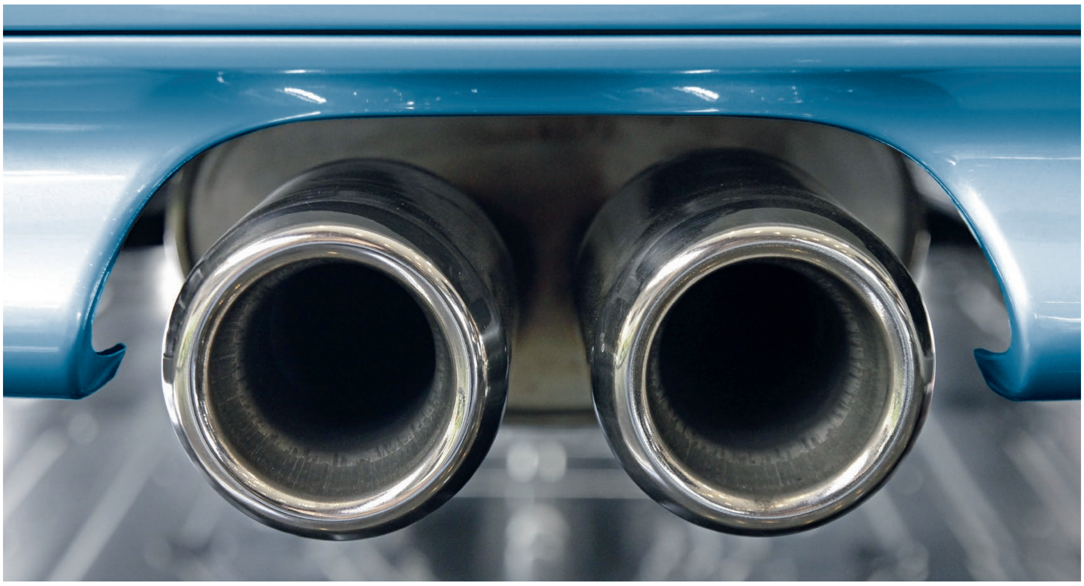
EMISSIONS OF NITROGEN OXIDES AND PARTICULATES OF DIESEL VEHICLES



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TNO innovation for life

AUTHORS
Gerrit Kadijk
Norbert Ligterink
Pim van Mensch
Jordy Spreen
Robin Vermeulen
Willar Vonk

TNO REPORT
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Emissions of nitrogen oxides and particulates of diesel vehicles

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CLIENT
Dutch Ministry of Infrastructure and the Environment

MANAGEMENT SUMMARY

In real-world conditions, modern Euro VI heavy-duty vehicles produce an average of ten times less nitrogen oxide (NO_x) emissions than previous generations of Euro IV and Euro V heavy-duty vehicles. However, Euro 6 passenger cars and light commercial vehicles present an entirely different picture since, despite a continual tightening of European emissions limits, the real-world NO_x emissions of new diesel passenger cars and light commercial vehicles have remained virtually unchanged over the last two decades. Real-world emissions have therefore remained significantly higher than the successive European limits set by emissions legislation.

The NO_x emissions from passenger cars and commercial vehicles contribute significantly to the concentration of harmful NO_2 in the atmosphere. To comply with European standards on air quality, a reduction in NO_x emissions from traffic on Dutch roads is essential.

Emission measurements have demonstrated that the real-world NO_x emissions of passenger cars and light commercial vehicles can be significantly reduced by applying an SCR catalytic converter in combination with EGR technology. An SCR catalytic converter is a system within the exhaust of a diesel vehicle that, with the addition of AdBlue, is able to break down nitrogen oxides (NO_x) in the exhaust emissions. EGR is a system for the recirculation of exhaust gases and has been used for some time now by manufacturers to reduce NO_x emissions. The low real-world emissions from Euro VI heavy-duty vehicles are achieved primarily with the EGR and SCR technologies. The combination of these EGR and SCR systems has now also been applied to passenger cars and light commercial vehicles.

However, in the tested Euro 6 diesel passenger cars, these systems have proved not to function optimally in real-world conditions and NO_x emissions remain relatively high. Lower real-world emissions are achievable by re-calibration of the EGR and SCR control. This means, however, that the AdBlue tanks in diesel passenger cars, currently around 15 to 25 litres in capacity, would need to be refilled in between maintenance checks. One of the tested vehicles has an AdBlue tank large enough to adequately reduce the NO_x emissions.

When the SCR technology is effectively applied, it can be a successful innovation towards significantly cleaner vehicles. In the past, the implementation of successful innovations, such as the three-way catalytic converter in petrol engines, and the particulate filter in the case of diesel engines, have also resulted in the reduction of pollutants by a factor of more than 10.

New European legislation that imposes standards for real-world NO_x emissions is necessary to ensure that SCR catalytic converters are effectively deployed in diesel passenger cars and light commercial vehicles. A new ‘Real Driving Emission’ test needs to be introduced as part of the European type-approval test, whereby real-world emissions will be measured and assessed on the road with mobile testing equipment.

Such European legislation is also necessary for trucks and buses in order to guarantee low NO_x emissions under urban driving conditions, since the latest findings reveal that it is precisely in urban areas where not all Euro VI trucks and buses have low NO_x emissions.

The particulate emissions have been reduced significantly over the last years. Euro VI trucks and buses and Euro 6 passenger cars and Euro 5 light commercial vehicles are all equipped with the very effective diesel particulate filter. The introduction of this particulate filter has ensured that real-world particulate emissions of the most modern road vehicles are well below the limit value set by the type-approval test.

INTRODUCTION

Since 1986, the Dutch Ministry of Infrastructure and the Environment has been commissioning TNO to carry out the In-Service Emissions Testing Programmes for passenger cars and light commercial vehicles (light-duty vehicles), as well as for trucks and buses (heavy-duty vehicles). These programmes involve the regular measurement by TNO of exhaust emissions of these vehicles to investigate whether they satisfy the EU type-approval standards and are also clean in real-world conditions.

To this end, TNO has produced four reports over the last two years concerning the real-world emissions of pollutants of diesel vehicles, involving measurements taken from a total of 26 passenger cars and light commercial vehicles, and 30 trucks and buses.

This document provides a summary of these four reports. It outlines the latest findings with regard to pollutants, especially the NO_x emissions of (1) modern Euro VI heavy trucks, (2) Euro VI buses and distribution trucks, (3) Euro 5 light commercial vehicles, and (4) Euro 6 passenger cars. It also deals briefly with particulate emissions (PM10) of these vehicles. The report begins, however, with a short explanation of the exhaust emissions of road vehicles, how these can be reduced, and how they are measured. The report then discusses and compares real-world NO_x emission performances of heavy trucks, buses and distribution trucks, and passenger cars and light commercial vehicles – in that order – before looking briefly at real-world particulate emissions.

WHICH EMISSIONS ARE THE WORST POLLUTANTS?

The exhaust emissions of a diesel vehicle cause more pollution than those of a petrol vehicle. Nitrogen oxide emissions of a modern diesel passenger car are 15 to 30 times higher than a modern petrol passenger car. Nitrogen oxides is a common denominator for nitrogen monoxide (NO) and nitrogen dioxide (NO_2), usually abbreviated to NO_x. Nitrogen oxides are harmful to health and lead to smog and acid rain. With regard to nitrogen dioxide (NO_2), there are European standards governing air quality. To reduce the NO_x emissions of road traffic, European standards have been imposed by means of 'Euro limits'.

Particulates are also harmful to health. The particulate emissions (PM10) of old diesel vehicles not fitted with a particulate filter are 10 to 25 times higher than of a modern (indirect fuel injected) petrol vehicle. There are also European limits in force to reduce the particulate emissions of road traffic. For this reason, modern diesel vehicles are fitted with a particulate filter. These particulate filters trap virtually all of the harmful particulates, so that particulate emissions (PM10) are no longer an issue with regard to modern diesel vehicles.

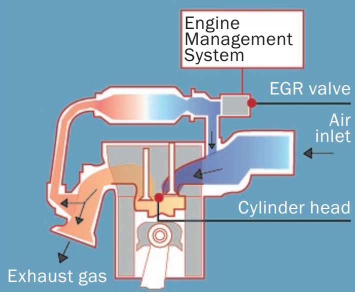
WHICH SYSTEMS REDUCE NO_x AND PARTICULATE EMISSIONS?

DPF – DIESEL PARTICULATE FILTER

A Diesel Particulate Filter (DPF) captures the particulates created by the combustion of diesel fuel. A particulate filter is fitted inside the exhaust of a diesel engine. If the exhaust gases are hot enough, the particulate trapped in the filter will burn of its own accord. In the event that the exhaust gases are not hot enough 'active regeneration' is applied, whereby the temperature of the exhaust gas is increased by, for example, temporarily injecting extra fuel.

EGR – EXHAUST GAS RECIRCULATION

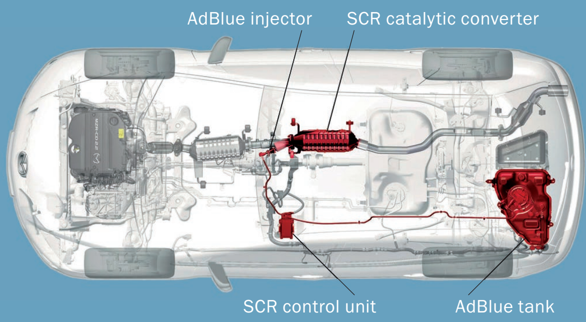
The EGR system involves some of the exhaust gas from the engine being directed back to the engine inlet. Some of the inlet air is thus replaced or supplemented by exhaust gases. When the EGR is applied, the inlet air contains less oxygen. This makes the combustion less intense, so that less NO_x is produced. The quantity of exhaust gases that are recirculated is regulated by the EGR valve. Depending on the required and technically feasible reduction in NO_x, the engine management system will determine the position of the EGR valve.



Source: www.tc.gc.ca/eng/programs/environment-etv-egr-eng-1144.htm

SCR – SELECTIVE CATALYTIC REDUCTION

The exhaust gases enter the SCR catalytic converter, fitted behind the engine. Within the SCR catalytic converter NO_x is converted into nitrogen and water with the help of ammonia. The ammonia originates from AdBlue, which is injected immediately before the SCR catalytic converter. The SCR catalytic converter must be at a sufficiently high temperature. Depending on the required and technically feasible reduction in NO_x, the engine management system will determine the quantity of AdBlue to be injected.



Source: cartype.com/pics/6975/full/urea-scr-system.jpg

HOW ARE EMISSIONS MEASURED?

TNO measures the emissions of vehicles in a laboratory and on the road. Laboratory measurements are performed on a chassis dynamometer. Laboratory measurements have a high accuracy, and are carried out in reproducible, controlled conditions. Measurements on the road are carried out under real-world conditions and provide an understanding of how vehicles perform in the real world.

LABORATORY MEASUREMENTS ON THE CHASSIS DYNAMOMETER

Chassis dynamometer tests are conducted under very well-controlled conditions in a laboratory. The vehicle and the measuring equipment operate under precisely calibrated conditions. This is necessary from the point of view of standardisation in order to be able to effectively compare the results of type-approval tests performed at various locations. Road conditions, by contrast, vary to a much greater extent and modern vehicles often have emission performances in real-world conditions that are different from their performances on the chassis dynamometer. Accordingly, to determine real-world emissions it is necessary to take measurements on the road using mobile measuring equipment.

Chassis dynamometer TNO – Mobility, Delft 1970.

Chassis dynamometer Horiba Oberursel, 2011.

TNO has over 30 years' experience in performing chassis dynamometer measurements. Currently, TNO and the Ministry of Infrastructure and the Environment are commissioning the performance of these chassis dynamometer measurements at the Horiba test laboratory in Oberursel, Germany.

MEASUREMENTS ON THE ROAD

Measurements can be taken on the road using two different measuring systems.

PEMS

The Portable Emission Measurement System (PEMS) enables TNO to accurately measure real-world emissions. The type-approval testing of heavy-duty vehicles, i.e. trucks and buses, requires a measurement using PEMS in accordance with the type-approval procedure. This procedure has resulted in a significant fall in the real-world emissions of heavy-duty vehicles. Further improvements in the procedure are needed to guarantee low emissions in urban areas. The type-approval testing of passenger cars does not require a PEMS test – a chassis dynamometer test is sufficient. Negotiations for the introduction of a PEMS test for passenger cars are currently underway in Brussels.

PEMS is a complex system that only expert personnel are able to install and use. For taking PEMS measurements, TNO usually uses vehicles from the Dutch vehicle fleet. Where appropriate, the vehicle's owner will be offered replacement transport. TNO will always notify the vehicle's importer of its PEMS measurement.

The PEMS system installed on a Euro VI long-haul commercial vehicle.

A PEMS system installed on a Euro VI city bus.

A PEMS system installed on a Euro 6 passenger car.

SEMS

The Smart Emission Measurement System, or SEMS, allows TNO to measure emissions of the vehicle on the road. SEMS has been developed by TNO to quickly provide a rough estimate of the NO_x emissions of a vehicle. SEMS is not a regulated measuring instrument and is less accurate than PEMS, but it is easy to install and take out. The vehicle can be used normally so that large volumes of measurement data can be collected over longer periods of normal use, for example, a month.

SEMS equipment is compact and takes up little room in the vehicle. When measurements are being taken, the owner can use the vehicle as normal.

The SEMS system includes one or two NO_x sensors and an NH_3 sensor, which can be easily attached to the exhaust of a vehicle.

EMISSIONS OF RECENT DIESEL VEHICLES

This section looks at the emission performances of, in turn, long-haul trucks, buses and distribution trucks, diesel light commercial vehicles, and diesel passenger cars. We then compare these emission performances against each other. Finally, we look briefly at the emissions of particulates of all the above vehicle categories.

CLEANER HEAVY-DUTY VEHICLES DUE TO IMPLEMENTATION OF EURO VI LEGISLATION

The introduction of Euro VI legislation is a large step towards cleaner heavy-duty vehicles. Since Euro VI heavy-duty vehicles are fitted with an advanced combination of EGR and an SCR catalytic converter to reduce NO_x emissions, these vehicles are significantly cleaner in terms of NO_x emissions than previous generations of commercial vehicles (Figure 1). They are also fitted with a particulate filter, which significantly reduces particulate emissions.

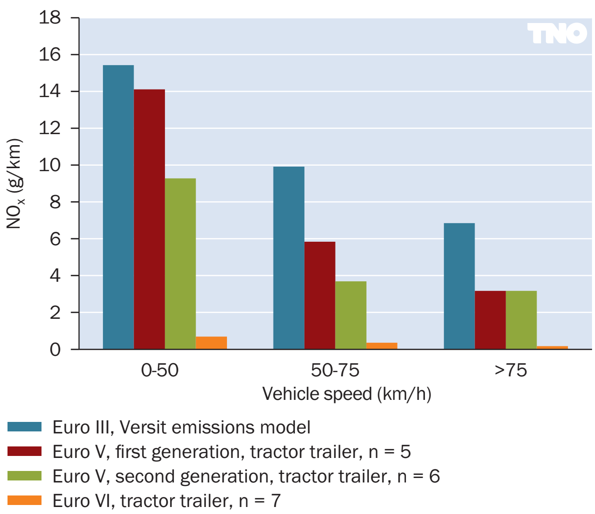


Figure 1. Euro VI long-haul trucks emit significantly less NO_x than previous generations of heavy-duty vehicles (Vermeulen, 2014).

As well as stipulating emission limits, the Euro VI legislation significantly tightens test procedures by including a real-world emission test as a mandatory part of the European type-approval test. This real-world test measures the emissions of the vehicle using mobile equipment on the road, thus checking whether the vehicle emissions are in accordance with the emission limits measured in the laboratory during the type-approval test. In the Euro V legislation the real-world emissions test was still optional. To meet the Euro VI standards for NO_x, vehicle manufacturers have developed new engines in combination with advanced systems to reduce the emission of pollutants. The emission of NO_x is significantly reduced by the application of a special catalyser, the Selective Catalytic Reduction (SCR), and by Exhaust Gas Recirculation (EGR), a system for the recirculation of exhaust gases. The implementation of the new legislation has led to heavy-duty vehicles becoming much cleaner. This success is down to the efforts of both legislators and vehicle manufacturers.

NOT ALL EURO VI DISTRIBUTION TRUCKS AND BUSES ARE CLEAN IN URBAN CONDITIONS

Measurements reveal that under urban conditions some Euro VI vehicles still emit a relatively large quantity of NO_x in comparison with long-haul commercial vehicles [1]. This is particularly true of distribution trucks and city buses. Under urban conditions, the engine usually operates at low load. As a result, the exhaust gases – and thus the SCR catalytic converter – are not hot enough to sufficiently hold back the NO_x emissions. Urban driving conditions thus form a greater challenge to reducing NO_x emissions than the driving conditions for long-haul trucks that drive long distances on motorways.

TNO tested two city buses and a distribution truck during typical daily use, as shown in Figure 2. Measurements for one of the buses tested revealed very low, stable NO_x emissions even under difficult urban conditions, comparable with the previously tested long-haul trucks. This good emission performance indicates the potential of the emissions reduction technology applied to Euro VI vehicles. However, the measurements for the second bus and distribution vehicle revealed relatively high and also very irregular NO_x emissions under the same conditions.

All the tested long-haul trucks, distribution trucks, and city buses meet the European type-approval standards in both the laboratory test and in the real-world test that has been added to the Euro VI type-approval test. Nevertheless, it appears that in an urban setting in particular not all vehicles are actually clean. This is due to the fact that typical urban conditions are rather neglected in the current European type-approval tests, both in the laboratory test and the real-world test.

1 Vermeulen, 2014. Vermeulen, Spreen, Ligterink and Vonk. The Netherlands In-Service Emissions Testing Programme for Heavy-Duty 2011-2013, 26 May 2014, TNO report TNO 2014 R10641 | 2

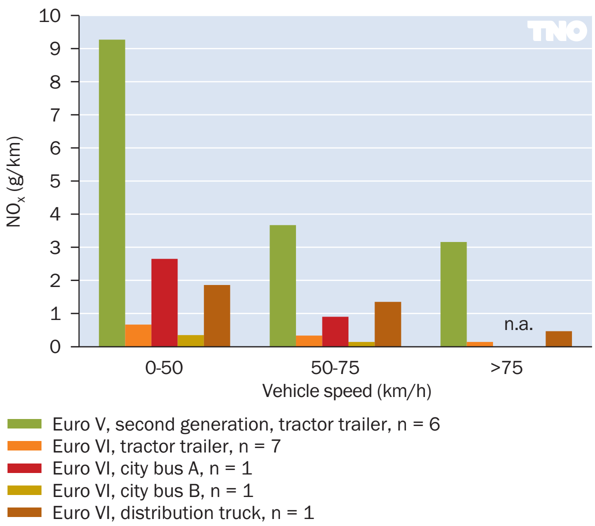


Figure 2. TNO tested two city buses and a distribution truck under conditions representative for these types of vehicles. In urban conditions, two of these Euro VI vehicles were still responsible for relatively high NO_x emissions in comparison to Euro VI long-haul trucks, although these emissions were significantly lower compared to Euro V vehicles. Euro VI buses produce widely differing emission levels: in urban conditions, bus A is not as clean as the Euro VI tractors that were measured, even though bus B shows that it is technically possible to achieve this. The emissions of Euro V vehicles and Euro VI long-haul trucks, highlighted in green and orange colours, respectively, are in accordance with the emissions highlighted in green and orange in Figure 1.

Typical urban driving conditions, whereby the exhaust gases from the engine and consequently from the SCR catalytic converter of a city bus or distribution truck do not reach the required temperature, are therefore still inadequately covered by the type-approval test.

These results argue in favour of further improvement of the type-approval test by increasing the focus of test conditions on urban situations for buses and distribution vehicles. Such an improvement would present manufacturers with a technical challenge to achieve very low NO_x emissions in all driving conditions. The measurements have demonstrated that this is technically possible. It should be pointed out here that in the design of Euro VI vehicles, vehicle manufacturers need to achieve a careful balance between a low emission of pollutants on the one hand and an optimum fuel consumption and CO_2 emissions on the other. A reduction in NO_x emissions can result in a higher fuel consumption and accompanying higher CO_2 emissions.

ON AVERAGE, NO_X EMISSIONS OF EURO 5 LIGHT COMMERCIAL VEHICLES IN REAL-WORLD TESTS ARE FIVE TO SIX TIMES HIGHER THAN THE EURO V LIMIT VALUE

At the end of 2014, in response to reports of high NO_x emissions of light commercial vehicles TNO screened the NO_x emissions of ten Euro 5 light commercial vehicles. Modern diesel light commercial vehicles, or vans, currently available on the market are Euro 5. Euro 6 is not mandatory for vans until 1 September 2016. During real-world trips on roads, the tested vehicles emitted an average five to six time more NO_x than the Euro 5 limit value of 280 mg/km; in real-world conditions the NO_x emissions of the tested Euro 5 vehicles varied between 1421 and 1670 mg/km [2]. It was also noteworthy that the results from the ten vehicles revealed a relatively small spread: all the vehicles emitted a great deal of NO_x. Prompted by these measurements, TNO adjusted the emission factors for light commercial vehicles upwards.

One light commercial vehicle underwent a more detailed examination on a chassis dynamometer in the laboratory. This investigation confirms the results of earlier studies: whilst diesel vehicles are able to meet the type-approval limit in the laboratory, their NO_x emissions are often significantly higher in real-world conditions. Despite the tightening of the emission limits, the target real-world reductions in the NO_x emissions of diesel passenger cars and diesel light commercial vehicles have not been achieved for years. The difference between the type-approval value and the real-world measurements is growing wider. There are various causes for this and they are difficult to establish.

Figure 3 shows the NO_x emissions of light commercial vehicles under urban conditions; given the very purpose for these vehicles, these are the most relevant emissions. The figure shows that the introduction of new emissions standards has not resulted in a fall in NO_x real-world emissions. Light commercial vehicles of Euro classes 1 to 5 emit a more or less similar amount of NO_x (1200-1500 mg/km). An improvement in these emission levels is possible, but rigorous legislation is needed to set standards for these real-world emissions.

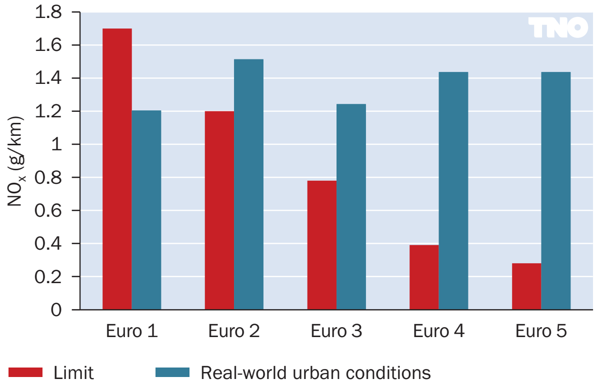


Figure 3. NO_x emissions of light commercial vehicles (vans) in urban conditions, compared to the emissions limit.

It is expected that changes to the test cycle, such as the new WLTP test procedure, will do little to reduce this problem. The solution to bringing real-world emissions under control must be sought by measuring, monitoring and limiting vehicle emissions on the road using mobile test equipment. The measurement of emissions on the road during type-approval tests is a part of the new RDE (Real Driving Emissions, see box) legislation currently being formulated in Brussels.

2 Kadijk, 2015b. Kadijk, Ligterink and Spreen. On-road NO_x and CO_2 investigations of Euro 5 Light Commercial Vehicles, 9 March 2015, TNO report TNO 2015 R10192.

NO_x EMISSIONS OF EURO 6 DIESEL PASSENGER CARS REMAIN AT THE SAME HIGH LEVELS

TNO measured the emission levels of a total of sixteen Euro 6 diesel passenger cars, both in the laboratory and on the road. The tests reveal that on the basis of the type-approval test all these sixteen vehicles meet the Euro 6 NO_x standard of 80 mg/km. In real-world conditions the NO_x emissions of the various types of Euro 6 diesel vehicles range from 150 to 600 mg/km [3]. However, the particulate emissions (PM_{10}) of the vehicles were well below the statutory limit of 4.5 mg/km, which can be attributed to the fitting of diesel particulate filters to these Euro 6 vehicles.

As can be seen from Figure 4, the real-world NO_x emissions in an average situation for diesel passenger cars on Dutch roads has for years exceeded the limits imposed by legislation. Moreover, the difference between the limit and the real-world emissions is growing bigger. In contrast to the type-approval testing of heavy-duty vehicles, the current type-approval procedure as applied to passenger cars includes no real-world test.

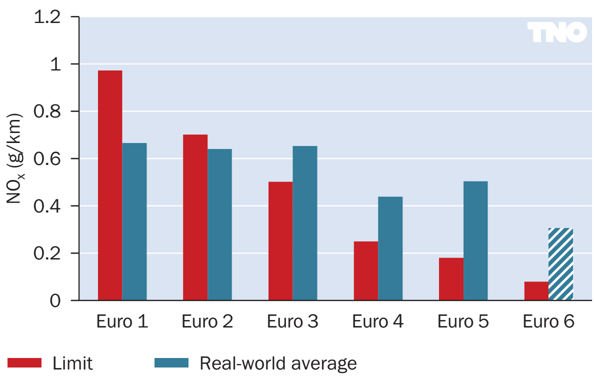


Figure 4. In real-world conditions, passenger cars still produce high NO_x emissions. Furthermore, the gap between the limit value and real-world measurements is growing. The numbers shown in the figure indicate the 'emission factors' for 2015: emissions on motorways and in urban conditions are weighed to produce an average value for NO_x emissions in grams per kilometre of distance travelled. Additional measurements have still to be made in respect of Euro 6 passenger cars. At the date of drafting this report not all vehicles models are available in a Euro 6 variant. The Euro 6 real-world emissions may still change in the future on the basis of new measurements and are therefore shown shaded.

Figure 5 demonstrates per Euro class the real-world NO_x emissions of passenger cars under urban driving conditions. It is clear to see that for years now the real-world emissions of diesel passenger cars have been reduced very little, if at all, and in some cases have even increased, despite the tightening of emissions limits for NO_x. Real-world emissions are important because various cities in the Netherlands and abroad still suffer from air quality issues. The high NO_x emissions of vehicles contribute to high NO_2 concentrations in the local air.

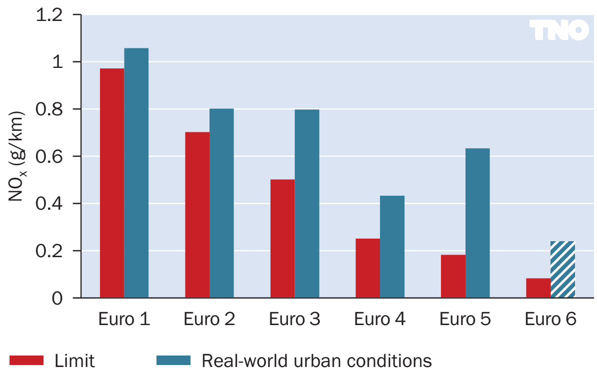


Figure 5. NO_x real-world emissions of passenger cars in urban conditions per Euro class. Despite a tightening of the emission limits for NO_x these real-world emissions of diesel passenger cars have scarcely fallen over the years, if at all. More measurements still need to be taken of Euro 6 passenger cars. At the date of drafting this report, not all vehicles models are available in a Euro 6 variant. The Euro 6 real-world emissions may still change in the future on the basis of new measurements and are therefore shown shaded.

For the measurement programme of a total of sixteen Euro 6 diesel passenger cars, measurements were carried out in 2010 (Phase 1) on four pre-production 'Euro 6' vehicles intended for the US market. In 2013 (Phase 2) six of the very first vehicles in production were measured, and in 2015 (Phase 3) six production models with SCR and EGR technology now available on the market were tested.

Almost all Euro 6 vehicles that were measured emitted significantly more NO_x in real-world conditions on the road than during a type-approval test in the laboratory. In real-world trips on the road, measurements for one vehicle tested in Phase 3 revealed average NO_x emissions of around 650 mg/km, whereas during all laboratory tests for chassis dynamometer measurements – thus also during cycles other than the type-approval test – the same vehicle easily complied with the Euro 6 limit of 80 mg/km. It is striking that in real-world conditions the NO_x emissions are more than eight times higher than the type-approval value. The difference illustrates that the settings for the engine, the EGR, and the SCR during a combined real-world trip are ineffective to achieve low NO_x emissions.

Only one of the Euro 6 production vehicles tested during Phase 3 measured relatively low real-world NO_x emissions of 150 mg/km. This vehicle, as with the other vehicles tested during Phase 3, was fitted with a combination of EGR and SCR. In contrast to the other vehicles, the settings for the engine, the SCR catalytic converter, and the EGR system for this vehicle were such that even under all real-world conditions NO_x emissions were significantly reduced. An effective EGR achieves low NO_x emissions from the engine of 650 mg/km, in combination with a NO_x reduction of 500 mg/km in the SCR system.

This one relatively well-performing vehicle shows that the combination of SCR and EGR has the potential to achieve low real-world NO_x emissions in all Euro 6 diesel passenger

3 Kadijk, 2015a. Kadijk, Mensch, van and Spreen. Detailed investigations and real world emission performance of Euro 6 diesel passenger cars, 18 May 2015, TNO report TNO 2015 R 10702.

cars. Given the current size of SCR catalytic converters, NO_x emissions can be reduced by a maximum of around 500 mg/km. Accordingly, an SCR system is therefore insufficient on its own: an effective EGR system is also needed to sufficiently reduce the NO_x emissions of diesel passenger cars.

The current capacity of the AdBlue tank of diesel passenger cars is around 15 to 25 litres and is mostly refilled during regular maintenance checks. To comply with the Euro 6 limit of 80 mg/km in real-world conditions, most vehicles currently available would require a 45 to 80% larger AdBlue tank, or the current AdBlue tanks would need to be filled in between maintenance checks. One of the vehicles tested has an AdBlue tank large enough to sufficiently reduce NO_x emissions without a required refill in between the regular maintenance checks.

It is anticipated that the smaller Euro 6 diesel vehicles, to appear on the market during 2015, will be fitted only with EGR technology, as is the case with Euro 5 vehicles, since smaller vehicles can meet the Euro 6 standard for NO_x emissions just with EGR – i.e. without the additional need for SCR. Given the real-world measurements of previously tested Euro 5 vehicles, it is expected that the real-world emissions on the road of these vehicles too will prove to be relatively high. To date, there is no legislation that sets standards for the real-world emissions of passenger cars and light commercial vehicles, and thus to effectively reduce on-road emissions. However, the European Commission is currently working on legislation for a new type-approval test (see box).

COMPARING THE NO_X EMISSIONS OF PASSENGER CARS AND LIGHT COMMERCIAL VEHICLES WITH THOSE OF HEAVY-DUTY TRUCKS

A comparison of the NO_x emissions of passenger cars with those of heavy-duty trucks is illuminating: the real-world emissions per kilometre driven of Euro VI trucks are very similar to the real-world emissions of Euro 6 diesel passenger cars (Figure 6). The transition from Euro V to Euro VI was a big step for trucks, both in absolute and relative terms. However, the results achieved by the transition from Euro 5 to Euro 6 in the case of passenger cars is, however, small. The NO_x emissions of Euro 5 light commercial cars, or vans, are between two and three times higher than those of Euro VI trucks, even though these heavy-duty trucks are five to ten times heavier.

This difference is primarily accounted for by the fact that the legislation for heavy-duty vehicles (Euro VI) requires the type-approval test to include the said real-world test. Currently, the Euro 6 legislation for passenger cars and light commercial vehicles involves no kind of real-world test whatsoever.

'REAL DRIVING EMISSIONS': LEGISLATION TO ACHIEVE LOW REAL-WORLD EMISSIONS

This legislation, referred to by the name '*Real Driving Emissions*' or RDE, is intended to regulate the emissions of diesel passenger cars under real-world driving conditions.

On 19 May 2015, the European Commission's Technical Committee – Motor Vehicles (the 'TCMV') reached agreement on the implementation of the RDE for passenger cars and light commercial vehicles. The details of this RDE legislation, including the limit values that real-world emissions must meet, will be worked out in due course. The European Commission has set itself the goal of drawing up the full legislation before the end of 2015, so that two years later, at the end of 2017, the limit values can be legally enforced in respect of the type-approval tests to be applied at that time. After another year, at the end of 2018, the procedure will be mandatory for all new vehicles.

The European automotive industry prefers, however, implementation of the RDE legislation to be postponed to 2020. It is therefore unlikely that this legislation will be able to contribute in the short term to solutions to air quality problems. Furthermore, the quality of this legislation and in particular the quality of the underlying test procedures and protocols will greatly influence the ultimate results in real-world conditions. The Ministry of Infrastructure and the Environment, the RDW, and TNO jointly sit on the TCMV and thereby contribute to the development of effective legislation.

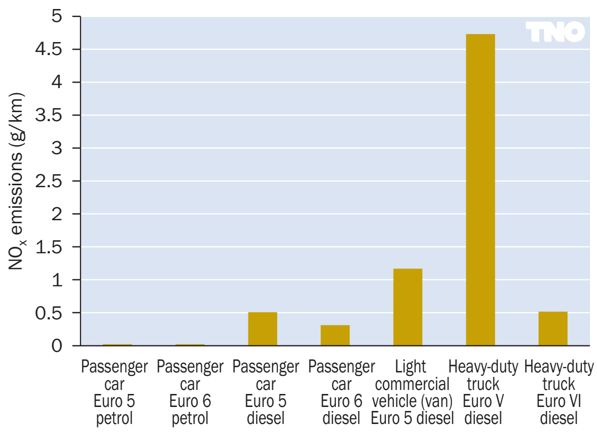


Figure 6. Comparison of the NO_x emissions of Euro 5/6 petrol and diesel passenger cars and Euro V/VI diesel heavy-duty vehicles. The absolute NO_x emissions of a Euro VI heavy-duty truck are at the same level as a Euro 5 or even a Euro 6 passenger car. The numbers in the figure indicate the 'emission factors' for 2015: emissions on the motorway, in rural and in urban conditions are weighed to produce an average value for NO_x emissions in grams per kilometre of distance travelled.

Given the still disappointing results for diesel passenger cars and diesel light commercial vehicles, the focus of emissions measurements for these vehicles over the coming years lies on the NO_x emissions of these vehicle categories. A further improvement of the Euro VI legislation for heavy-duty vehicles can consolidate the good results of the commercial vehicles group that still sometimes lags behind: city buses and distribution trucks. The Ministry of Infrastructure and the Environment and TNO use the measurements from the emission measurement programmes to argue in Brussels for the introduction of an effective real-world test as a part of the type-approval test for passenger cars and a tightening of the standards for heavy-duty vehicles.

EMISSIONS OF PARTICULATES (PM) BY DIESEL VEHICLES

Modern diesel passenger cars, light commercial vehicles, and heavy-duty vehicles are all fitted with a diesel particulate filter to reduce particulates (PM, particulate matter). In real-world conditions, the PM emissions of these vehicle categories are very low.

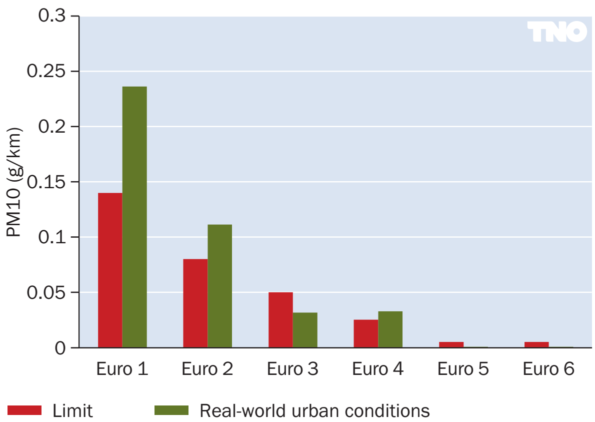


Figure 7. Over the years, particulate emissions of passenger cars have decreased significantly. Euro 5 and 6 passenger cars are fitted with a diesel particulate filter and produce very low particulate emissions. The real-world emissions of these vehicles are a long way beneath the limit value and scarcely measureable at all.

The introduction of the Euro 4 standard in 2005 halved the particulate limit value for diesel passenger cars. The five-times stricter limit for particulate emissions in the 2009 Euro 5 regulations meant that vehicle manufacturers could only comply with the legislation by fitting vehicles with particulate filters during their manufacture. Approximately half of all Euro 4 vehicles have also already been fitted with a particulate filter as part of a national subsidy programme. Figure 7 shows that the level of particulate emissions of diesel passenger cars in urban conditions has fallen significantly over the years. The more dramatic fall following the introduction of the Euro 5 limit value can clearly be identified. The real-world emissions of these vehicles are scarcely measurable, and therefore not visible in this figure.

A similar trend can be identified in respect of diesel light commercial vehicles (Figure 8). In 2010, Euro 5 introduced the fitting of particulate filters to diesel light commercial vehicles during their manufacture.

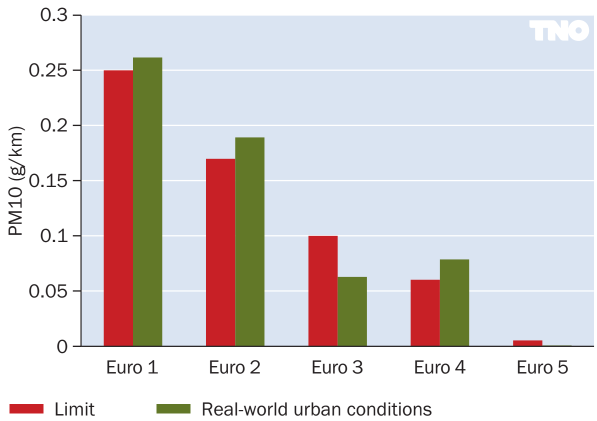


Figure 8. Particulate emissions of light commercial vehicles have also been significantly reduced over the last decade. Euro 5 light commercial vehicles are fitted with a diesel particulate filter resulting in extremely low particulate emissions, that are much less than the limit value and scarcely measurable at all.

The introduction of particulate filters has also resulted in a steep fall in the particulate emissions of heavy-duty vehicles (Figure 9).

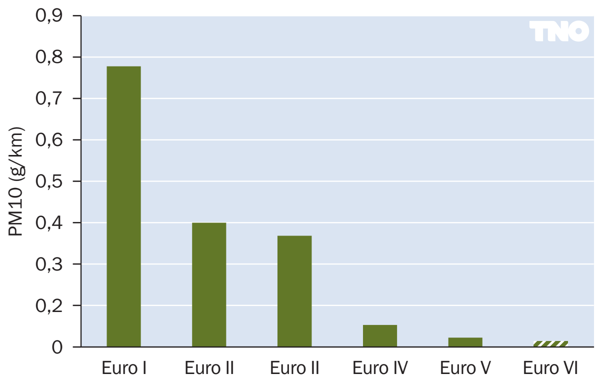


Figure 9. The particulate emissions of heavy-duty vehicles in urban conditions have been significantly reduced. The legislation governing the PM10 emissions of heavy-duty vehicles is not standardised in g/km because for this vehicle category standards have been set in respect of these vehicles' engines. Accordingly, no limit values are shown in this figure. Since not all real-world information concerning Euro VI commercial vehicles is yet available, the particulate emissions for these vehicle classes are shown shaded.

To ensure that these low particulate emissions will be maintained, TNO has been commissioned by the Ministry of Infrastructure and Environment to keep monitoring these emissions. In daily, real-world conditions the assurance of the presence and good working order of an effective particulate filter is essential. Such assurance checks can be carried out, for example, as part of an MOT inspection or equivalent vehicle safety, roadworthiness, and exhaust emissions inspection.

CONCLUSIONS

1 In the case of heavy-duty vehicles, the real-world test set by the Euro VI legislation has resulted in a significant reduction of real-world NO_x emissions.

2 In not all cases do the real-world NO_x emissions of Euro VI buses and distribution trucks appear to be as low as may be expected on the basis of the new Euro VI limit values. Because these vehicles are mostly driven in urban conditions, it is desirable for the real-world emissions of these vehicles also to be low.

3 The real-world emissions of Euro 5 light commercial vehicles are between 5 and 6 times higher than the Euro 5 type-approval limit value for NO_x. In terms of NO_x emissions, light commercial vehicles are therefore two to three times more polluting than Euro VI heavy-duty trucks. In the future they will therefore still substantially contribute to high NO_2 concentrations in the air. In the coming years, commercial vehicles will have to comply with Euro 6 legislation. Until there is legislation governing Real Driving Emissions (RDE), real-world NO_x emissions are not expected to fall very much, if at all.

4 Almost all the Euro 6 passenger cars measured emitted much more NO_x in real-world on-road conditions than during a type-approval test in the laboratory. The NO_x real-world emissions of Euro 6 passenger cars currently in production are up to eight times higher than the limit value of the type-approval test and are on average just below the level of Euro VI heavy-duty vehicles.

5 One of the six Euro 6 diesel passenger cars currently in production that was tested in 2015 with EGR and SCR reached average NO_x emissions in real-world on-road conditions of around 650 mg/km, even though in laboratory tests all chassis dynamometer measurements – i.e. also during cycles other than the type-approval test – the same vehicle easily satisfied the Euro 6 limit value of 80 mg/km. It is striking that real-world NO_x emissions are more than eight times as high as the type-approval limit values. The difference illustrates that the settings for the engine, the EGR, and the SCR during a combined real-world trip are ineffective to achieve low NO_x emissions.

6 Only one of the six diesel passenger cars currently in production that was tested in 2015 with EGR and SCR did achieve relatively low real-world emissions. In contrast to the other vehicles, the settings for the engine, the SCR, and the EGR are such that NO_x emissions under real-world conditions are significantly reduced. This vehicle's NO_x emissions of 150 mg/km are achieved through its engine's low NO_x emissions of 650 mg/km, combined with a NO_x reduction of approximately 500 mg/km within the SCR system.

7 In real-world conditions, the EGR and SCR systems applied to tested Euro 6 diesel passenger cars do not function optimally. Lower real-world emissions are possible by adjusting the settings of the EGR and SCR systems. This means that the AdBlue tanks of diesel passenger cars – which currently have a capacity of around 15 to 25 litres – would need to be refilled in between maintenance checks. One of the vehicles tested has an AdBlue tank large enough to sufficiently reduce NO_x emissions without a required refill in between the regular maintenance checks.

8 It has also been shown that - just as in the case with heavy-duty vehicles - the combination of SCR and EGR has the potential to achieve low real-world NO_x emissions in all Euro 6 diesel passenger cars. Given that current legislation does not lay down limits for real-world emissions, low real-world NO_x emissions will be seldom achieved at the present time.

9 The introduction of RDE legislation, which imposes limits on the real-world emissions of Euro 6 passenger cars, is necessary to ensure that a significant reduction in real-world NO_x emissions is achieved in respect of all diesel vehicles. On 19 May 2015, agreement was reached on the introduction of such RDE legislation for light-duty vehicles. The details of this legislation, including the limits to be set for real-world emissions, will be decided in the future. The European Commission has set itself the goal of drafting the full legislation before the end of 2015 so that two years later, by the end of 2017, the application of the limit values to the type-approval tests to be conducted at that time can be made mandatory. One year later still, at the end of 2018, the procedure will become mandatory for all new vehicles. The Ministry of Infrastructure and the Environment, the RDW, and TNO jointly sit on the TCMV and thereby contribute to the development of effective legislation.

10 For all vehicles fitted with a diesel particulate filter the real-world particulate emissions measure well below the limit values of the type-approval test. To ensure these low particulate emission levels in real-world conditions, these vehicles with particle filter technology do need to be tested for the presence and good working order of an effective particulate filter.

APPENDIX – LIST OF TESTED PASSENGER CARS

Summary of vehicles tested and type of emission tests per vehicle

Investigation phase	Vehicle type	Vehicle code	Chassis dynamometer tests (#)	PEMS tests (#)	SEMS tests (#)
Phase 1	prototypes	H2	6	-	-
		H3	3	-	-
		A2	3	-	-
		E4	6	-	-
Phase 2	first Euro 6 production models	H4	7	-	-
		H6	9	-	-
		H7	0	14	-
		E6	8	15	-
		J1	8	-	-
		J2	10	17	17
Phase 3	selection of Euro 6 vehicles with SCR	K1	19	-	-
		K2	7	16	16
		L1	12	11	16
		M1	7	14	37
		N1	7	-	55
		O1	7	14	20
Total number of tests			**119**	**101**	**161**

Phase 1 – Euro 6 prototypes, tested in 2010

Vehicle code	-	H2	H3	A2	E4*
Capacity	(kW)	>150	>150	>150	100-125
Engine displacement	(cm^3)	>2000	>2000	>2000	1750-2000
Odometer	(km)	2,354	16,634	9,466	9,400
Fuel	-	Diesel	Diesel	Diesel	Diesel
Empty weight	(kg)	1700	1930	2040	1590
Emissions class	-	Euro 6	Euro 6	Euro 6	Euro 6
Vehicle type	-	Sedan	Sedan	Sedan	Sedan
System for reducing NO_x emissions	-	LNT**	LNT**	SCR	SCR

* Three vehicles

** Lean NO_x Trap, an alternative method to reduce NO_x emissions

Phase 2 – First Euro 6 production models, tested in 2012 and 2013

Vehicle code	-	H4	H6	H7	E6	J1	J2
Capacity	(kW)	125-150	100-125	100-125	100-125	100-125	100-125
Engine displacement	(cm^3)	1750-2000	1750-2000	1750-2000	1750-2000	1750-2000	1750-2000
Odometer	(km)	10,965	28,376	3,000	26,200	20,100	11,616
Fuel	-	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
Empty weight	(kg)	1590	1470	1810	1590	1590	1590
Emissions class	-	Euro 6	Euro 6	Euro 6	Euro 6	Euro 6	Euro 6
Vehicle type	-	Wagon	Sedan	Sedan	Sedan	MPV	MPV
System for reducing NO_x emissions	-	LNT**	LNT**	LNT**	SCR	EGR	EGR

Phase 3 – Selection of Euro 6 vehicles fitted with an SCR system, tested in 2014 and 2015

Vehicle code	-	K1	K2	L1	M1	N1	O1
Capacity	(kW)	100-125	100-125	75-100	100-125	>150	>150
Engine displacement	(cm^3)	1500-1750	1500-1750	1500-1750	>2000	>2000	>2000
Odometer	(km)	3,500	15,000	10,125	20,000	19,500	11,400
Fuel	-	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
Empty weight	(kg)	1700	1700	1250	1590	2270	1930
Emissions class	-	Euro 6	Euro 6	Euro 6	Euro 6	Euro 6	Euro 6
Vehicle type	-	MPV	MPV	Wagon	Sedan	MPV	Sedan
System for reducing NO_x emissions	-	SCR	SCR	SCR	SCR	SCR	SCR

TNO
Earth, Life & Social Sciences
Van Mourik Broekmanweg 6
2628 XE Delft
The Netherlands

P.O. Box 49
2600 AA Delft
The Netherlands

TNO.NL