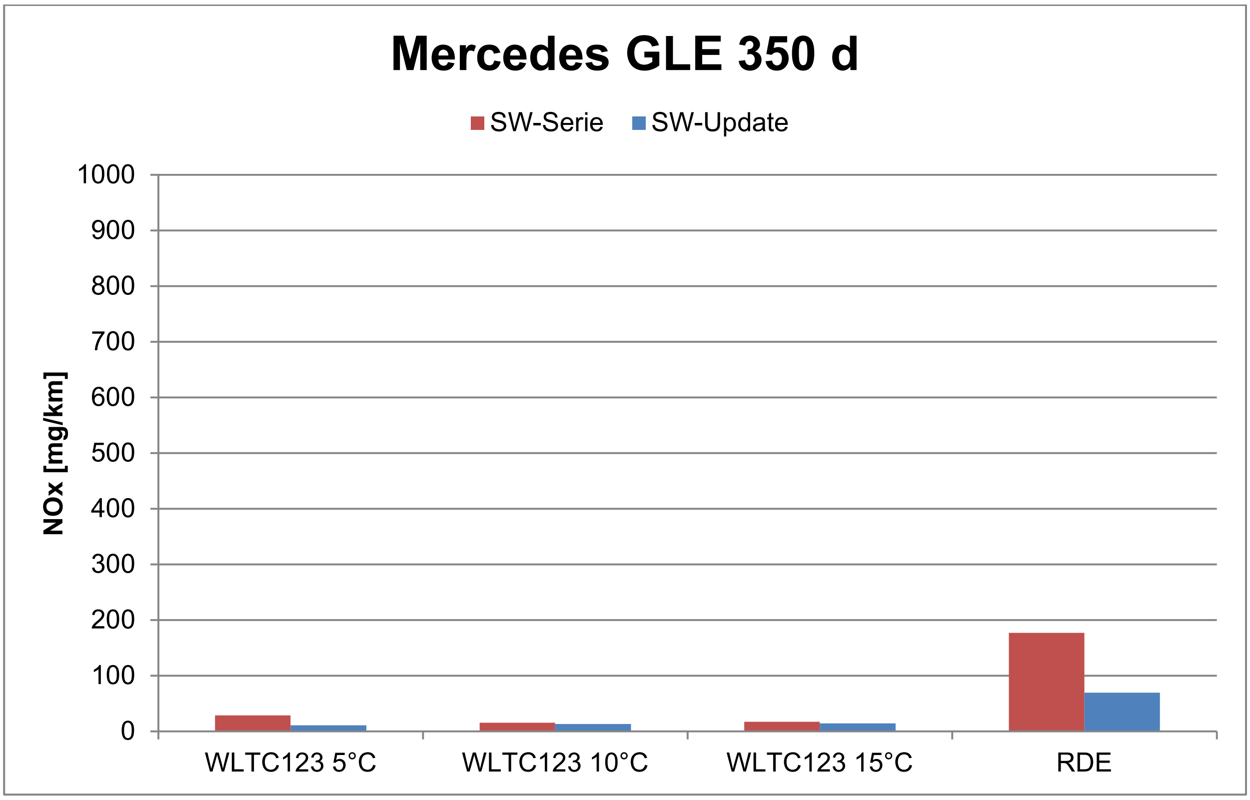

Figure 77: Bar chart NO_X reduction Mercedes GLE 350 d

m. Mercedes C 220 d (Euro 6)

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

The RDE tests were carried out at ambient temperatures of 6 °C with series software and 6 °C with update software.

The test vehicle and the results for obtaining the general type approval No 91743 are presented in the following.

Figure 78: Test vehicle Mercedes C 220 d

Manufacturer:		Mercedes
Trade name:		C 220 d
Vehicle category:		M1
Engine capacity (ccm):		2,143
Engine power (kW):		125
Odometer reading (km):		16,776
Approval number:		e1*2001/116*0457*32
Emissions approval number:		e1*715/2007*136/2014W*1177*08
Emission standard:		EU6
Type/model/version:		204K / R20RP0 / NZAA0521
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	x

Table 79: Vehicle data Mercedes C 220 d

	Mercedes C 220 d			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	133	17	116	87
WLTC123 10 °C	75	17	58	78
WLTC123 15 °C	37	20	17	46
RDE measurement	853	57	796	93

Table 80: NO_X reduction Mercedes C 220 d

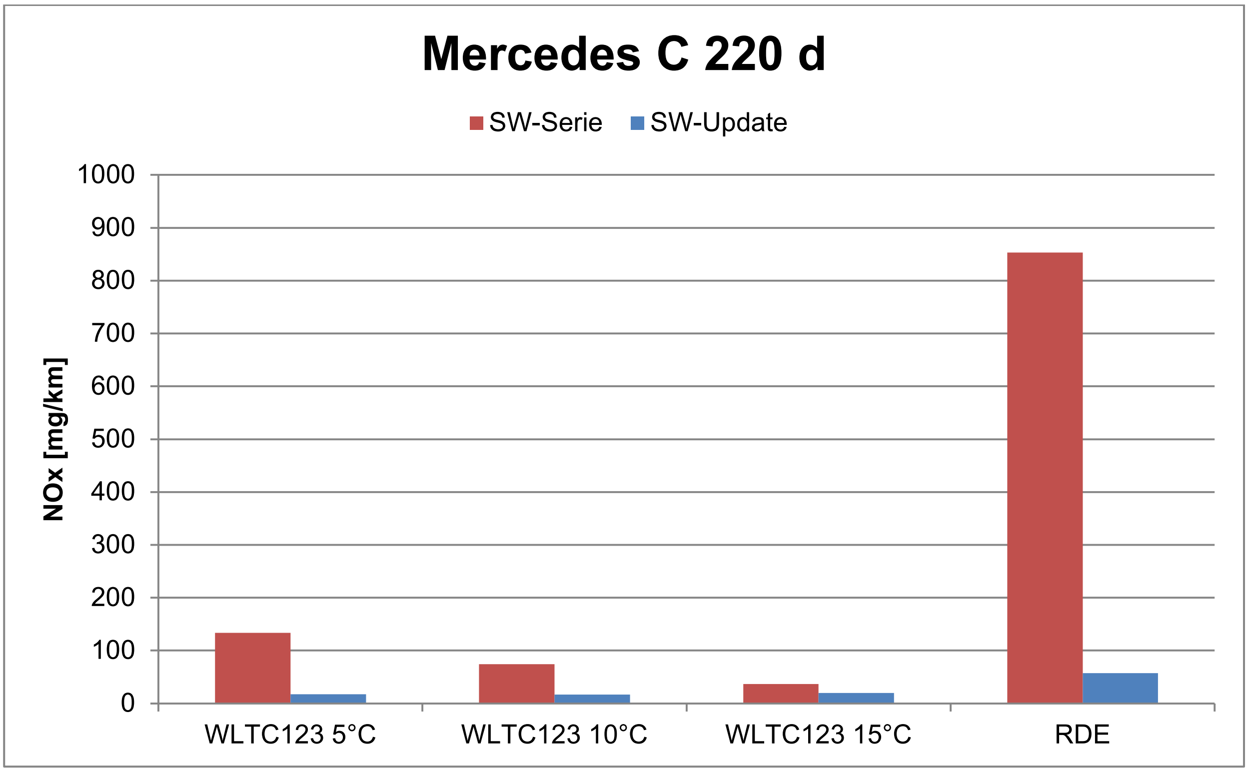

Figure 79: Bar chart NO_X reduction Mercedes C 220 d

n. Mercedes GLC 220 d 4MATIC (Euro 6)

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

The RDE tests were carried out at ambient temperatures of 28° C with series software and 28° C with update software.

The test vehicle and the results for obtaining the general type approval No 91708 are presented in the following.

The approval numbers e1*2001/116*0480*16 to 22 form part of a mandatory recall.

Figure 80: Test vehicle Mercedes GLC 220 d

Manufacturer:		Mercedes
Trade name:		GLC 220 d 4MATIC
Vehicle category:		M1
Engine capacity (ccm):		2,143
Engine power (kW):		125
Odometer reading (km):		13,482
Approval number:		e1*2001/116*0480*21
Emissions approval number:		e1*715/2007*136/2014W*1177*10
Emission standard:		EU6
Type/model/version:		204 X / R70RP1 / CZAA0501
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	x

Table 81: Vehicle data Mercedes GLC 220 d

	Mercedes GLC 220 d 4MATIC			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	282	56	227	80
WLTC123 10 °C	137	51	86	63
WLTC123 15 °C	98	47	52	53
RDE measurement	144	95	49	34

Table 82: NO_X reduction Mercedes GLC 220 d 4MATIC

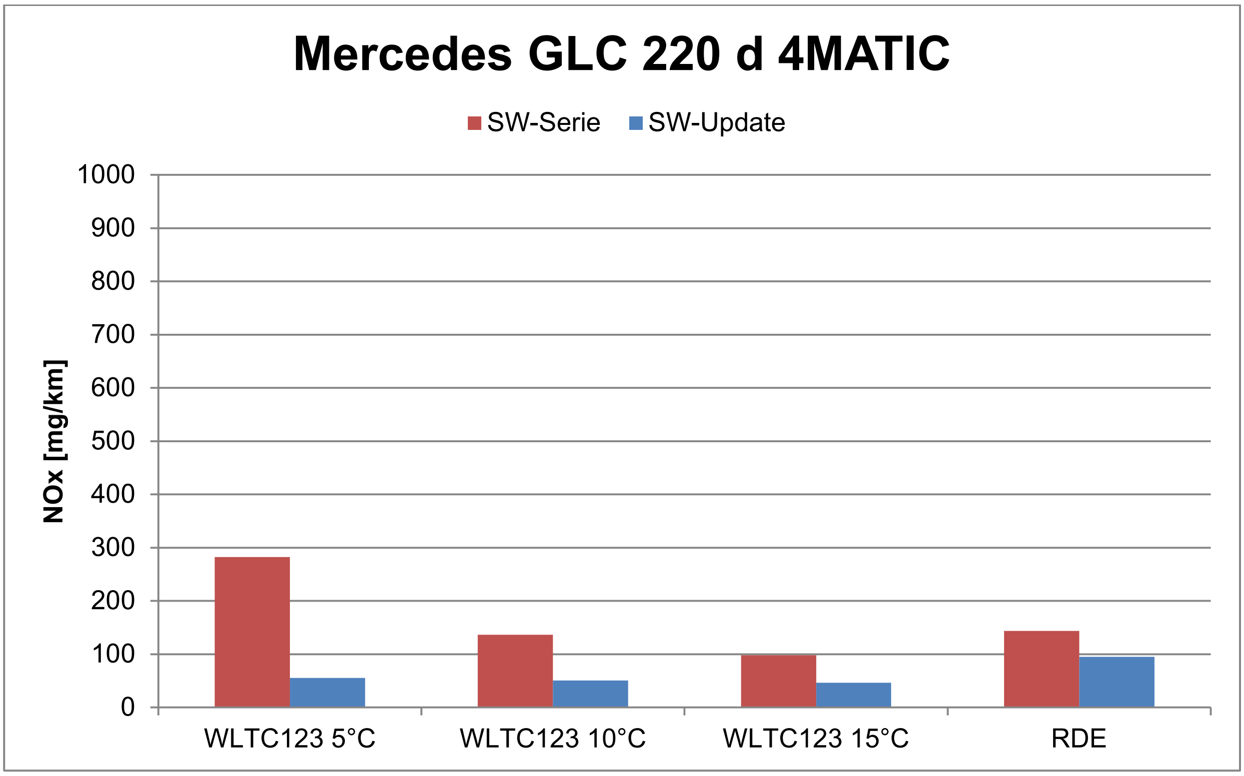

Figure 81: Bar chart NO_X reduction Mercedes GLC 220 d 4MATIC

o. Mitsubishi Outlander 2.2l Di-D (Euro 6)

The RDE tests were carried out at ambient temperatures of 10.0° C with series software and 8.7°C with update software.

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures, as well as the operational range of the NSC.

Figure 82: Test vehicle Mitsubishi Outlander 2.2l Di-D

Manufacturer:		Mitsubishi
Trade name:		Outlander 2.2 Di-D
Vehicle category:		M1
Engine capacity (ccm):		2,268
Engine power (kW):		110
Odometer reading (km):		4,372
Approval number:		e1*2001/116*0406*28
Emissions approval number:		e1*715/2007*136/2014W*1303
Emission standard:		EU6
Type/model/version:		CW0 / GF621 / ALCGC6A7AAAA
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	x
	Particulate trap	x
	SCR cat	

Table 83: Vehicle data Mitsubishi Outlander 2.2 Di-D

	Mitsubishi Outlander 2.2l Di-D			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	459	209	249	54

Table 84: NO_X reduction Mitsubishi Outlander 2.2 Di-D

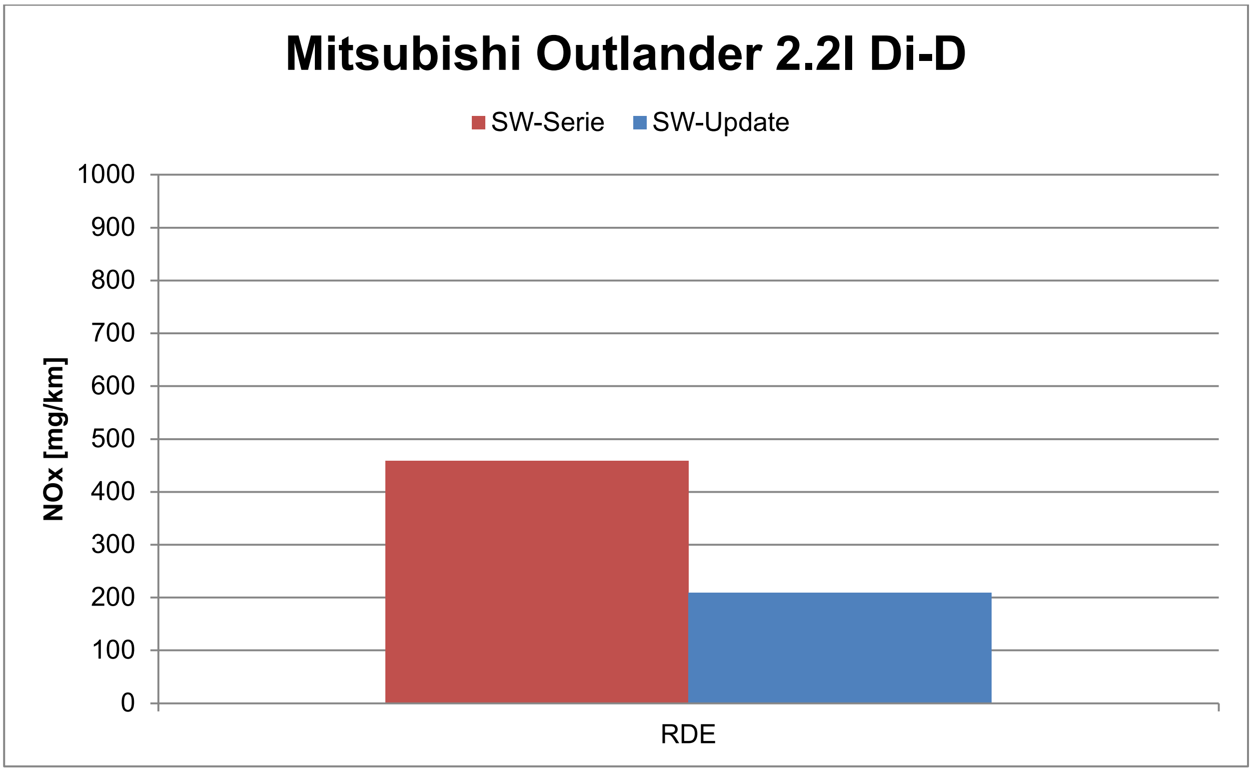

Figure 83: Bar chart NO_X reduction Mitsubishi Outlander 2.2 Di-D

p. Opel Corsa 1.3 CDTi (Euro 6)

The RDE tests were carried out at ambient temperatures of 13.1° C with series software and 6.7° C with update software.

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures, as well as the operational range of the NSC.

Figure 84: Test vehicle Opel Corsa 1.3l CDTi

Manufacturer:		Opel
Trade name:		Corsa 1.3l CDTi
Vehicle category:		M1
Engine capacity (ccm):		1,248
Engine power (kW):		70
Odometer reading (km):		19,127
Approval number:		e1*2001/116*0379*36
Emissions approval number:		e1*715/2007*136/2014W*1125*05
Emission standard:		EU6
Type/model/version:		S-D / CACE12 / BX2F5EEHJ5
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	x
	Particulate trap	x
	SCR cat	

Table 85: Vehicle data Opel Corsa 1.3 CDTi

	Opel Corsa 1.3l CDTi			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measurement	515	243	272	53

Table 86: NO_X reduction Opel Corsa 1.3 CDTi

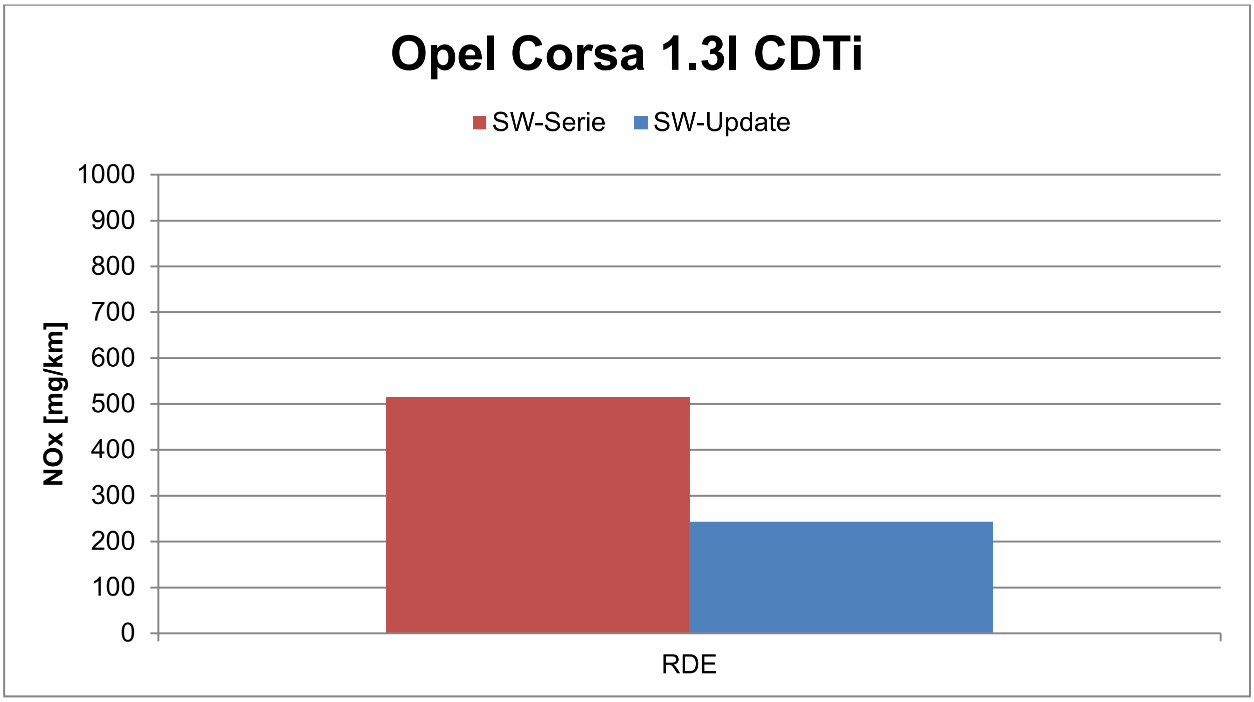

Figure 85: Bar chart NO_X reduction Opel Corsa 1.3 CDTi

q. Opel Insignia 1.6 CDTi (Euro 6)

The RDE tests were carried out at ambient temperatures of 22.0° C with series software and 20.7 °C with update software.

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures, as well as the operational range of the NSC.

Figure 86: Test vehicle Opel Insignia 1.6 CDTI

Manufacturer:		Opel
Trade name:		Insignia 1.6 CDTi
Vehicle category:		M1
Engine capacity (ccm):		1,598
Engine power (kW):		100
Odometer reading (km):		30,217
Approval number:		e1*2007/46*0374*18
Emissions approval number:		e1*715/2007*136/2014W*1228*01
Emission standard:		EU6
Type/model/version:		0G-A / DAEGA12 / BA1N4AJ8J5
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	x
	Particulate trap	x
	SCR cat	

Table 87: Vehicle data Opel Insignia 1.6 CDTI

	Opel Insignia 1.6 CDTi			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	521	225	297	57

Table 88: NO_X reduction Opel Insignia 1.6 CDTi

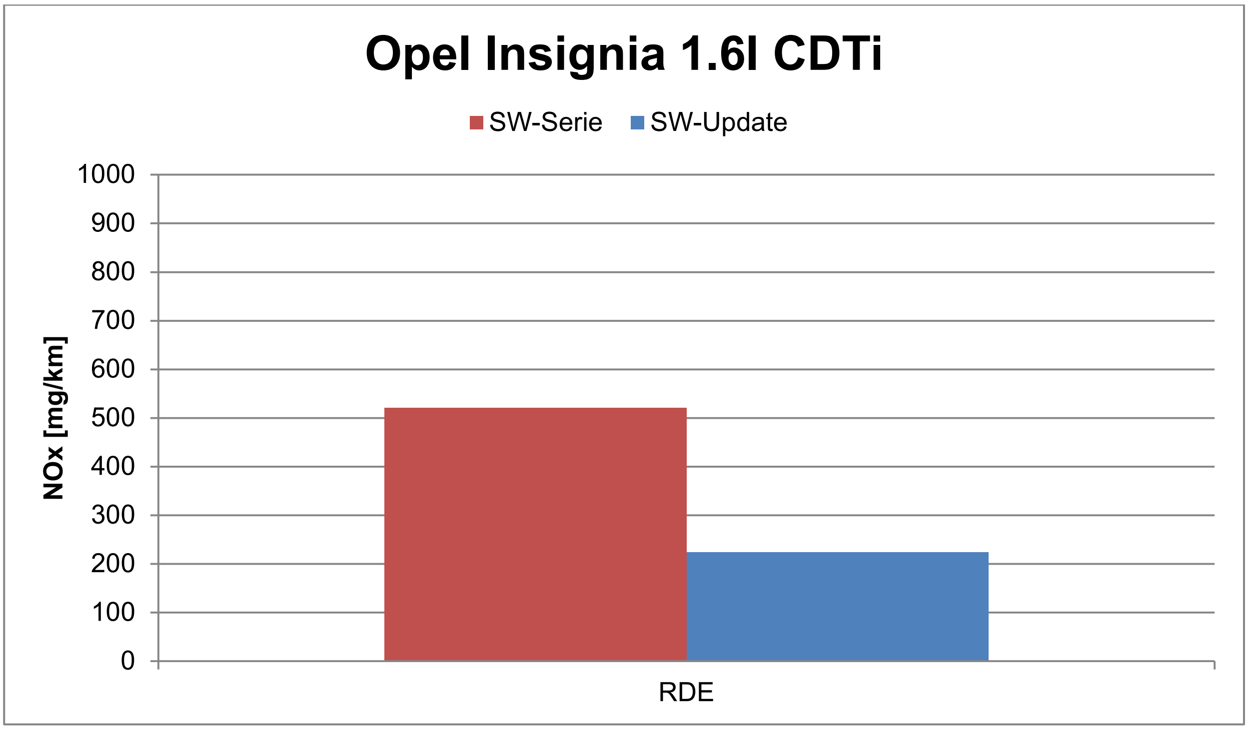

Figure 87: Bar chart NO_X reduction Opel Insignia 1.6 CDTi

r. Subaru Outback 2.0 D (Euro 6)

The RDE tests were carried out at ambient temperatures of 4.7°C with series software and 6.3°C with update software.

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

Figure 88: Test vehicle Subaru Outback 2.0l

Manufacturer:		Subaru
Trade name:		Outback 2.0 D
Vehicle category:		M1
Engine capacity (ccm):		1,998
Engine power (kW):		110
Odometer reading (km):		98,375
Approval number:		e1*2007/46*1320*00
Emissions approval number:		e13*715/2007*136/2014W*6604
Emission standard:		EU6
Type/model/version:		B6 / BSD / C8L
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	
	Particulate trap	x
	SCR cat	

Table 89: Vehicle data Subaru Outback 2.0 D

	Subaru Outback 2.0 D			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
RDE measure-ment	2,261	498	1,763	78

Table 90: NO_X reduction Subaru Outback 2.0 D

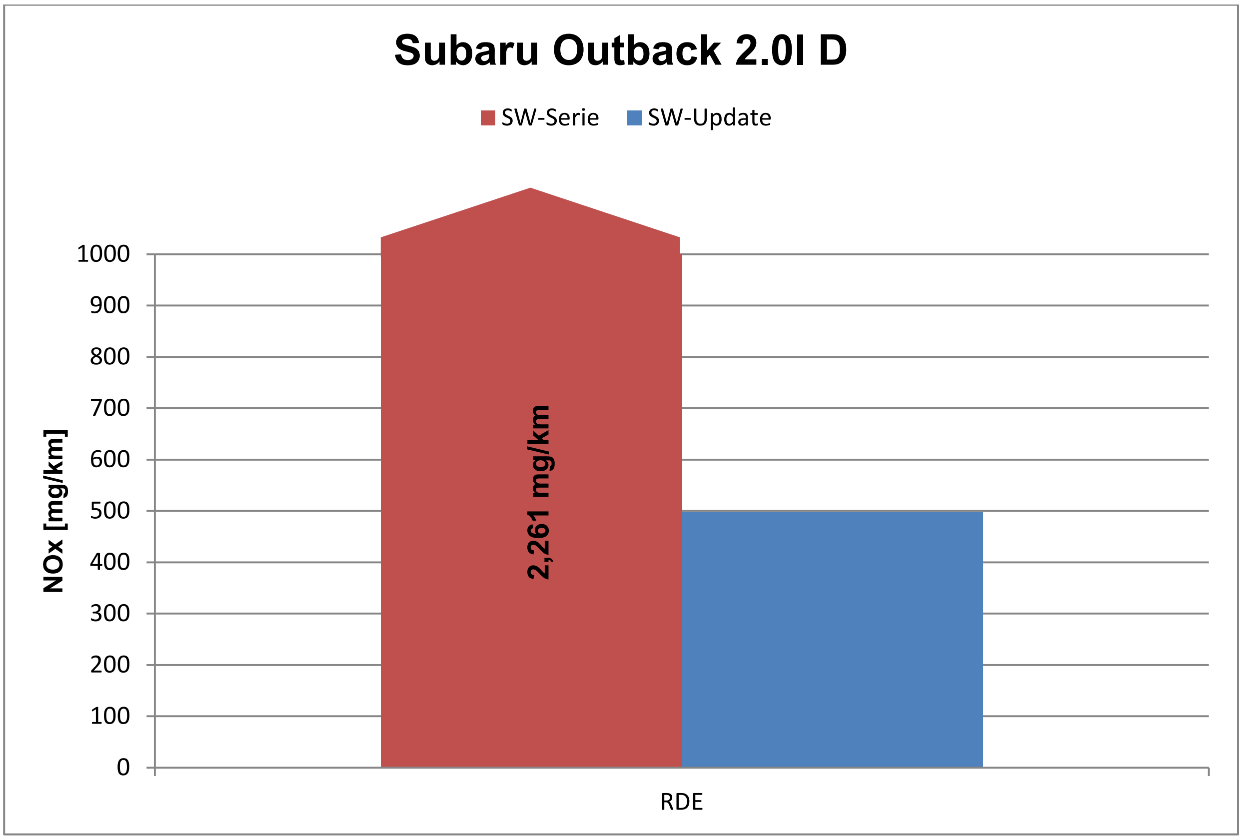

Figure 89: Bar chart NO_X reduction Subaru Outback 2.0 D

s. VW Crafter/Amarok 2.0l TDI (Euro 5)

Table 92 below shows the test results of the 2.0l VW Crafter/Amarok. The vehicles are exclusively equipped with a high-pressure EGR.

Figure 90: Test vehicle VW Amarok 2.0l TDI

	Vehicle 1	Vehicle 2	Vehicle 3
Manufacturer	VW	VW	VW
Trade name	Amarok 2.0l TDI	Amarok 2.0l TDI	Crafter 2.0l TDI
Type approval	e1*2007/46*356*11	e1*2007/46*0750*08	e1*2007/46*0514*10
Type / model / version	2H /	2H /	2EKE2 /
Odometer reading **[km]**	8,107	12,397	3,802
Emission standard	Euro 5	Euro 5	Euro 5
Engine capacity [ccm]	1,968	1,968	1,968
Engine power [kW]	132	103	100

Table 91: Vehicle data VW Crafter/Amarok 2.0l TDI

For the verification of the VW Crafter/Amarok 2.0l TDI, the measurements were performed according to the NEDC driving profile. In order to show the potential for improvement at low temperatures, the temperature of the test chamber was gradually reduced. The measurement results can be seen from Table 92.

Vehicle	Cycle	NO_X SSW [mg/km]	NO_X USW [mg/km]	Reduction absolute [mg/km]	Reduction relative [%]
1	NEDC cold	212	198	14	7
2		174	192	-18	-10
3		201	164	37	18
1	NEDC warm	297	289	8	3
2		197	208	-11	-6
3		214	222	-8	-4
1	NEDC back	273	240	33	12
2		212	180	32	15
3		189	187	2	1
1	NEDC + 10 %	471	449	22	5
2		293	262	31	11
3		415	371	44	11
1	NEDC 15°C	598	286	312	52
2		298	244	54	18
3		693	275	418	60
1	NEDC 10 C	2130	604	1526	72
2		1032	472	560	54
3		1425	515	910	64
1	NEDC 5 C	2195	919	1276	58
2		1455	682	773	53
3		1514	589	925	61

Table 92: Overview of the tests VW Crafter/Amarok 2.0 l TDI NO_X reduction

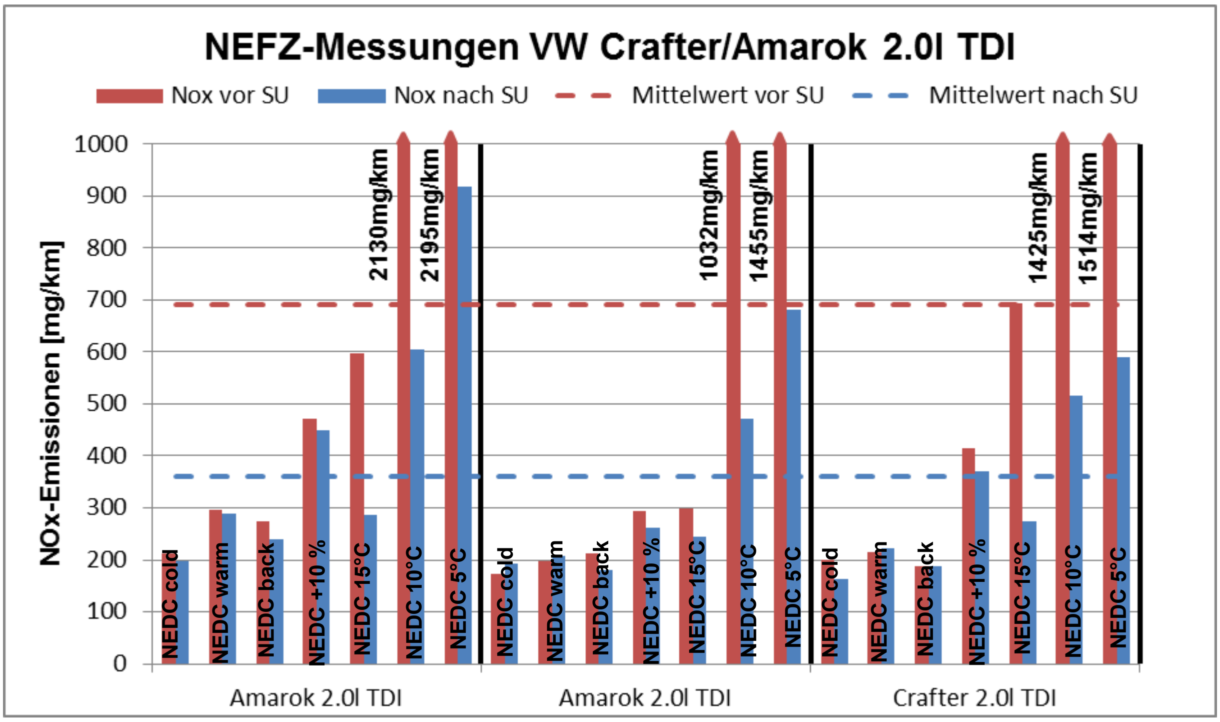

Figure 91: Bar chart VW Crafter/Amarok 2.0l TDI NO_X reduction

t. VW T6 2.0 TDI (Euro 6)

In order to optimize the NO_X emissions, the NO_X conversion rate of the SCR is raised. As a result, the dosage of DEF is increased. The interaction between the optimized EGR and SCR strategies leads to the improvement of the exhaust after treatment.

The RDE tests were carried out at ambient temperatures of -1.4°C with series software and 8.5°C with update software.

The test vehicle and the results for obtaining the general type approval No 91775 are presented in the following.

Figure 92: Test vehicle VW T6 2.0l TDI

Manufacturer:		VW
Trade name:		T6 2.0 TDI Transporter
Vehicle category:		M1
Engine capacity (ccm):		1,968
Engine power (kW):		75
Odometer reading (km):		32,048
Approval number:		e1*2007/46*0130*21
Emissions approval number:		e1*715/2007*136/2014Y*1307*01
Emission standard:		EU6
Type/model/version:		7J0 / GCXGB280X0 / LNFM52Z1116NVR217MMG3SL6323
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	x

Table 93: Vehicle data VW T6 2.0 TDI

	VW T6 2.0 TDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	226	170	56	25
WLTC123 10 °C	213	136	77	36
WLTC123 15 °C	150	131	19	13
RDE at the KBA	181	144	37	21

Table 94: NO_X reduction VW T6 2.0 TDI

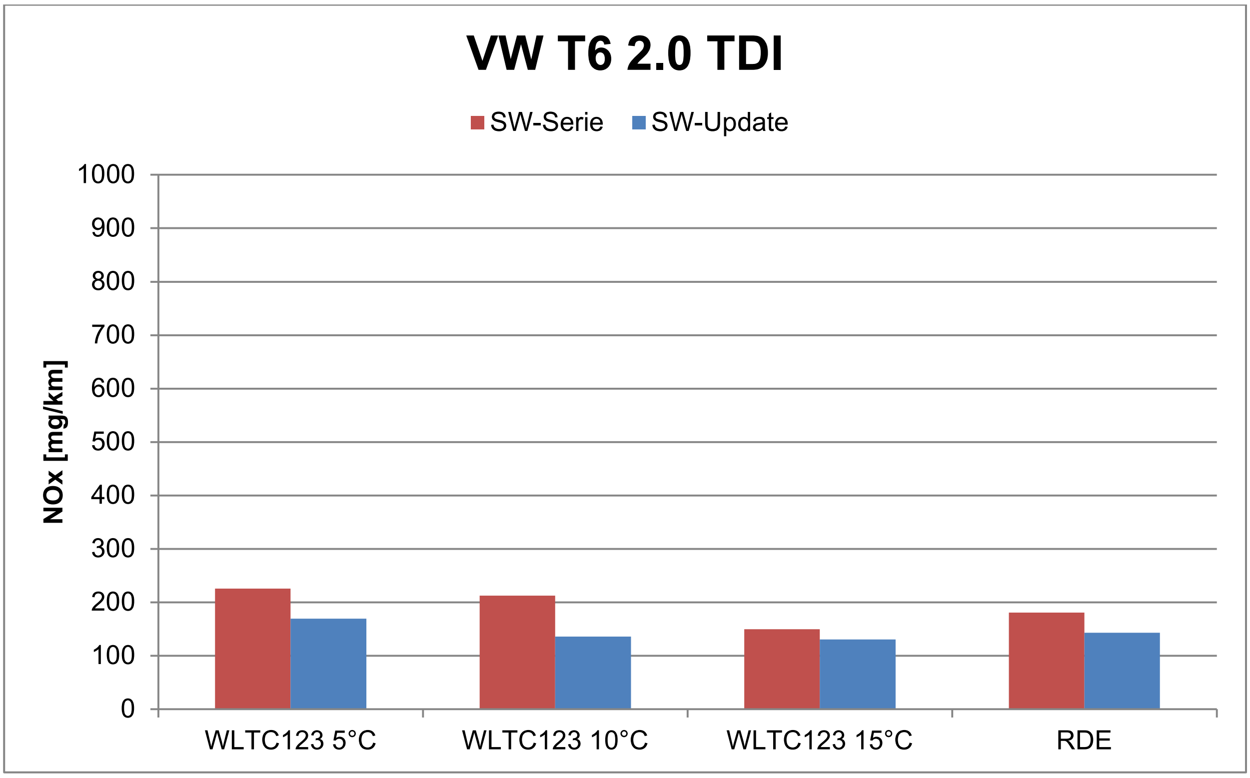

Figure 93: Bar chart NO_X reduction VW T6 2.0 TDI

u. VW Touareg 3.0l TDI (Euro 5)

In order to optimize the NO_X emissions, the EGR range is extended, especially at low ambient air temperatures.

The RDE tests were carried out at ambient temperatures of 4.3°C with series software and 7.6°C with update software.

The test vehicle and the results for obtaining the general type approval No 91761 are presented in the following.

Figure 94: Test vehicle VW Touareg 3.0 TDI

Manufacturer:		Volkswagen
Trade name:		Touareg 3.0 V6 TDI BM Technology
Vehicle category:		M1
Engine capacity (ccm):		2,967
Engine power (kW):		180
Odometer reading (km):		88,190
Approval number:		e1*2007/46*0376*09
Emissions approval number:		e1*715/2007*630/2012J*0798*00
Emission standard:		EU5
Type/model/version:		7P / ACCRCAX1 / AA8AA8C8022NVR67MJ0
Existing exhaust after treatment systems	Oxy cat	x
	EGR	x
	NSC	-
	Particulate trap	x
	SCR cat	-

Table 95: Vehicle data VW Touareg 3.0 TDI

	VW Touareg 3.0 TDI			
	NO_X [mg/km]		Reduction	
	Software series	Software update	Absolute [mg/km]	Relative [%]
WLTC123 5 °C	1,450	256	1,194	82
WLTC123 10 °C	1,066	260	806	76
WLTC123 15 °C	1,103	243	860	78
RDE at the KBA	3,029	435	2,594	86

Table 96: NO_X reduction VW Touareg 3.0 TDI

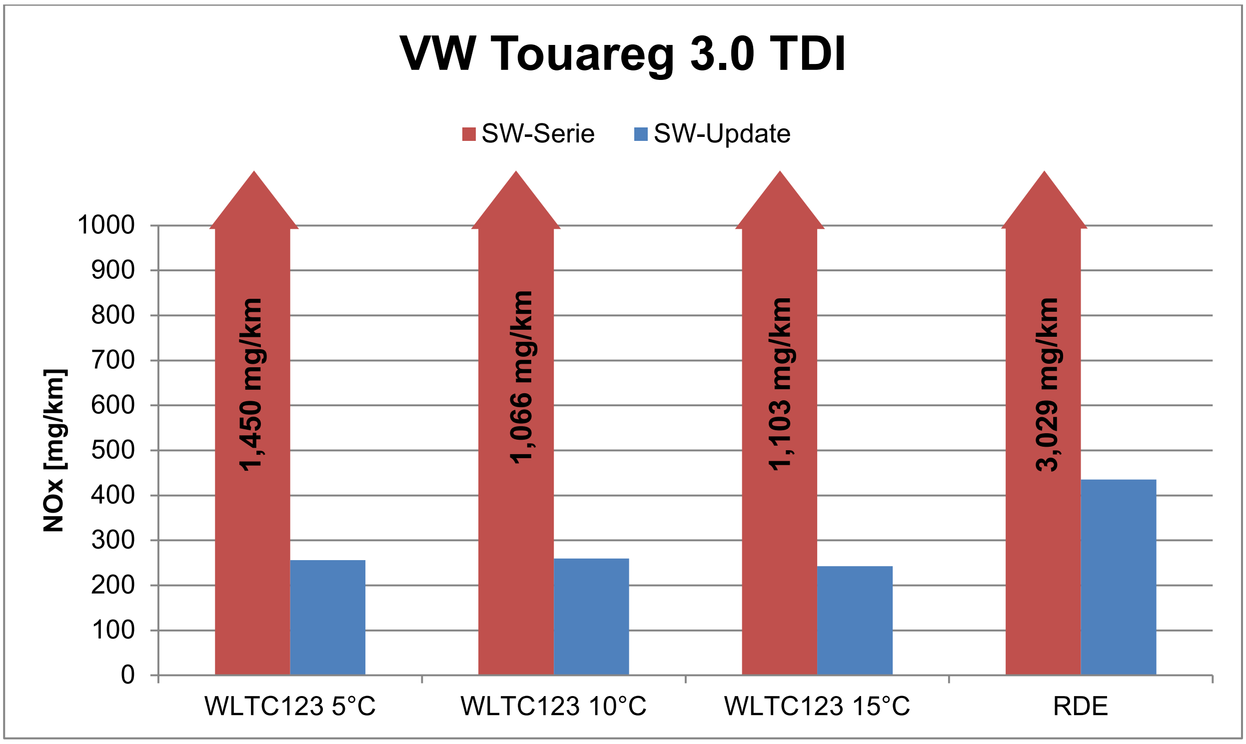

Figure 95: Bar chart NO_X reduction VW Touareg 3.0 TDI

III. Evaluation and analysis

1. General evaluation

This chapter presents the results of the measurements carried out on the vehicles. Given the high number of measurements conducted, not every individual measurement is evaluated. On the basis of selected vehicle models, the behaviour detected with regard to the NO_X reduction by the implementation of software updates is shown.

a. Possible corrections of the EGR

By means of additional examples, the relevant EGR corrections are to be illustrated. In principle, there is a basic map which determines the EGR rate, depending on speed and load. Correction factors and correction characteristics have to be added which usually reduce the EGR rate.

With reference to the correction of the EGR which depends on the ambient air, mainly vehicles which were tested in the context of voluntary service measures can be considered because of the measuring programme performed. The relevant WLTC123 measurements show the impact of the ambient air temperature (15°C, 10°C, 5°C) in a cycle representing urban and rural traffic. The extension of the uncorrected range varies for the different engine concepts in consideration of the existing potential.

An example of an especially strong reduction of NO_X emissions is the Audi A6 3.0l EU5 with 180 kW. In the WLTC123 and RDE measurements, the emission of NO_X consistently decreased by more than 75%, which means a reduction of up to 1240 mg/km in absolute figures during the RDE on-road test. This behaviour was confirmed by the software analysis. The manufacturer succeeded in obtaining this significant improvement due to a considerable gain in experience.

The measurement results of the BMW 320d make it evident that there is no reduction potential for this vehicle in the temperature range of 15°C. As from the WLTC123 measurement at 10°C, an improvement is discernible with regard to the original database which becomes more distinct for the measurement at 5°C.

In the case of these two vehicle models the RDE measurements deviate in some cases clearly from the results of the WLTC123 measurements. It has to be noted here that an RDE measurement also includes a motorway share (higher speed, higher load). WLTC123 measurements are, however, designed to evaluate the emissions of urban and rural traffic. Mainly on the motorway share with higher loads, there also occur load-dependent corrections for reasons of engine protection, apart from EGR corrections through ambient air temperature. Moreover, there are also EGR corrections at high engine speeds.

b. Exhaust after treatment by NSC / SCR

Besides the NO_X reduction by EGR, the exhaust after treatment by means of NSC and SCR is decisive for the proper functioning of the emission reduction systems of EU6 vehicles. In the case of operational exhaust after treatment systems, the recirculation rate of the EGR can be adapted, thus keeping the overall emissions on a low level.

The arrangement of the SCR catalysts can vary according to the space available and the age of the vehicle design. In the case of the Audi A6 EU6 240 kW, the SCR catalytic converter is installed relatively near to the engine which leads to a more rapid activation of the catalytic reaction due to the more rapid heating-up. For this vehicle, the update performed includes adaptations when changing the operation modes as well as a quicker operational readiness of the SCR catalytic converter. Furthermore, the function of the reduced DEF dosage in the case of a low DEF fill level has been deactivated.

When considering the so-called tailpipe emissions (exhaust gas at the exhaust pipe), the VW T6 2.0l TDI can serve as a good example. This vehicle shows an interaction between the EGR and a SCR catalytic converter. The SCR catalytic converter which is installed away from the engine can in certain low-load driving situations, due to the structural arrangement, store less heat than would be required for the chemical reaction of ammonia and NO_X. In such situations the SCR catalyst converts less, which can, however, in this approach be compensated by the EGR. This system design makes it possible for the vehicle, within the context of the RDE measurement, to already achieve NO_X emissions (143.5 mg/km) even at low temperatures, i.e. are below the limit of pollutant category EU6 d-TEMP (168 mg/km).

Fiat 500X EU6 is a vehicle equipped with a NSC which has an original standard dataset which induces a de-activation of the NSC regeneration after a period of about 4,000s. This irregularity has been eliminated with the updated dataset which now ensures a permanent periodic regeneration of the NSC. In more recent software versions, an improvement has been achieved in this respect which enables a more frequent NSC regeneration.

c. Identified potential for improvement

The fundamental potential for improvement includes especially extensions of the EGR operating ranges, the improvement of the purge behaviour of vehicles with NSC as well as a demand-responsive SCR dosing. If an exhaust after treatment (NSC / SCR) is used, a quicker operational readiness can be ensured by the relevant warming-up/conditioning.

Audi A6 3.0 TDI EU5 180 kW is a vehicle model which experiences a very significant improvement of the NO_X emissions by the software update. The potential for improvement as compared with the standard dataset has proven to be very high (>75%) for this vehicle. In the case of this pure EGR approach this is attributable to the fact that the original dataset provided for an uncorrected EGR only in a range of 18°C - 34°C. This range was considerably increased with the update towards the low ambient temperatures of up to 2°C. The manufacturers were able to extend the original layout of the EGR maps due to their gain in experience on the basis of modern engine concepts.

For the Mercedes C 220 d EU6, a significant potential for improvement has been exploited during the RDE measurements, especially as regards low temperatures. RDE comparative measurements at outside temperatures of around 6°C showed a significant improvement of the NO_X emissions (>90 %). This vehicle even falls short of 80 mg/km during the RDE tests with the update.

Here, it should be noted that there is no legal requirement for the software update to fall below the NO_X emission value of 80 mg/km (180 mg/km EU5) for RDE runs. It is only since the introduction of the RDE requirements for pollutant emission category Euro6 d-TEMP and Euro6 d that passenger cars have to comply with a limit value in on-road tests.

Mercedes GLK 220 CDI shows only a slight improvement (approx. 18%) during the RDE runs with the series dataset as well as with the update dataset. The reason for this is that the outside temperature is taken into account during the measurements (19°C as well as 24°C). In this temperature range, the impact of the update software is in this case only low (see also WLTC123 at 15°C). The improvements only became apparent at ambient temperatures < 10°C.

2. Overview of the measurement results

a. Presentation in tabular form

Manufac-turer	Type	Stand-ard	Cycle	Ambient-temperature [°C]	NO_x (SW series) [mg/km]	NO_x (SW update) [mg/km]	Improve-ment absolute [mg/km]	Im-prove ment rela-tive [%]
Voluntary software update								
Audi	**A6 3.0l TDI**	EU5	WLTC123	5 °C	1013	204	809	80
	180 kW		WLTC123	10 °C	819	184	635	78
	4G		WLTC123	15 °C	675	167	509	75
			RDE	Series = 14.4 °C; Update = 14.5 °C	1,649	408	1,241	75
BMW	**320d**	EU5	WLTC123	5 °C	602	419	183	31
	135 kW		WLTC123	10 °C	468	333	136	29
	3K		WLTC123	15 °C	338	340	-2	-1
			RDE	Series = 21.9 °C; Update = 22.8 °C	526	451	75	14
BMW	**520d**	EU5	WLTC123	5 °C	722	280	442	61
	135 kW		WLTC123	10 °C	326	320	6	2
	5K		WLTC123	15 °C	241	261	-21	-9
			RDE	Series = 19°C; Update = 26°C	342	306	37	11
Fiat	**500X 2.0**	EU6	RDE	Series = 11.2°C Update = 13.3°C	1,358	394	964	71
	103 kW							
	334							
Mazda	**6 2.2l SkyActive**	EU6	RDE	Series = 2°C Update = 4°C	275	257	18	7
	129 kW							
	GH							
Mercedes	**A 180d**	EU6	NEDC	23	35	34	1	3
	80 kW		NEDC warm	23	158	89	69	44
	245 G		NEDC back	23	83	35	48	58
			NEDC +10 %	23	97	88	9	9
			NEDC 15°C	15	112	119	-7	-6
			NEDC 10°C	10	148	80	68	46
			NEDC 5°C	5	379	85	294	78
Mercedes	**GLA 180d**	EU6	NEDC	23	56	57	-1	-2
	80 kW		NEDC warm	23	176	160	16	9
	245 G		NEDC back	23	108	108	0	0
			NEDC +10 %	23	147	148	-1	-1
			NEDC 15°C	15	200	177	23	12
			NEDC 10°C	10	311	186	125	40
			NEDC 5°C	5	411	105	306	74
Mercedes	**B 160d**	EU6	NEDC	23	79	46	33	42
	66 kW		NEDC warm	23	223	129	94	42
	245 G		NEDC back	23	99	60	39	39
			NEDC +10 %	23	149	106	43	29
			NEDC 15°C	15	169	140	29	17
			NEDC 10°C	10	206	151	55	27
			NEDC 5°C	5	412	124	288	70
Mercedes	**B 180 CDI**	EU5	WLTC123	5 °C	334	235	99	30
	80 kW		WLTC123	10 °C	384	263	121	32
	246		WLTC123	15 °C	342	249	93	27
			RDE	Series = 15°C; Update = 18°C	441	341	100	23
Mercedes	**C 220 CDI**	EU5	WLTC123	5 °C	287	149	139	48
	125 kW		WLTC123	10 °C	331	250	80	24
	204 K		WLTC123	15 °C	291	218	73	25
			RDE	Series = 19°C; Update = 24°C	503	311	192	38
Mercedes	**E 350 CDI**	EU5	WLTC123	5 °C	387	276	111	29
	170 kW		WLTC123	10 °C	320	259	61	19

Manufac-turer	Type	Stand-ard	Cycle	Ambient-temperature [°C]	NO_x (SW series) [mg/km]	NO_x (SW update) [mg/km]	Improve-ment absolute [mg/km]	Im-prove ment rela-tive [%]
Voluntary software update								
	212K		WLTC123	15 °C	292	273	19	6
			RDE	Series=7.9°C; update=11.3°C	723	489	234	32
Mercedes	**B 200d**	EU6	WLTC123	5 °C	192	68	124	65
	100 kW		WLTC123	10 °C	162	80	82	50
	245G		WLTC123	15 °C	161	82	80	49
			RDE	Series=4.8°C; update=3.4°C	502	186	316	63
Mercedes	**GLK 220 CDI**	EU5	WLTC123	5 °C	492	200	292	59
	125 kW		WLTC123	10 °C	370	226	144	39
	204X		WLTC123	15 °C	289	264	26	9
			RDE	Series=19°C; update=24°C	412	339	73	18
Mercedes	**GLC 220 d**	EU6	WLTC123	5 °C	282	56	227	80
	125 kW		WLTC123	10 °C	137	51	86	63
	204X		WLTC123	15 °C	98	47	52	53
			RDE	Series=28°C; update=28°C	144	95	49	34
Mercedes	**C 220 d**	EU6	WLTC123	5 °C	133	17	116	87
	125 kW		WLTC123	10 °C	75	17	58	78
	204K		WLTC123	15 °C	37	20	17	46
			RDE	Series=6°C; update=6°C	853	57	796	93
Mercedes	**GLE 350 d**	EU6	WLTC123	5 °C	29	11	17	61
	190 kW		WLTC123	10 °C	16	13	2	16
	166		WLTC123	15 °C	18	15	3	17
			RDE	Series=4.6°C; update=4.5°C	177	70	108	61
Mitsubishi	**Outlander 2.2l AT**	EU6	RDE	Series=10.0°C; update=8.7°C	459	209	249	54
	110 kW							
	CW0							
Opel	**Corsa**	EU6	RDE	Series=-13.1 °C; update=6.7 °C	515	243	272	5 3
	70 kW							
	S-D							
Opel	**Insignia**	EU6	RDE	Series=-22°C; update=20.7°C	521	225	297	5 7
	100 kW							
	0G-A							
Subaru	**Outback**	EU6	RDE	Series=-4.7°C; update=6.3°C	2,2 61	498	1,763	7 8
	110 kW							
	B6							
VW	**Amarok 2.0l TDI**	EU5	NEDC	23	212	198	14	7
	132 kW		NEDC warm	23	297	289	8	3
	2H		NEDC back	23	273	240	33	12
			NEDC +10 %	23	471	449	22	5
			NEDC 15°C	15	598	286	312	52
			NEDC 10°C	10	2130	604	1526	72
			NEDC 5°C	5	2195	919	1276	58
VW	**Amarok 2.0l TDI**	EU5	NEDC	23	174	192	-18	-10
	103 kW		NEDC warm	23	197	208	-11	-6
	2H		NEDC back	23	212	180	32	15
			NEDC +10 %	23	293	262	31	11
			NEDC 15°C	15	298	244	54	18
			NEDC 10°C	10	1032	472	560	54
			NEDC 5°C	5	1455	682	773	53
VW	**Crafter 2.0l TDI**	EU5	NEDC	23	201	164	37	18

Manufac-turer	Type	Stand-ard	Cycle	Ambient-temperature [°C]	NO_x (SW series) [mg/km]	NO_x (SW update) [mg/km]	Improve-ment absolute [mg/km]	Im-prove ment rela-tive [%]
				Voluntary software update				
	100 kW		NEDC warm	23	214	222	-8	-4
	2EKE2		NEDC back	23	189	187	2	1
			NEDC + 10 %	23	415	371	44	11
			NEDC 15°C	15	693	275	418	60
			NEDC 10°C	10	1425	515	910	64
			NEDC 5°C	5	1514	589	925	61
VW	**T6 2.0l TDI**	EU6	WLTC123	5 °C	226	170	56	25
	75 kW		WLTC123	10 °C	213	136	76	36
	7J0		WLTC123	15 °C	150	131	19	13
			RDE	Series=-1.4°C; update=8.5°C	181	144	37	21
VW	**Touareg 3.0l TDI**	EU5	WLTC123	5°C	1,450	256	1,194	82
	180 kW		WLTC123	10 °C	1,066	260	806	76
	7P		WLTC123	15 °C	1,103	243	860	78
			RDE	Series=4.3°C; update=7.6°C	3,029	435	2,594	86
				Mandatory software update				
Audi	**A6 3.0l TDI**	EU6	RDE	Series=19.8°C; update=22.3°C	510	239	272	53
	240 kW							
	4G							
Audi	**A8 4.2l TDI**	EU6	RDE	Series=25.8°C; update=21.8°C	849	288	561	66
	283 kW							
	4H							
BMW	**750d xDrive**	EU6	RDE	Series = 3°C; Update = 2°C	608	564	44	7
	280							
	7L							
Mercedes	**C200d**	EU6	RDE	Series = 7.8°C; update = 4.6°C	563	109	454	81
	100 kW							
	204K							
Mercedes	**Vito 1,6l CDI**	EU6	RDE	Series = 22.3°C; update = 15°C	57	32	25	44
	65 kW							
	639/2							
Opel	**Zafira Tourer 1.6l CDTI**	EU6	NEDC	23	47	53	-6	-13
	88 kW		NEDC warm	23	238	37	201	84
	P-J/SW		NEDC back	23	86	20	66	77
			NEDC + 10 %	23	180	36	144	80
			NEDC 15°C	15	578	29	549	95
			NEDC 10°C	10	615	17	598	97
			NEDC 5°C	5	426	71	355	83
Opel	**Zafira Tourer 1.6l CDTI**	EU6	NEDC	23	38	44	-6	-16
	100 kW		NEDC warm	23	161	46	115	71
	P-J/SW		NEDC back	23	20	15	5	25
			NEDC +10 %	23	79	30	49	62
			NEDC 15°C	15	453	55	398	88
			NEDC 10°C	10	511	31	480	94
			NEDC 5°C	5	396	72	324	82
Opel	**Insignia Sports Tourer 2.0l CDTI**	EU6	NEDC	23	46	57	-11	-24
	125		NEDC warm	23	35	9	26	74
	0G-A		NEDC back	23	13	2	11	85
			NEDC +10 %	23	38	8	30	79
			NEDC 15°C	15	156	16	140	90

Manufac-turer	Type	Stand-ard	Cycle	Ambient-temperature [°C]	NO_x (SW series) [mg/km]	NO_x (SW update) [mg/km]	Improve-ment absolute [mg/km]	Im-prove ment rela-tive [%]
Voluntary software update								
			NEDC 10 C	10	380	27	353	93
			NEDC 5°C	5	317	31	286	90
Opel	**Insignia Sports Tourer 2.0l CDTI**	EU6	NEDC	23	56	70	-14	-25
	125		NEDC warm	23	45	44	1	2
	0G-A		NEDC back	23	24	19	5	21
			NEDC + 10%	23	45	39	6	13
			NEDC 15°C	15	73	37	36	49
			NEDC 10°C	10	344	33	311	90
			NEDC 5°C	5	405	58	347	86
Opel	**Insignia 4x4 2.0l CDTI**	EU6	NEDC	23	80	58	22	28
	125		NEDC warm	23	114	17	97	85
			NEDC back	23	23	17	6	26
			NEDC + 10 %	23	190	20	170	89
			NEDC 15°C	15	249	30	219	88
			NEDC 10°C	10	877	66	811	92
			NEDC 5°C	5	949	52	897	95
Porsche	**Macan 3.0l Diesel**	EU6	RDE	Series = -5°C; update = 5°C	746	191	555	74
	190 kW							
	95B							
Porsche	**Cayenne 3.0l Diesel**	EU6	RDE	Series = -6.5°C; update = 8.5°C	190	83	107	56
	193kW							
	92A							

Table 97: Table providing an overview of the overall measurement results

b. Summarized assessment of the mandatory recalls

The KBA carried out RDE measurements in order to assess the effectiveness of the mandatory recalls. The following figure shows the results of the RDE measurements (including the number of vehicles in the respective vehicle cluster for which the average NO_X emissions were determined).

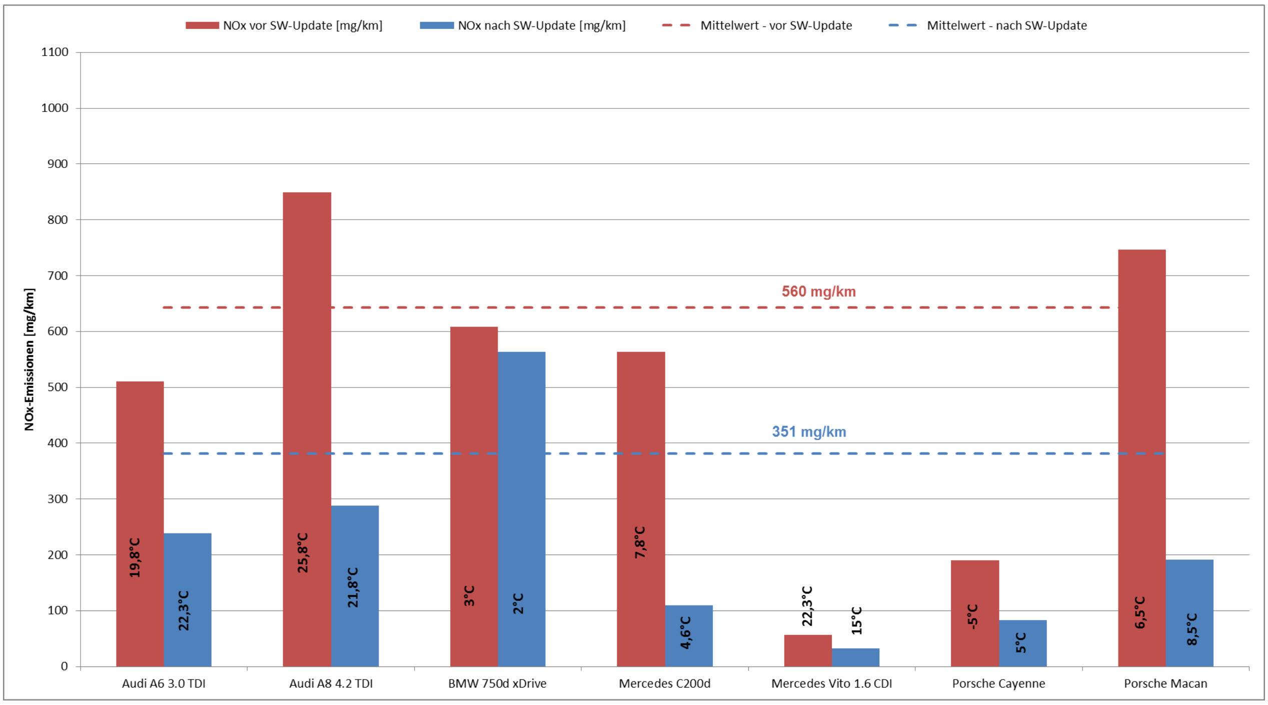

Figure 96: NO_X emissions of the mandatory software updates, results RDE (series / update)

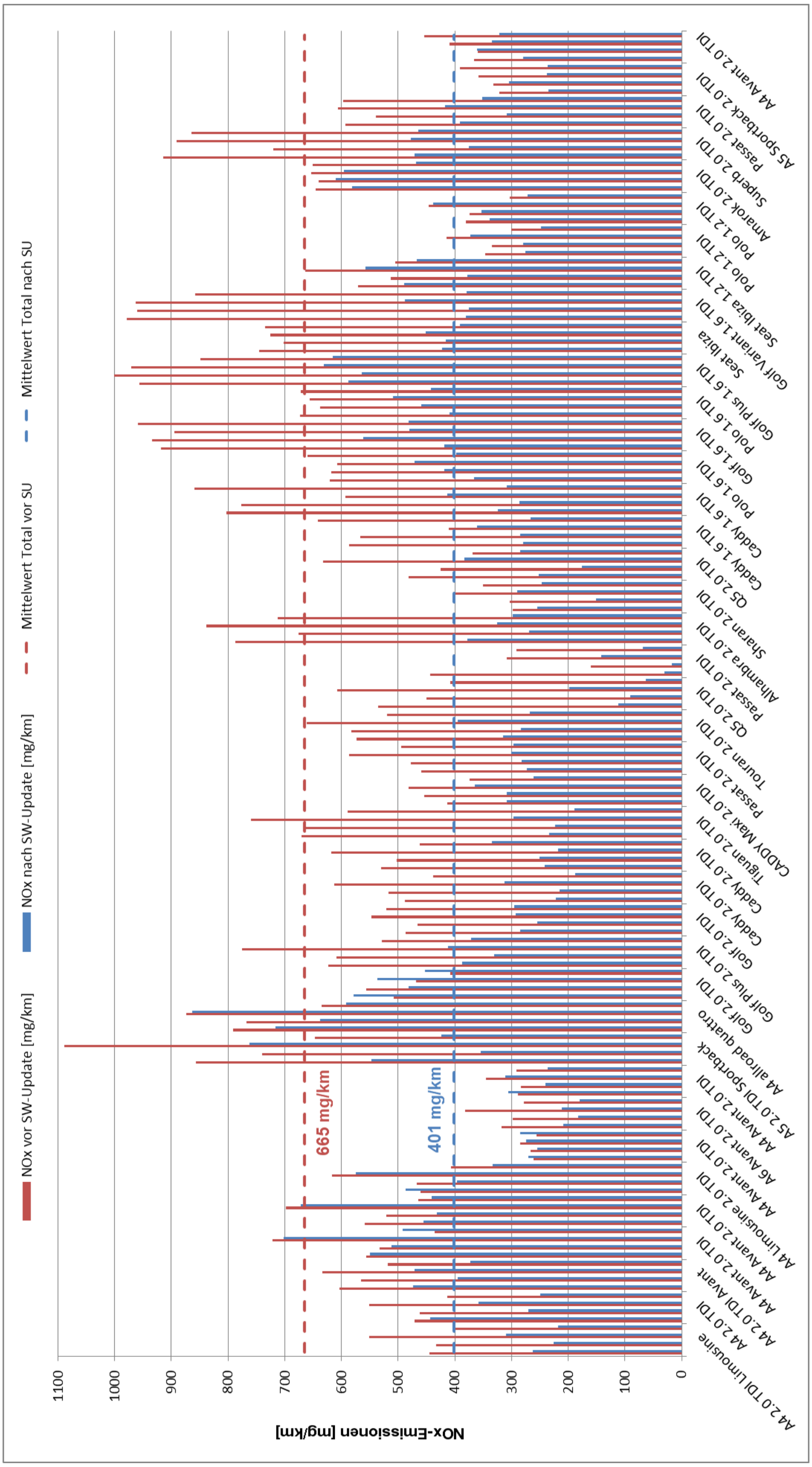

Figure 97: NO_X emissions of vehicles with EA189 engines, PEMS measurements (series / update)

The presentation of the NO_X emissions measured with PEMS also shows the average values for series and update datasets for the EA189 fleet. With the aid of the software update it was possible to reduce this average value from **665 mg/km** to **401 mg/km**.

The RDE measurements are subject to the ambient conditions (air temperature, air pressure, traffic situation) prevailing during the test period, which is the reason why these measurements can in some cases show considerable discrepancies against comparative measurements and between the different test runs. The aim of comparative measurements is to perform the tests in a temperature range which is as similar as possible.

On the basis of these assumptions, the following absolute and relative NO_X savings can be obtained:

Manufacturer	Clustering	NO_X before update [mg/km]	NO_X after update [mg/km]	NO_X reduction absolute [mg/km]	NO_X reduction relative [%]
VW	**Cluster#1**	504	337	167	33
	Cluster#2	537	504	33	6
	Cluster#3	296	247	49	17
	Cluster#4	664	612	52	8
	Cluster#5	541	390	152	28
	Cluster#6	571	243	328	57
	Cluster#7	506	305	202	40
	Cluster#8a	400	90	310	77
	Cluster#8b	523	276	247	47
	Cluster#9a	652	315	337	52
	Cluster#9b	742	451	291	39
	Cluster#10	740	476	263	36
	Cluster#11	429	372	57	16
	Cluster#12	647	564	84	13
	Cluster#13	716	407	309	43
	Cluster#14	374	289	85	23
Audi	**A6 240kW**	510	239	272	53
	A8 283kW	849	288	561	66
BMW	**750d xDrive**	608	564	44	7
Mercedes	**C200d 100kW**	563	109	454	81
	Vito 65kW	57	32	25	44
Opel	**Zafira Tourer 1.6 CDTI**	273	40	179	86
	Insignia 2.0 CDTI	212	34	234	84
Porsche	**Cayenne**	190	83	107	56
	Macan	746	192	555	74

Table 98: Evaluation RDE absolute/relative, mandatory recalls

The assessment of all clusters in relative terms shows that a reduction of **41 %** was realized. In real road operation (RDE), the average NO_X emissions were reduced from **643 mg/km** on the average to **381 mg/km**.

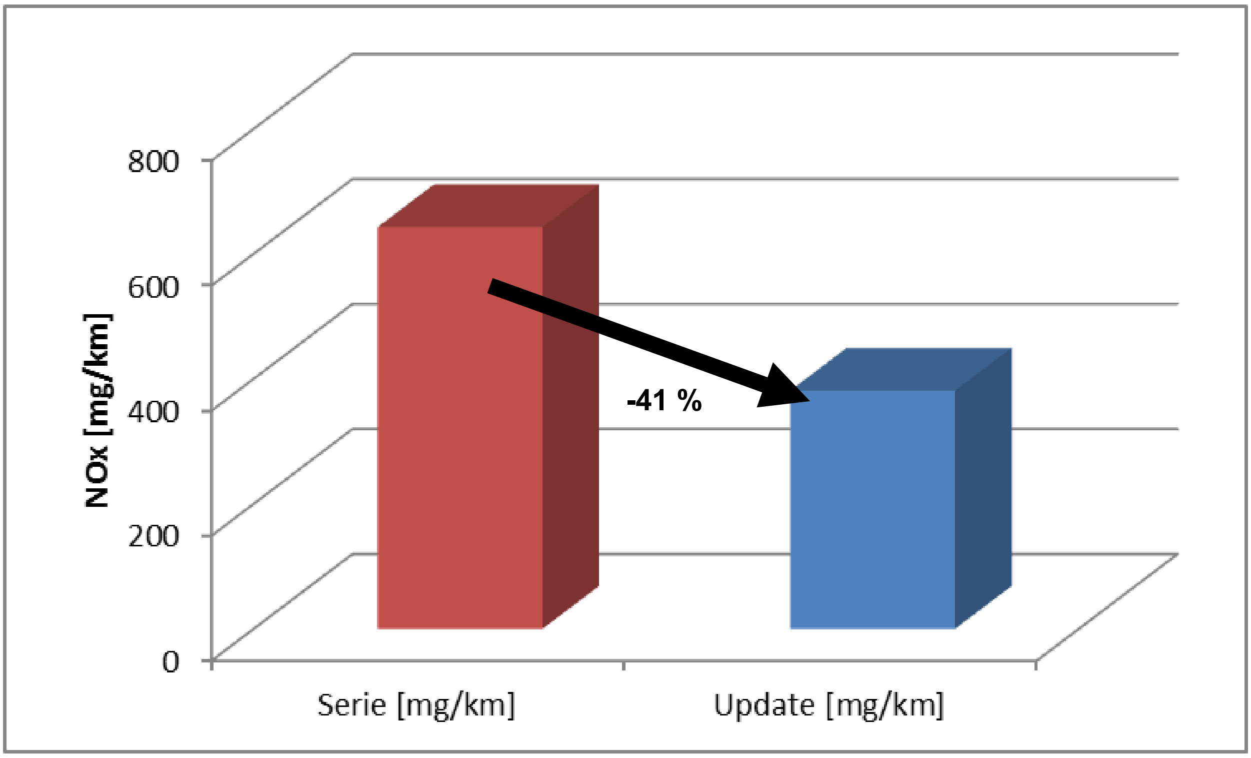

Figure 98: Overall NO_X reduction [mg/km] as a result of mandatory software updates, RDE (series / update)

c. Summarized assessment of the voluntary service actions

Within the framework of the voluntary software updates, RDE measurements were carried out to prove the effectiveness of the update in real world traffic, as well as WLTC123 measurements (at 5°C, 10°C, 15°C) on the chassis dynamometer to test the effectiveness of the update at low ambient temperatures. The results of the RDE measurements are presented in the following and are supplemented by a value averaged over the number of vehicles.

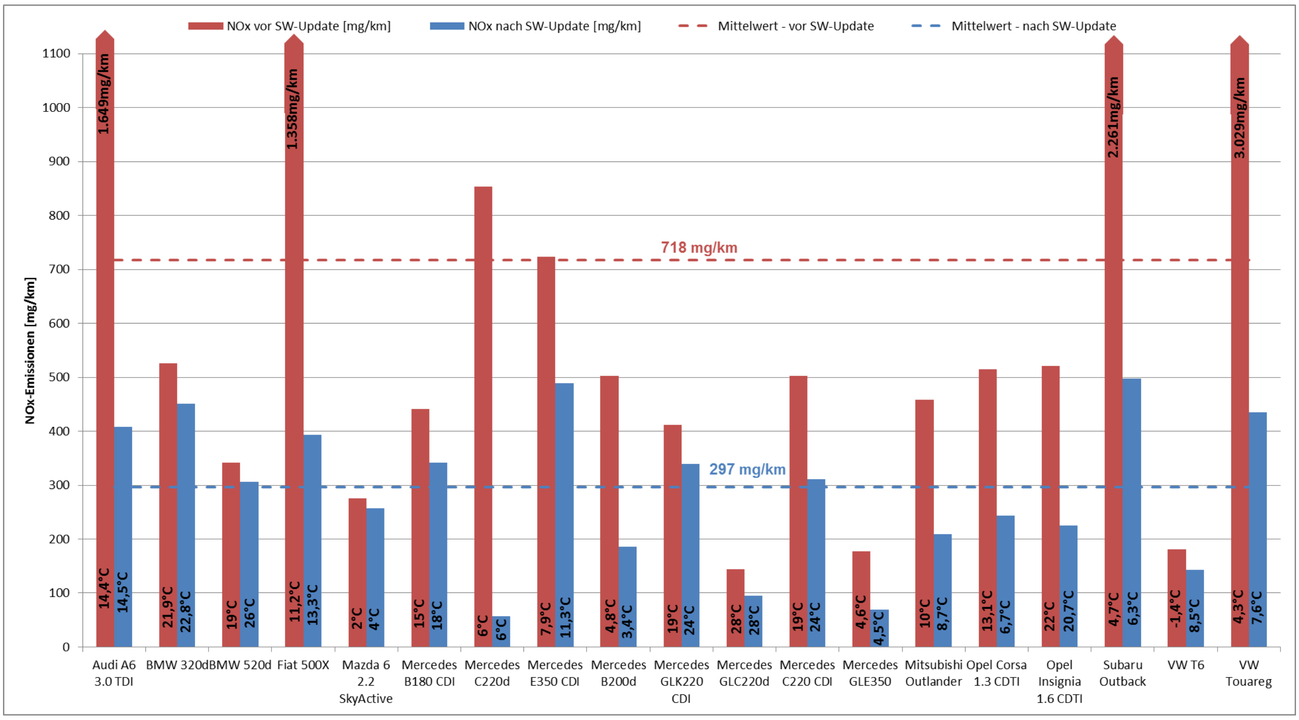

Figure 99: NO_X emissions of the voluntary software updates, results RDE (series / update)

The following table shows the absolute and relative changes of the NO_X emissions:

Manufacturer	Clustering	NO_X before update [mg/km]	NO_X after update [mg/km]	NO_X reduction absolute [mg/km]	NO_X reduction relative [%]
Audi	**A6 180 kW**	1,649	408	1241	75
BMW	**320d**	526	451	75	14
	520d	342	306	37	11
Fiat	**500X**	1,358	394	964	71
Mazda	**6 2.2 SkyActive**	275	257	18	7
Mercedes	**B 180 CDI**	441	341	100	23
	C 220 CDI	503	311	192	38
	E 350 CDI	723	489	234	32
	GLK 220 CDI	412	339	73	18
	B 200 d	502	186	316	63
	GLE 350d	177	70	108	61
	C 220d 125 kW	853	57	796	93
	GLC 220d	144	95	49	34
Mitsubishi	**Outlander**	459	209	249	54
Opel	**Corsa**	515	243	272	53
	Insignia	521	225	297	57
Subaru	**Outback**	2,261	498	1,763	78
VW	**T6 2.0 TDI**	181	144	37	21
	Touareg 3.0l TDI	3029	435	2594	86

Table 99: Evaluation RDE absolute/relative, voluntary updates

The average NO_x emissions of the voluntary updating measures which were determined on the basis of the RDE measurements, were reduced by **59%** from **718 mg/km** to **297 mg/km**.

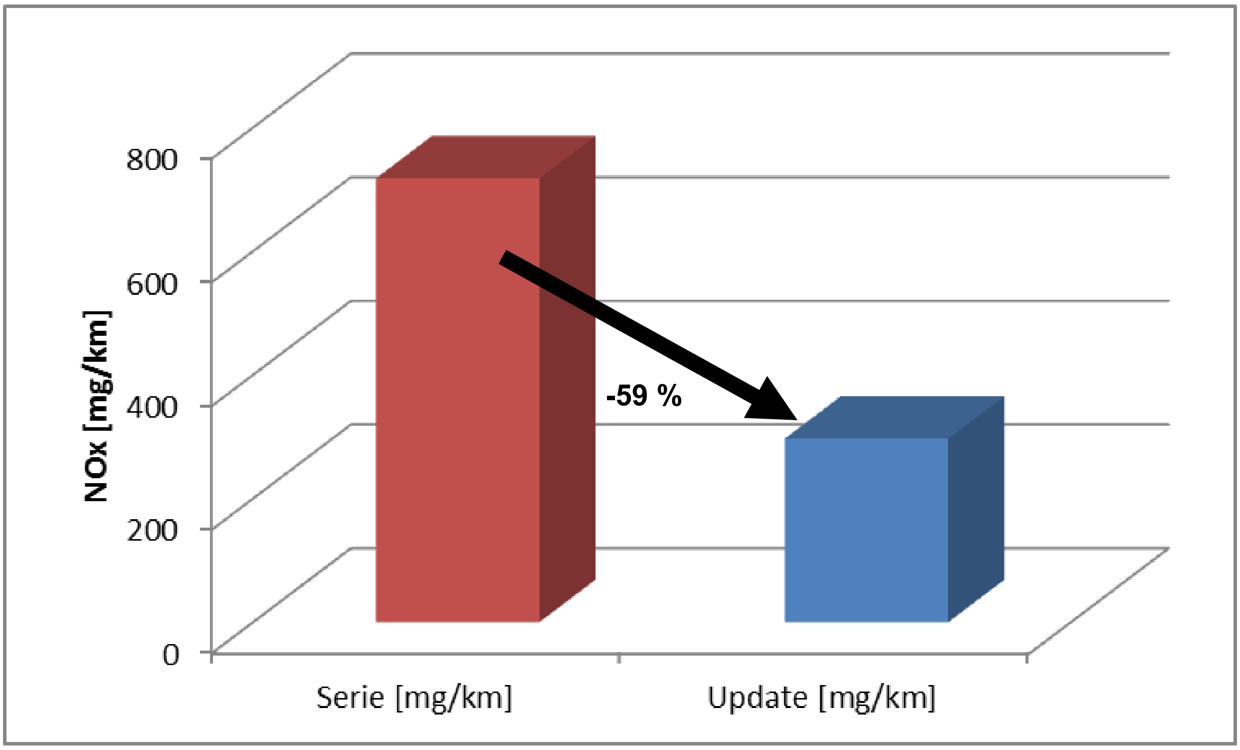

Figure 100: Overall NO_X reduction [mg/km] as a result of voluntary software updates, RDE (series / update)

Within the context of the voluntary software updates, measurements were performed at different ambient temperatures (15°C, 10°C, 5°C) according to the WLTC123 cycle on the chassis dynamometer. This test programme is to show the effectiveness of the enhanced exhaust purification even at low ambient temperatures (up to 5°C). When considering the relevant temperature ranges, a significant improvement of the exhaust purification towards 5°C can be identified. In the following, the improvements achieved in the relevant clusters and those of the total fleet (vehicles receiving the voluntary update) are shown.

Manufac-turer	Clustering	Temperature [°C]	NO_X before up-date [mg/km]	NO_X after up-date [mg/km]	NO_X re-duction absolute [mg/km]	NO_X reduction relative [%]
VW	**T6 2.0 TDI**	5	226	170	56	25
		10	213	136	77	36
		15	150	131	19	13
	Touareg 3l TDI	5	1450	256	1194	82
		10	1066	260	806	76
		15	1103	243	860	78
Audi	**A6 180 kW**	5	1013	204	809	80
		10	819	184	635	78
		15	675	167	509	75
BMW	**320d**	5	602	419	183	31
		10	468	333	136	29
		15	338	340	-2	-1
	520d	5	722	280	442	61
		10	326	320	6	2
		15	241	261	-21	-9
Mercedes	**B 180 CDI**	5	334	235	99	30
		10	384	263	121	32
		15	342	249	93	27
	C 220 CDI	5	287	149	139	48
		10	331	250	80	24
		15	291	218	73	25
	E 350 CDI	5	387	276	111	29
		10	320	259	61	19
		15	292	273	19	6
	GLK 220 CDI	5	492	200	292	59
		10	370	226	144	39
		15	289	264	26	9
	B 200d	5	192	68	124	65
		10	162	80	82	50
		15	161	82	80	49
	GLE 350d	5	29	11	17	61
		10	16	13	2	16
		15	18	15	3	17
	C 220d	5	133	17	116	87
		10	75	17	58	78
		15	37	20	17	46
	GLC 220d	5	282	56	227	80
		10	137	51	86	63
		15	98	47	52	53

Table 100: Evaluation WLTC123 absolute/relative

On the basis of the WLTC123 results (5°C, 10°C, 15°C) the following conclusions can be drawn:

WLTC123	Averaged NO_X emissions before update [mg/km]	Averaged NO_X emissions after update [mg/km]	NO_X reduction absolute [mg/km]	NO_X reduction relative [%]
5 °C	394	155	240	61
10 °C	337	183	154	46
15 °C	287	171	116	41

Table 101: Evaluation WLTC123 absolute/relative - total fleet -

It becomes evident that a relative and absolute improvement with regard to the reduction of the NO_X emissions occurs with decreasing temperatures.

3. Overall analysis of the results

The KBA has conducted verification measurements to check the NO_X reduction potential and thus the effectiveness of software updates made within the context of mandatory recalls and voluntary service actions of the manufacturers. The measurements confirmed that the NO_X emissions performance of the vehicle models improves significantly by implementing the software updates.

On vehicles which were subject to voluntary service actions, a correction of the EGR depending on the ambient air was identified, especially at lower temperatures. These findings were confirmed by the WLTC123 measurements on the chassis dynamometer at different temperatures to verify the exhaust gas behaviour in urban and rural traffic. Considering the total vehicle fleet concerned, the following relative NO_X savings were achieved at temperatures of 5°C, 10°C and 15°C.

WLTC123	NO_X reduction [%]
5 °C	61
10 °C	46
15 °C	41

Table 102: NOx reduction relative (WLTC123)

Here, a more significant improvement of the NO_X emissions occurs with decreasing temperatures. Especially at 5°C, about **61 %** of the NO_X emissions are saved by means of the software update.

The RDE measurements to prove the effectiveness of the software updates in real world operations show that a NO_X reduction of **59 %** on the average is possible.

For vehicles which were subject to a mandatory recall, only verification measurements in real world traffic were made to check the software updates. In the majority of cases, the RDE measurements showed very significant improvements. The mandatory software updates achieve a NO_X saving of approx. **41 %.**

The RDE measurements show a significant reduction of the NO_X emissions in the whole temperature range, even at low temperatures.

The tests confirmed that the software updates have a consistently positive effect on the exhaust emissions of the vehicles.

The verification of the scope for savings provided by the voluntary service actions and mandatory recalls shows, that the improvement target of 25 to 30% of the NO_X emissions by software updates in road operation was significantly exceeded.

4. Transparency of software updates

Despite the improvement of the air pollutant levels in the last few years, the air quality is still affected in numerous German cities. Therefore, the Federal Government has taken various measures to reduce the NOx emissions from diesel-powered motor vehicles. This includes especially the commitment obtained from the automotive industry to implement software updates in approx. 5.3 million diesel-powered passenger cars which are covered by this report.

The KBA has undertaken to analyse the effectiveness of this measure by conducting tests of its own with the software updates; it explains in this report that the expectations as to the effectiveness of the software updates were met. It is considered reasonable to introduce a procedure in order to make the implementation of the software update in an individual vehicle transparent. This enables the vehicle holders to furnish proof of the updating of their vehicle. Thus, it is possible for the vehicle holder to make enquiries at the KBA in order to know whether his vehicle has undergone the update process. For this purpose, the procedure described below should be implemented.

The manufacturer or the authorized automotive repair shop issues a certificate to the vehicle holder, confirming the implementation of the software update and specifying the general type approval granted by the KBA for the update.

This certificate is handed over to the vehicle holder, upon his request, by the manufacturer or the authorized automotive repair shop.

In this way, the holder can submit an application to the registration authority in order to have this modification to his vehicle entered in part 1 of the registration certificate.

This entry is recorded in the Central Vehicle Register (ZFZR) and is made available to the authorities entitled to make such requests, even in the automated procedure.

D. Summary

The implementation of the software update leads noticeably to a significant reduction of the NO_X emissions, even without using a retrofit system. On the basis of the evaluations it can be stated that the software improvements have a consistently positive effect on the exhaust emissions. Thus, it was not only possible to consistently reduce the NO_X emissions during the RDE measurements as part of the mandatory recalls and the voluntary service actions, but a positive effect could also be proven for the voluntary updates at low temperatures by means of the WLTC123 cycle intended for urban operation.

The software updates carried out as part of voluntary service measures reduce the NO_X emissions of the vehicles affected in real world conditions by about **59 %**.

As regards urban and rural traffic, a reduction of the NO_X emissions by up to **61 %** (5°C ambient temperature, WLTC123) can be achieved for the vehicles affected within the context of the voluntary software updates.

For the vehicles which are subject to the mandatory recalls, a NO_X reduction of approximately **41 %** in real world operations is achieved by software improvements.

In summary, it can be concluded that the software updates lead to a significant improvement of the emissions performance. This improvement is especially effective in the case of ambient air temperatures which are well below 20°C. Thus, a software update predominantly leads to a reduction of the nitrogen oxide emissions at temperatures around the German average annual temperature of 9.6°C (average temperature in 2017) and contributes to an improvement of the air quality in cities.

The evaluation of the measurement results shows that the target laid down by the National Diesel Forum on 2 August 2017, i.e. an average reduction of the NO_X emissions by 25-30% by the implementation of a software update, was significantly exceeded.

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