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TNO report

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In-use compliance programme passenger cars
Annual Report 2004

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Summary

This report presents a general overview of the results of the Dutch In-Use Compliance programme for passenger cars over the year 2004. The work in this year was executed under a contract with the Dutch Ministry of Housing, Spatial Planning and the Environment for the period 2000-2004. The passenger car In-Use Compliance programme basically assesses car emission performance in use, against the corresponding emissions legislation.

In 2000 the Euro 3 emission legislation and limits entered into force. In the years 2001 to 2004 the In-Use Compliance programme therefore focused on gathering information on the emission performance of this generation of vehicles. In these years a large number of Euro 3 and Euro 4 vehicles was tested. Anticipating the 2005 introduction of the Euro 4 limits, the regular programme of 2004 focused on expanding the emission database.

Additional to checking under type approval test conditions, further testing has been done to establish real-world emission factors of passenger cars in order to understand the mechanisms that lead to differences between Type Approval (TA) and real-world testing. These insights are also important for emission factors modelling purposes. For this purpose additional tests were executed using two sets of special test cycles:

- Highway traffic situations, using the categorisation from the Dutch Emissions & Congestion project, in order to extend the existing emission database with Euro 3 and Euro 4 data (initially only Euro 1 and 2 were included).
- General real-world emissions, using the Common Artemis Driving Cycle (CADC), in order to establish emission data under dynamic circumstances for the purpose of advanced emission modelling closely linked to other European research work.

In 2002 it was agreed with the Ministry of Housing, Spatial Planning and the Environment to set up the programme differently in order to be able to fulfil the actual research needs of the Ministry. As a consequence additional research topics were addressed in 2004 in several different sub-programmes. These sub-programmes which were identified in co-operation with the Ministry were the following:

- The **cold start effect under real world conditions**. For this purpose a CADC Urban cycle was driven with a cold start at 9°C.
- The effect of **chiptuning** on emissions
- Emissions of 4 new **Dutch real world highway cycles**
- Testing done for the EU 5th Framework project **'OSCAR'** (co-financed)

The next table gives an overview of the vehicles tested in 2004:

Table 1 Number of vehicle types tested in 2004 per sub-programme

	Petrol	Diesel	LPG
Regular programme	5	3	2
Real world cold start	9	9	2
Chiptuning		1	
Dutch real world highway cycles	9	9	2
'OSCAR'	9	9	2

Besides the information of in-use emission performance, valuable information is gathered in order to support policy makers. This is made available through direct communication with the Ministry as well as by means of the output of the Dutch vehicle emission model VERSIT and the future emission model VERSIT+. The Dutch annual traffic emissions are calculated by input based on the VERSIT model given to RIVM through the channels of the Dutch "Taakgroep Verkeer".

Further dissemination is achieved by TNO-Automotive actively taking part in ARTEMIS workshops and the DACH+NL group. Furthermore, publications have been made which were presented at the annual Transport and Air Pollution conference.

The main findings and conclusions for the year 2004 were the following.

For the **petrol vehicles** tested in the **regular programme** of 2004 it can be concluded that they had very low emissions levels, just like in previous years. Most of the vehicles tested (both Euro 3 and 4) complied with the Euro 4 limits. The Euro 4 vehicles did not show a significantly different emissions characteristic compared with the Euro 3 vehicles. A considerable proportion of the emissions was produced during the cold start.

The results for **the Euro 3 diesel vehicle types** show that the technology has reached a level where the limits can be reached easily. Only one exception occurred in 2004, where one vehicle had a PM result of 10% above the limit value. As already mentioned in the 2003 report, the problems with Euro 3 diesel vehicles as encountered in earlier years of the in use compliance programme now definitively belong to the past.

As Euro 3 diesel vehicles are almost faultless nowadays, this can't be said for **Euro 4 diesel vehicles** however. Although only one of the first Euro 4 vehicles types that have become commercially available has been tested, the same scenario as for the early Euro 3 vehicle types seems to repeat itself, at least for vehicles without additional aftertreatment devices such as particulate traps or DeNO$_x$ systems. As the next legislative step tightens the limits considerably, the 'old' Euro 3 technology has been optimised even further to become Euro 4 technology. As a result, the first instance of this Euro 4 technology, as seen in the 2004 in use compliance programme, failed to meet the Euro 4 PM limits on initial test in all three instances. Furthermore this vehicle type appeared to be very sensitive to the maintenance condition and the test procedure followed. Especially pre conditioning and optimised drive wind cooling, as prescribed by a manufacturer, seem to influence the result considerably. As a vehicle in general only can meet the limits on a set of boundary conditions specified by the manufacturer, a vehicle will not automatically meet the limits in any other laboratory, even if this laboratory is officially equipped to perform type approval test procedures as prescribed by the European Union.

The two **LPG vehicle types** tested in 2004, one OEM Euro 3 vehicle and one retrofit G3 vehicle, both performed very well on an average basis. On an individual basis one failure of meeting the HC+NO_x limit can be reported for the retrofit G3 vehicle. When both vehicles are compared, the OEM vehicle has a somewhat more stable emission result and the lowest cold start effect for CO and HC.

The results from additional tests on the **real-world testcycles** ('Emissions and congestion' cycles and Common Artemis Driving Cycles) were added to the results that had been gathered in previous years to improve the statistical foundation of the emission characteristics. The emission results under **real world cold start conditions** show that the individual results vary a lot, especially for the components CO and HC. A statistical sound cold start effect under real world conditions therefore can not be determined yet with the results that were obtained.

Regarding the tests with **chip-tuning**, a distinction between 'simple' and 'sophisticated' types of chip-tuning must be made. The tests have shown that the largest effects occur with the simple chip-tuning, where by means of "fooling" the ECU, the amount of fuel injected is increased. Since no adaptations to the injection timing are made, the change in fuel amount and injection duration has its effects on the NO_x (decrease) and PM (increase) emissions. The effects measured on the more sophisticated types of chip-tuning are of a lower magnitude, and in many cases the emissions remained close to the level of the standard vehicle.

In recent years the need for a more refined set of **real world highway driving cycles** within the speed range of 80 to 100 km/h became apparent. Especially situations with a speed limit of 80 with trajectory speed limit enforcement became subject of much public and political attention. For this reason TNO decided to develop four more driving cycles that address these specific situations. These cycles were developed within the framework of the "Driving cycles" target funding programme in 2003 and 2004. The four driving cycles that were developed can be described as follows:

Table 2 Characterisation of additional Dutch real world highway cycles

Cycle no.	**Speed limit [km/h]**	**Traffic characterisation**	**Speed limit enforcement**	**Location of recorded traffic data**
80FF	80	Free flow	Trajectory speed limit enforecement	A13, Delft - Rotterdam
80MI	80	Medium interaction	Trajectory speed limit enforecement	A13, Delft - Rotterdam
100FF	100	Free flow	High density speed radars	A9, Schiphol - Amstelveen
100MI	100	Medium interaction	High density speed radars	A9, Schiphol - Amstelveen

Based on emission test with 20 vehicles the general conclusion can be drawn that the 80FF cycle is the traffic regime that is to be preferred from an emissions point of view over the 100FF cycle, compared to the 100MI. Especially the effect for NO_x emissions from diesel vehicles seems significant, and in combination with the fact that this vehicle category has the largest absolute emission levels too for both NO_x and PM, the effect of imposing a 80FF traffic regime can have an effect on the air quality as well. It is difficult at this point to attach a percentage to the amount with which the emissions could be reduced however. This strongly depends on the reference situation (speed limit regime, congestion) and the vehicle fleet composition. But also the emission test results show a variation of such kind that it is impossible to calculate any statistical significant emission factors for each vehicle class (e.g. diesel Euro 4), for use in air quality modelling. Before this can be done, the number of vehicles per vehicle class that have been tested on these cycles must be increased. Therefore an extension of the number of emission tests with the new Dutch real world highway cycles has been planned for 2005.

In 2004 TNO Automotive participated in the EU 5th Framework project **OSCAR**. OSCAR will deliver a tool to enable users to evaluate road traffic-related air pollution, and to identify suitable impact reduction options. The tool (the OSCAR 'Assessment System') will be designed primarily to address the management of local air quality during periods of traffic congestion. The 10 newly developed OSCAR driving cycles were supplied to TNO Automotive, where the emission tests were conducted on a chassis dynamometer on a total of 20 vehicles. The primary goal of these emission measurements was to expand existing emission databases for slow-moving and stationary traffic on which the emissions will be modelled in the OSCAR Emissions Module. This Emissions Module is planned as a separate entity in the OSCAR system, and would act as an input to all air quality prediction models.

Contents

1 Introduction

This report presents a general overview of the results of the Dutch In-Use Compliance programme for passenger cars over the year 2004. The work in this year was executed under a contract with the Dutch Ministry of Housing, Spatial Planning and the Environment for the period 2000-2004. The passenger car In-Use Compliance programme basically assesses car emission performance in use, against the corresponding emissions legislation.

The passenger car In-Use Compliance programme was started in 1986 in order to obtain objective relevant data on the environmental performance of the then sold first generation of "clean" vehicles. These vehicles received a tax incentive based on the expected environmental benefits, but these benefits still had to be proven in real-world use. This basic concept of vehicles proving their actual environmental performance in real-world use is still utilised in the ongoing programme for the years 2000-2004, but with evolving vehicle technology and legislation over the years, the set-up of the In-Use Compliance programme has changed also. A major point that has gained importance over the years is real-world driving conditions during testing. In this respect the European Type Approval Procedure proves to be insufficiently representative for real-world driving. Therefore next to testing vehicles on the type approval procedure, additional tests are conducted to gain insight into the real-world emission behaviour of passenger cars. The data gained from testing have proved to be very useful for emission modelling purposes. Therefore gathering information on the real-world emission behaviour of passenger cars has become one of the basic targets of the Dutch In-Use Compliance programme.

The basic programme generally consists of testing about 50 different types of vehicles per year (tested basically in threefold per type). The selection of the vehicles to be tested is based on the actual sales (in the year before) of certain engine families. Generally relatively young cars are tested (usually below 35,000 kilometres in the so-called initial test) in order to check whether the cars that have actually been sold during the last years meet their emission limits "in use" also. Executing the In-Use Compliance programme in this set-up for many executive years now supplies a valuable database on the emission performance of the Dutch passenger car fleet. In addition to the "initial vehicles", vehicles with a higher age and mileage are tested to check whether the durability of exhaust aftertreatment systems meets the durability requirements.

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The next table gives an overview of the vehicles tested in 2004:

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In the next chapters an overview is given of the results of each of the above-mentioned subjects.

2 Description of the general procedures

In this section, short descriptions are given to show how the basic elements of the In-Use Compliance programme are arranged.

2.1 Selection of the vehicle types

Vehicle types which are eligible for the test programme are selected on the basis of Dutch sales registrations held by the National Road Traffic Department (RDW). Every quarter the RDW provides an overview of the number of sales in the previous quarter. Because a certain engine can be available in various models and/or brands, this information is used to draft a list of sales figures per engine type sold in the Netherlands. TNO Automotive then makes a suggestion for a vehicle selection on the basis of number of sales per engine type, and also taking account of the engine types tested in previous years. Per engine type that meets these criteria, the vehicle type that has the highest sales figures is added to the vehicle selection.
The vehicle selection is then proposed to the Ministry of the Environment and the steering committee of the In-Use Compliance programme. After their approval TNO Automotive continues with the mailing (see below).

2.2 Mailing

After the vehicle selection has been approved, the names and addresses are requested of owners of the appropriate vehicle types living in Delft and surroundings. About 25-30 persons per vehicle type are approached. In the case of vehicles with low sales figures, names and addresses are requested for a wider area. The cars used for the In-Use Compliance programme are primarily borrowed from private individuals. In some cases companies and/or commercial drivers are approached as well.

On the basis of the response to the mailing a decision will be made as to whether or not a vehicle is in principle suitable for the programme. This is based on the reply coupons that have been filled out. If different tires have been fitted to a vehicle or modifications have been made to the engine, the vehicle in question will not be used for the programme.

Initially, three vehicles per type will be used for the In-Use Compliance test.

2.3 Checks at reception

On arrival the vehicles are checked for possible visible damage. They are also checked with the technical specifications provided by the manufacturer. The vehicle is weighed to verify the inertia class. The serial numbers of the engine, engine accessories, exhaust system etc. are then verified and a check is made on whether the tire size is the same as the original (with regard to transmission ratio). If any discrepancies are found in any of these items, the test is terminated.

2.4 Preconditioning

After the checks at reception of the vehicle, a preconditioning cycle is driven. Petrol and LPG vehicles drive for 15 minutes at 80 km/h in order to discharge the canister of the evaporation control system (if necessary). Diesel vehicles drive the preconditioning cycle according to the Directive. Then the vehicle is placed in a conditioned hall (20-30°C) for a minimum of 6 hours until the oil and water temperatures differ from the ambient temperature by a maximum of ± 2°C. In practice this means that the vehicle is not tested until the following day. In the case of diesel vehicles, the conditioning period is limited to 36 hours. In practice this is not exceeded for petrol vehicles as well.

2.5 Tests before correction

Next day, the first test is the one that was the basis for certification. At present this test is in nearly all cases the Eurotest, also known under the name New European Driving Cycle (NEDC) or the MVEG-B cycle. The Eurotest consists of the Urban Driving Cycle (UDC) and the Extra Urban Driving Cycle (EUDC). The Eurotest is driven from a cold start at 20°C.

2.6 Correction

In case a vehicle does not comply to the limit values on the first test, the vehicle is checked on a number points relating to tuning and maintenance. The following aspects are examined (e.g.):

- EOBD read out
- Ignition timing
- Spark plugs: electrode gap and general condition (petrol vehicles)
- Air cleaner: contamination

If at a certain aspect a problem is encountered, parts will be adjusted or exchanged. However, in cases where no problem can be found, the importer or manufacturer is contacted for help or advice. The problem may be related to a typical part of a certain vehicle type. The importer can also prescribe a different preconditioning procedure than the one already used.

2.7 Test after correction

After the necessary actions have been undertaken, the vehicle is put away again for preconditioning and the following day another test is done. In case the vehicle again doesn't comply to the limits, the importer and or manufacturer are notified in order to look for a possible cause of this. If necessary, the vehicle will be tested again after the modification.

In cases where a problem occurs with only one vehicle of the three vehicles tested per type, the problem is regarded as an incident. However, when there seems to be a more structural problem, two more vehicles of that type will be tested as well. In such a case five vehicles per vehicle type have been tested. If the problem persists, i.e. a vehicle type consequently fails the emission test, the Ministry of the Environment has discussions with the importer or manufacturer to make agreements which are intended to lead to an improvement of the situation. If necessary, this is verified by TNO in further tests on a new series of vehicles.

2.8 Additional tests

When a vehicle does not need to be retested after the first Eurotest, the vehicle is used for additional tests. Annually these tests are agreed with the Ministry of the Environment and are based on its actual research needs. Usually these tests include some type of real world driving cycles or cold start tests. These additional tests are only done with one vehicle per vehicle type.

Sometimes the vehicles needed for tests for a certain research need of the Ministry of the Environment falls outside the scope of the regular programme. In such cases, the vehicles are arranged from private persons or from importers. None of the above described procedures are applicable to these vehicles however.

3 Petrol passenger vehicles

3.1 Initial tests

The vehicles tested in 2004 were both Euro 3 and Euro 4 vehicles. The emission limit values in force for the petrol vehicles tested in the 2004 programme are shown in Table 2.

Table 4 Emission limits for type approval of petrol passenger vehicles

Emission component	Euro 3 limit value [g/km]	Euro 4 limit value [g/km]
CO	2,3	1,0
HC	0,20	0,10
NO_x	0,15	0,08

The exhaust emissions are measured using the standard Euro 3 test procedure with a cold start at 20°C. Since 1 January 2002 the –7°C cold start test is compulsory at type approval for every new vehicle type. Although this test is applicable to any of the vehicles tested, this test has not been done as the TNO facilities are not equipped to do cold start testing. Therefore the tests executed represent the full type approval test set-up for exhaust emissions, with the exception of the –7°C cold start test and of the use of market fuel rather than reference fuel.

Table 3 shows the 5 vehicle types that were tested in 2004.

Table 5 Vehicle types tested in 2004 (petrol)

Vehicle make	Vehicle type	Euro 3	Euro 4	DI
Kia	Sorento 2.4	✓		
Mazda	6 1.8		✓	
Peugeot	307 SW 1.6 16v	✓		
Suzuki	Alto 1,1	✓		
Volkswagen	Touran 1.6 FSI		✓	✓

In Figure 1, the average emissions test results (for 3 vehicles tested per vehicle type) of each vehicle type are plotted in comparison with the Euro 3 and Euro 4 limits.

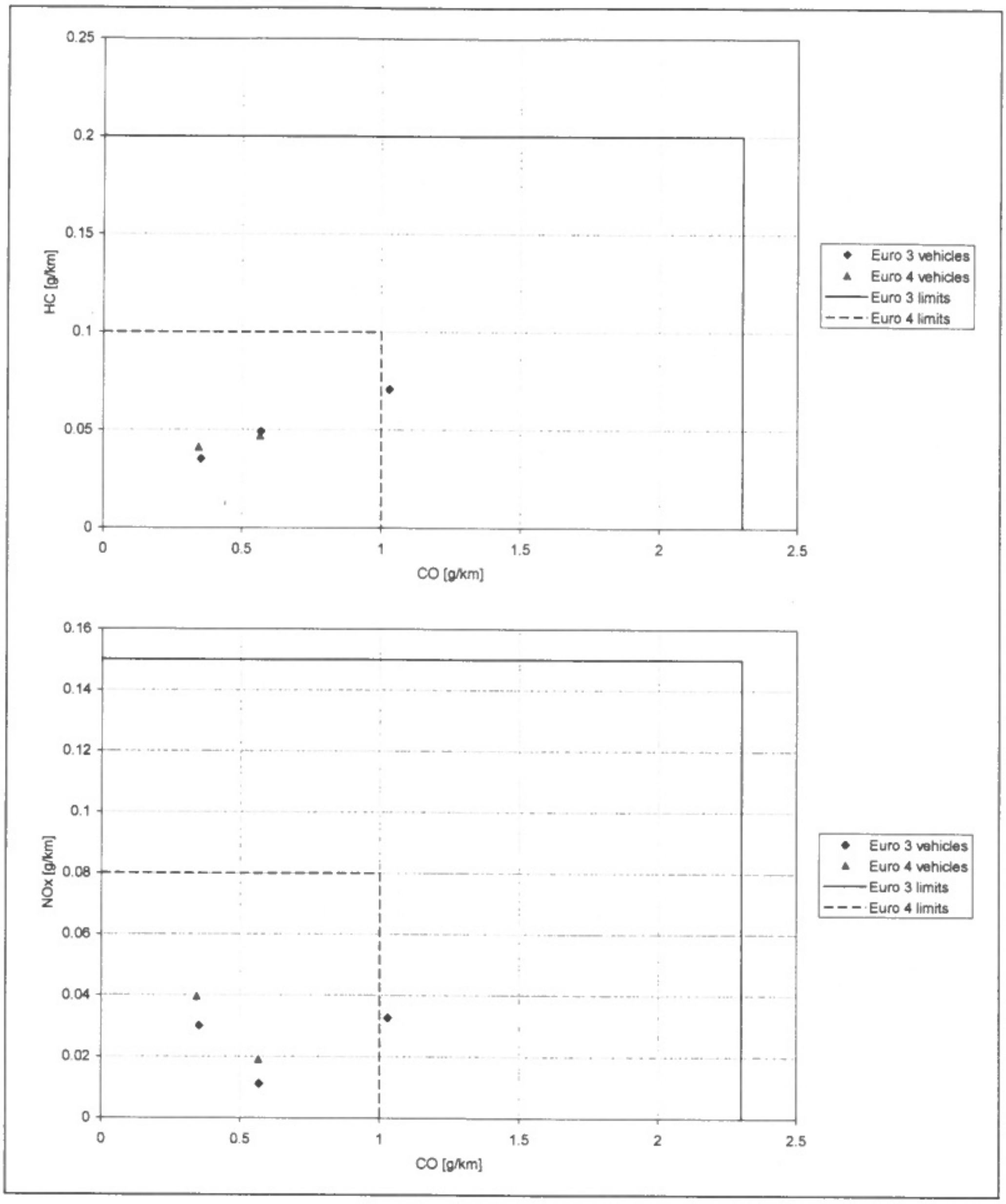


Figure 1 - Results of in-use petrol vehicle types during the standard type approval test procedure (average per vehicle type).

As shown in Figure 1, all vehicle types comply with their corresponding Euro 3 or Euro 4 limits for all emission components. Further, two out of three Euro 3 vehicle types tested also complied with the Euro 4 limits, and in almost every respect performed even better than the Euro 4 vehicle types. Apparently in the years before the entry into force of the Euro 4 limits, the difference between Euro 3 and Euro 4 vehicle types has become a certification matter only, without any difference in emission control technology and the corresponding emission levels. A reason for this could be the discontinuation of the Euro 4 stimulation subsidies and some manufacturers therefore choose for a safer margin towards the limit values, especially regarding the long-term durability. As Euro 4 is due to be enforced in 2005, this approach would also reduce the engineering changes required due to the introduction of the stricter legislation. The individual vehicle results, shown in Figure 2, indicate this also.

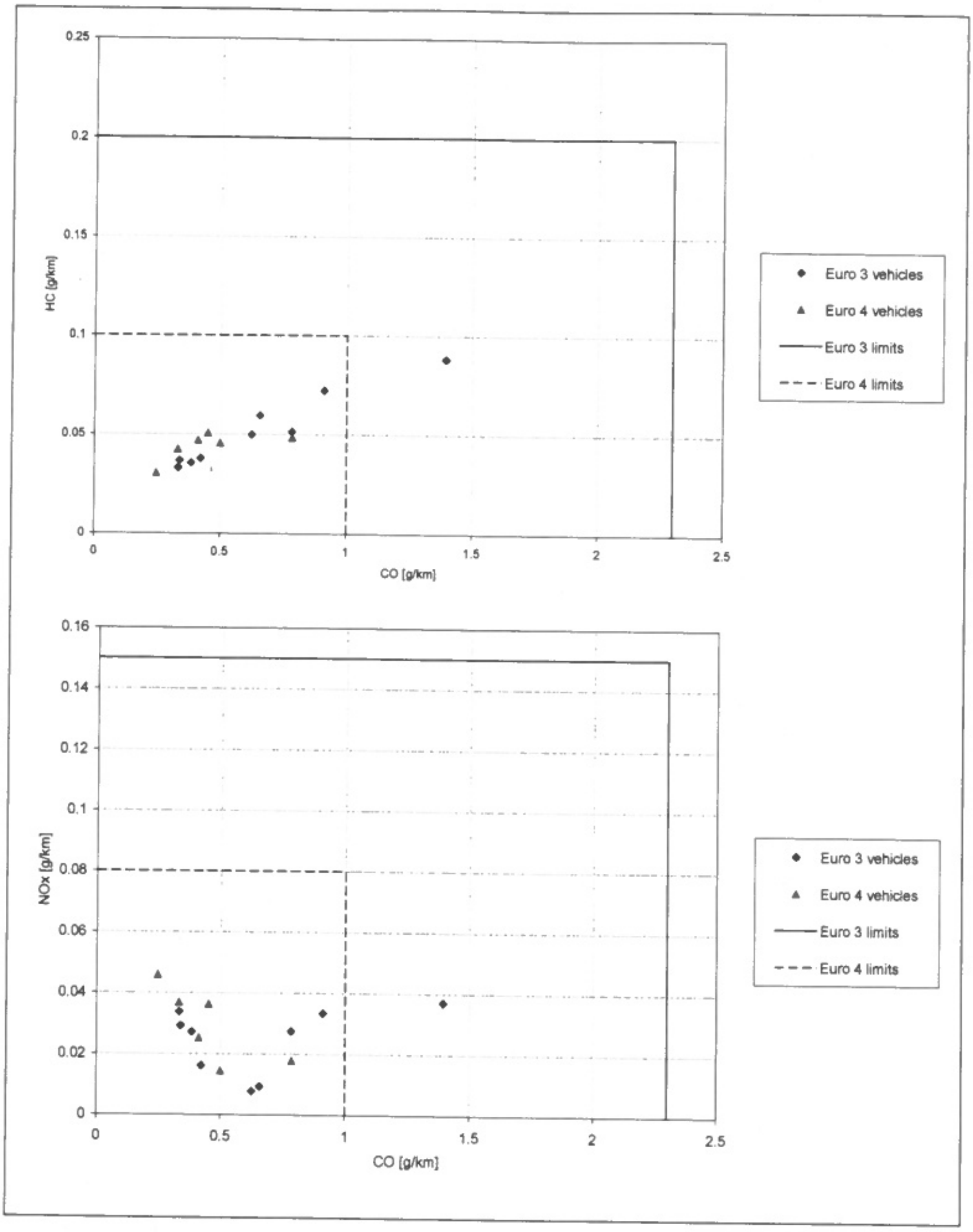


Figure 2 - Results of in-use petrol vehicle types during the standard type approval test procedure (individual results).

When observing the individual vehicle results (Figure 2), the large level of scatter typical for petrol vehicles is apparent. Only one Euro 3 vehicle was not able to achieve Euro 4 results due to a slightly higher CO emission level, but still within the Euro 3 limit with a considerable margin. Per vehicle type, the spread in emission results per type is shown in Figures 3-5.

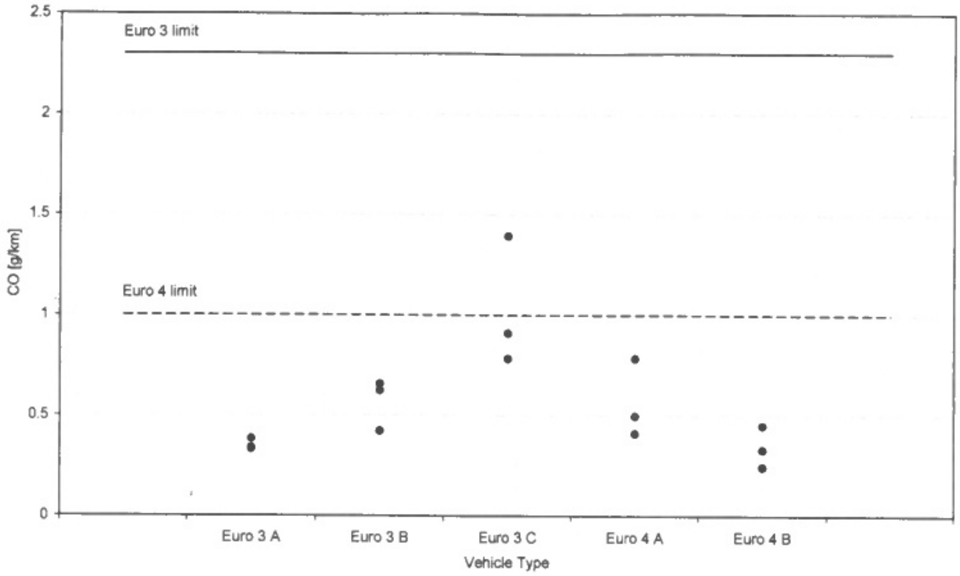


Figure 3 - CO-emission of individual petrol vehicles.

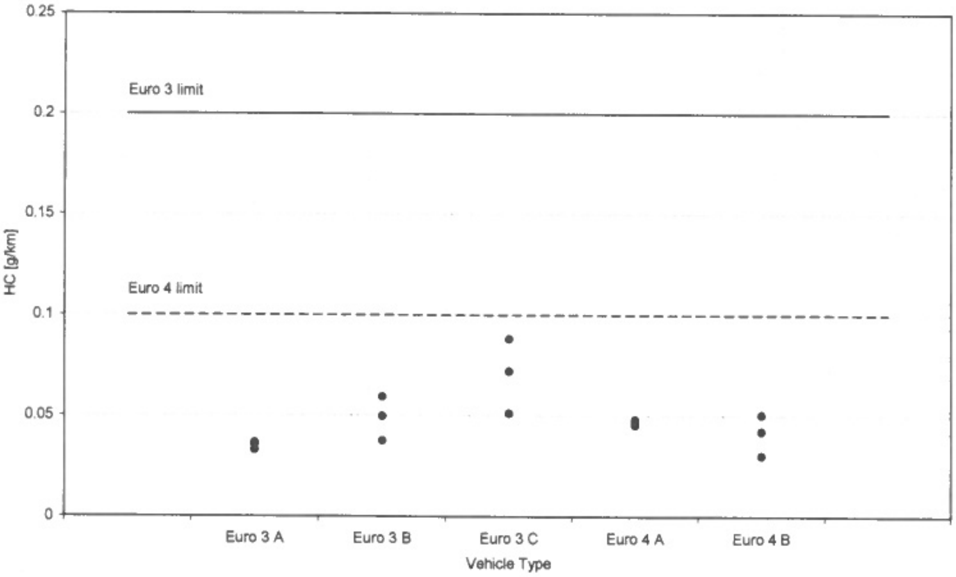


Figure 4 - HC-emission of individual petrol vehicles.

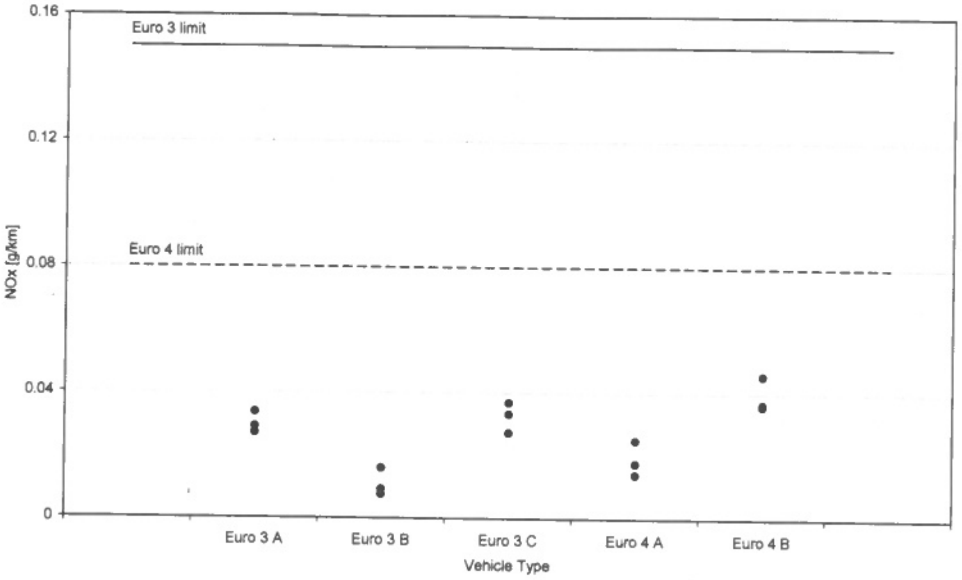


Figure 5 - NO_x-emission of individual petrol vehicles.

It appears that, as observed in previous years, the CO, HC and NO_x emissions show a relatively small spread for vehicles of the same type, with the exception of the CO result of one of the Euro 3 C vehicle type. Especially the Euro 3 A vehicle type showed a very small spread.

3.2 Cold start emissions

Apart from executing the standard Euro 3 test cycle with a 20°C cold start, one vehicle per vehicle type underwent an additional test to collect data on the effects of a cold start on emissions. For this purpose, the urban part of the Eurotest (the UDC) was driven twice:

1. With a cold start from 20°C, and
2. With a hot start (conditioned on a full UDC + EUDC).

The differences in emissions between cold and hot start are mainly caused by the time it takes for the catalyst to reach light-off temperature from cold start. Cold start enrichment (and therefore non $\lambda=1$ operation) will most probably play no role of any importance, since at or above 20°C this fuelling method is not often utilised anymore in modern multi-point injected engines. In Figures 6-9, the results for petrol engines are presented per emission component.

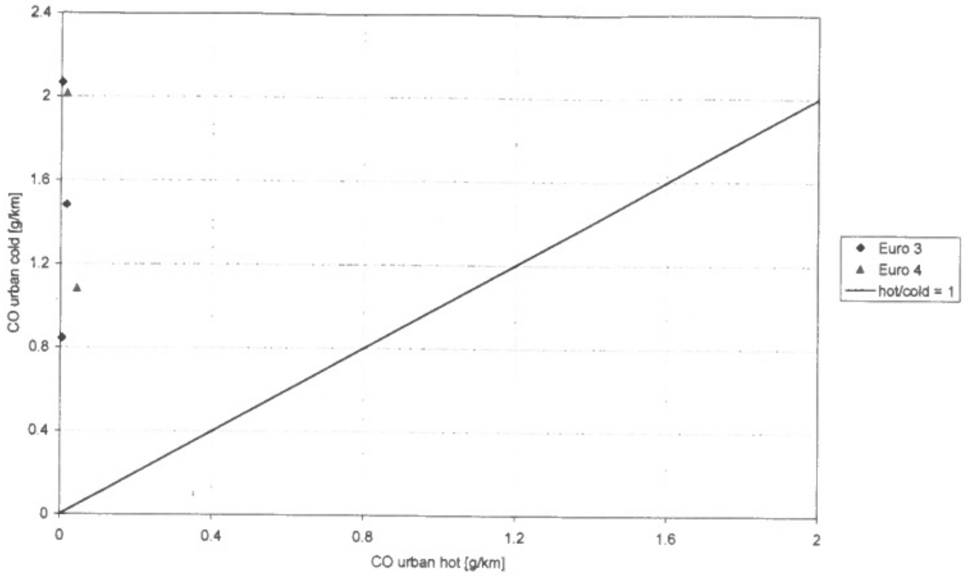


Figure 6 - UDC cold start emissions versus UDC hot start emissions for petrol vehicles: CO

As can be concluded from Figure 6, the CO emissions after hot start are mostly close to zero, whereas the cold start emissions are higher and vary considerably from 0.8 g/km to 2.1 g/km. Apparently the 'hot' and 'cold' emissions have no direct relation to each other and differ considerably from car type to car type. Euro 3 and Euro 4 vehicle types are intermixed. As already noticed in previous years, a clear separation of Euro 3 and 4 vehicles is not evident.

Although Euro 4 approval also involves meeting the –7°C test, it appears that this has not influenced the difference between vehicle emissions from a 20°C cold start and that of a warm start. A possible reason for this is that any reduction of catalyst light-off time through application of catalysts with lower heat capacity can be traded off by reducing exhaust gas temperature, leading to increased engine thermal efficiency. As most Euro 3 vehicles complied with Euro 4 limits, further reduction of light-off times is not necessary and the existing air-fuel ratio control seems sufficient for 20°C cold starts. The extra –7°C requirement has therefore likely lead to extension of the light-off control to cover the temperature range of –7°C to 20°C, with the main concern being HC emissions during cold start (Figure 7). The basic structure of the aftertreatment system is not significantly different for stoichiometric engines for Euro 3 and Euro 4.

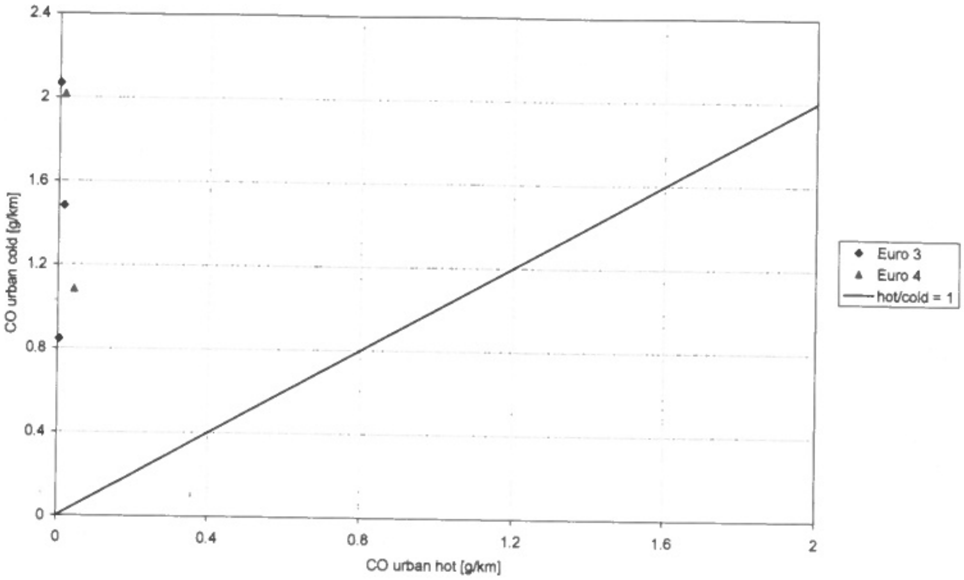


Figure 7 - UDC cold start emissions versus UDC hot start emissions for petrol vehicles: HC

The HC emissions present a similar result. The warm start emissions are very low, while the cold start emissions are considerably higher and widely spread, ranging from 0.08 to 0.13 g/km. As for CO, the Euro 3 and 4 vehicles are intermixed.

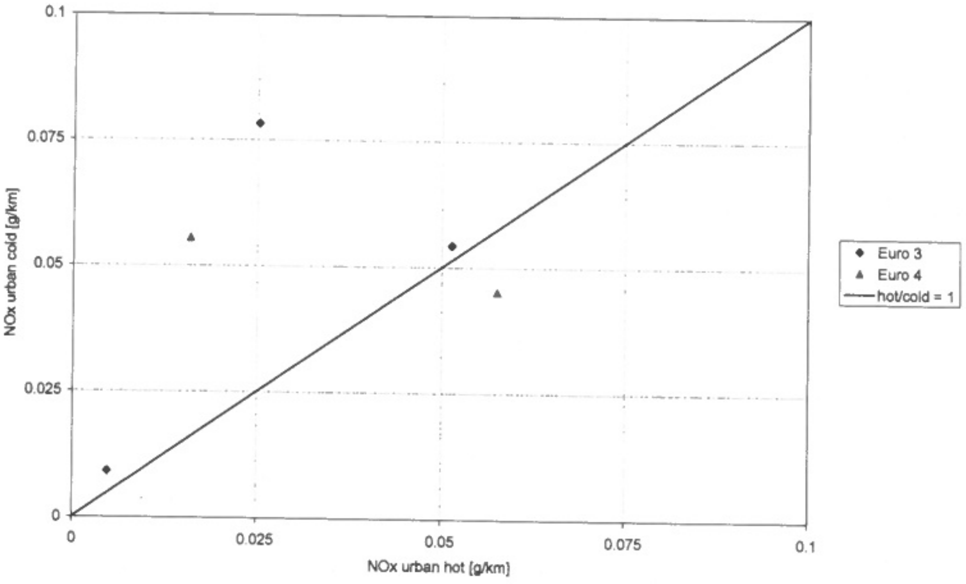


Figure 8 - UDC cold start emissions versus UDC hot start emissions for petrol vehicles: NO_x

The NO_x behaviour shows less dependency of this emissions component on the cold start. Note that the values are relatively low, due to the low loads and engine temperatures on the UDC. For one vehicle, the cold start resulted in lower NO_x emissions than the warm start. It is evident that catalyst light-off has a lower effect on the NO_x emissions than for HC and CO. Once again, the Euro 3 and 4 vehicles are not clearly distinguishable. DI vehicles can have a better NO_x behaviour on a cold start than on a warm start.

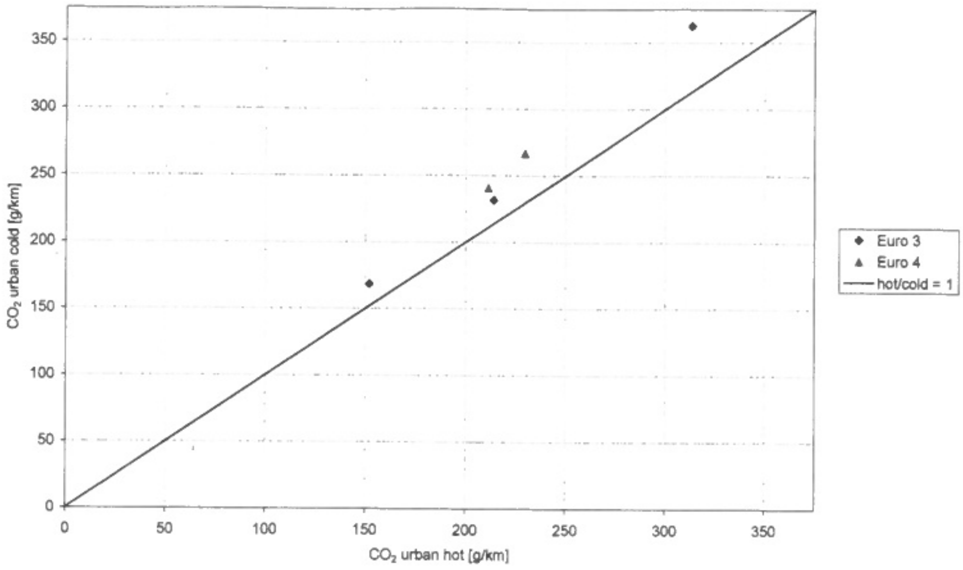


Figure 9 - UDC cold start emissions versus UDC hot start emissions for petrol vehicles: CO_2

The CO_2 emissions increase due to cold start shows a stable pattern. The average cold start penalty for Euro 3 and Euro 4 vehicles amounts to 13%. This effect points at increased friction at a 20°C start, increased thermal losses and probably some minor cold start enrichment effects.

In 2004 additional work has been done on cold start behaviour under real world circumstances. The results of this work are described in chapter 6.

3.3 Summary of results for petrol vehicles

From the previous section it can be concluded that new petrol vehicles have very low emissions levels. Most of the vehicles tested (both Euro 3 and 4) complied with the Euro 4 limits. The Euro 4 vehicles did not show a significantly different emissions characteristic compared with the Euro 3 vehicles. On a per vehicle type basis the emissions also appear to be very stable. A significant proportion of the emissions is produced during the cold start. The initial impression is that the –7°C test has had little effect on emissions from a 20°C cold start.

4 Diesel passenger vehicles

4.1 Initial tests

In 2004 three diesel vehicle types were selected in the In-Use Compliance programme, of which two fell into the Euro 3 category. Since the Euro 4 limits enter into force from 2005 onwards, vehicles falling into this category were sold in 2004 already. Therefore TNO was able to select one of the first Euro 4 diesel vehicles available on the Dutch market.

The emission limit values in force for diesel Euro 3 and Euro 4 vehicles are shown in Table 4.

Table 6 Emission limits for type approval of diesel passenger vehicles

Emission	Euro 3 limit value [g/km]	Euro 4 limit value [g/km]
CO	0,64	0,50
NO_x	0,50	0,25
$HC + NO_x$	0,56	0,30
PM	0,05	0,025

The exhaust emissions are measured using the standard Euro 3 test procedure. The three vehicle types tested in 2004 are shown in Table 5.

Table 7 Vehicle types tested in 2004 (diesel)

Vehicle make	Vehicle type	Euro 3	Euro 4
[anonymous]*	[anonymous]*		✓
Alfa Romeo	147 1.9 JTD	✓	
Renault	Megane 1,5 dCi	✓	

* In the light of the further discussions in this chapter, this vehicle type has been made anonymous because it is the only Euro 4 diesel vehicle that was tested in 2004.

All vehicles were, apart from an oxidation catalyst and EGR, equipped with no additional aftertreatment devices such as a particulate filter or a $DeNO_x$ system.

In figure 10, the average emissions test results (for three vehicles tested per vehicle type) of each vehicle type are plotted in comparison with the Euro 3 and Euro 4 limits.

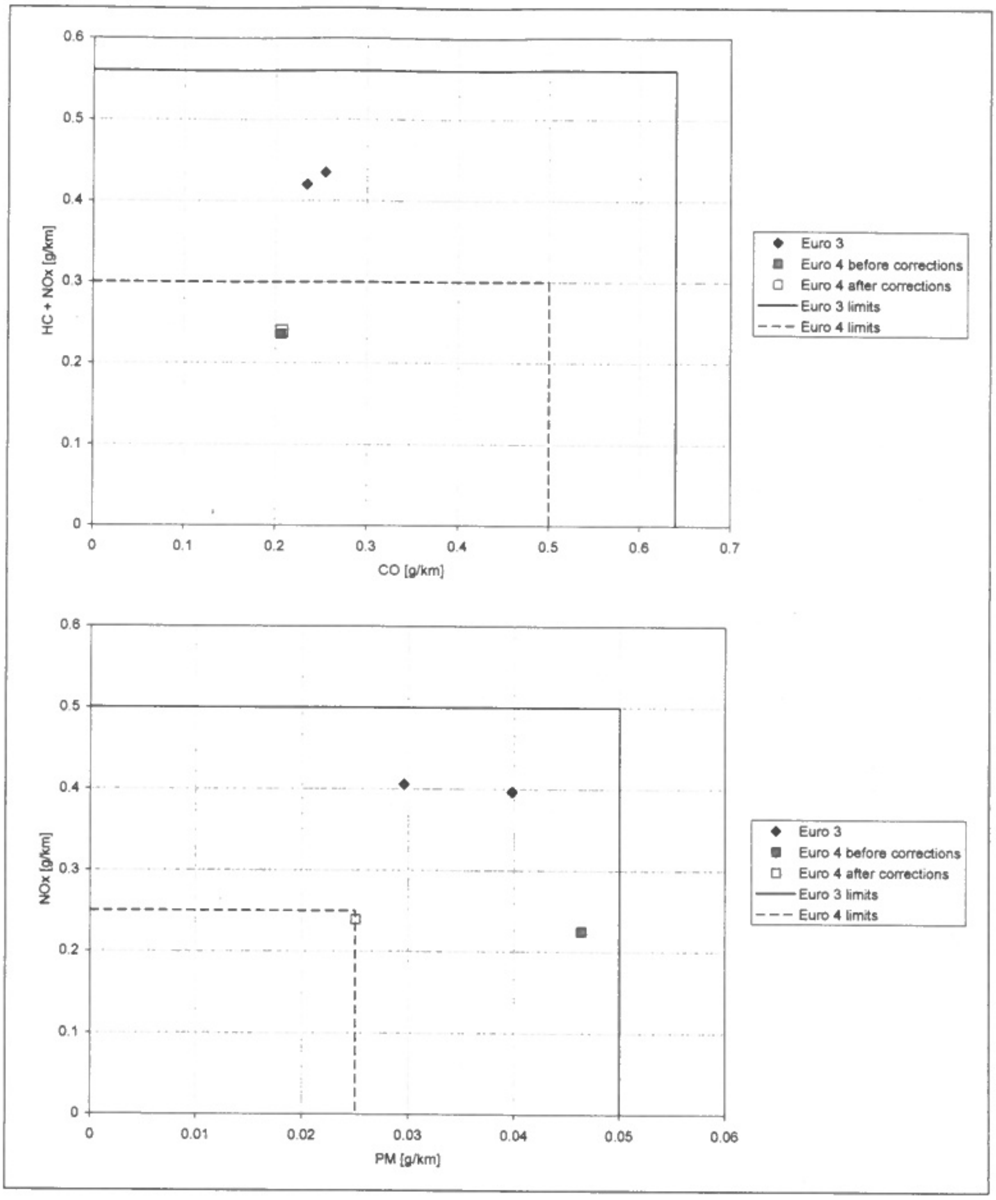


Figure 10 - Results of in-use diesel vehicle types during the standard type approval test procedure (average per vehicle type).

From these figure can be concluded that both Euro 3 vehicle types meet the limits for all components by a rather safe margin. For the Euro 4 vehicle the situation was slightly different however. For the components CO, NO_x and $HC+NO_x$ this vehicle type met the Euro 4 limit, but not for PM. On the initial test this vehicle type showed on average (three vehicles) a PM emission of almost twice the Euro 4 limit. Only after corrections and adjustments had been applied to the vehicles by TNO and the manufacturer, this vehicle type about averaged the Euro 4 limit value. A further discussion will follow the next figures where the individual results have been displayed.

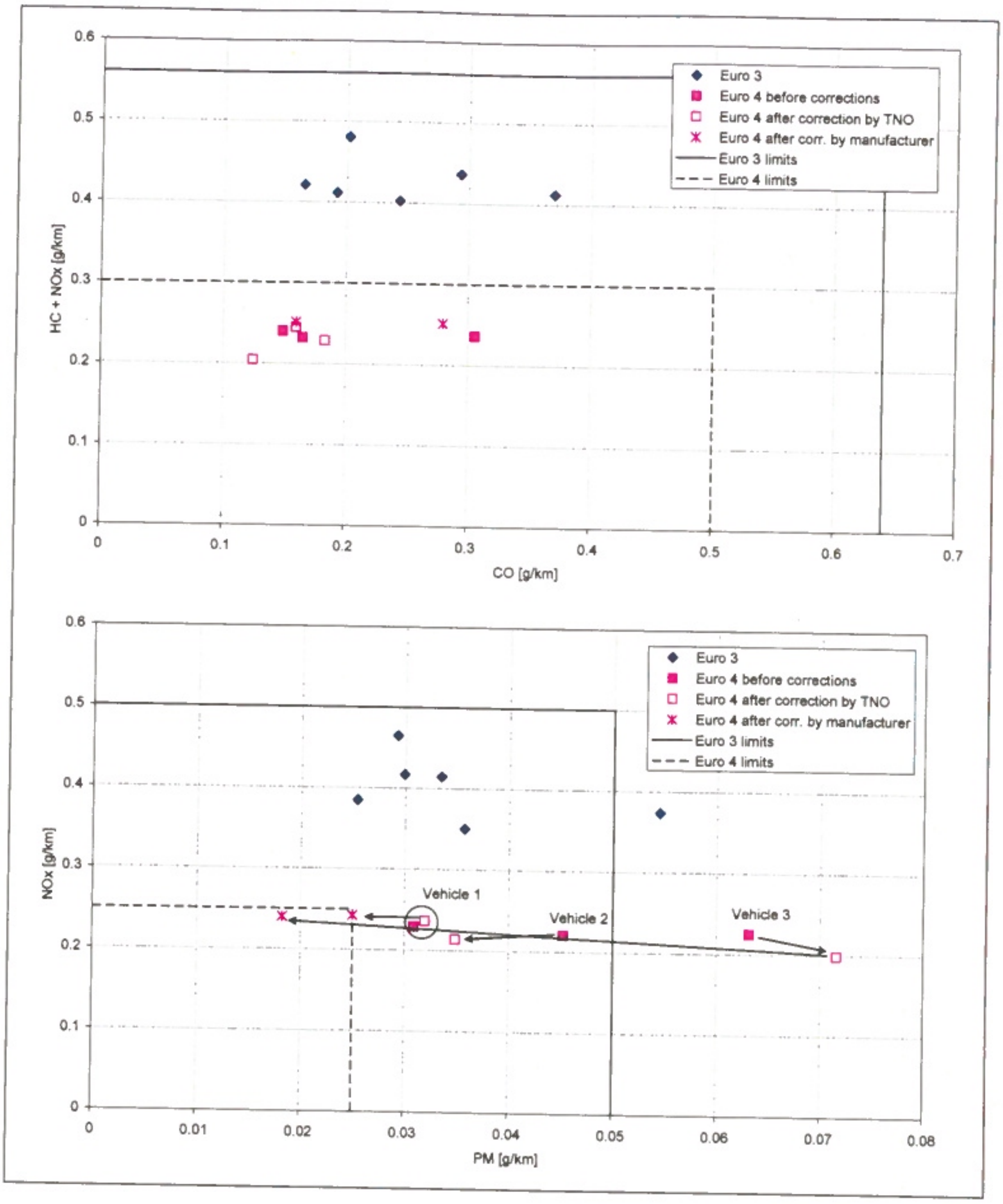


Figure 11 - Results of in-use diesel vehicle types during the standard type approval test procedure (individual results).

The Euro 3 vehicles all (except one) met the limits on an individual vehicle base. One vehicle exceeded the PM limit by 10%. As the other vehicles of this type performed very well, and the average of the three vehicles was within the limit value, this single exceedance was considered to be an incident. No further tests were undertaken.
The Euro 4 vehicle type counted three individual vehicles, which all failed to meet the Euro 4 PM limit on the initial test at TNO. What happened then will be described shortly per vehicle.

<u>Vehicle 1</u>

After the initial test on vehicle 1 the engine oil and the oilfilter were changed, and the vehicle was fuelled with reference diesel fuel. On advice of the manufacturer, of which representatives were present at TNO during testing of this vehicle type, a 'heavy preconditioning' and a 'stabilization pre-conditioning' procedure were done. The tests following these procedures still showed the same result as the initial test of around 0,030 g/km. It was decided then to send the vehicle to the manufacturer for further investigations. Although the manufacturer did not specify what procedures were followed or which parts were exchanged, the vehicle emitted 0,022 g/km PM at the manufacturer's facility. On return at TNO the vehicle showed a result of 0,025 g/km, which is exactly the limit value. A probable cause for the difference between the TNO result and the manufacturer result is the drive wind simulation, by means of a large fan that is placed directly in front of a vehicle. Drive wind is needed to cool the engine during the measurements. At the manufacturer's facility the fan is fitted with an additional air guide to direct the cool air directly at the intercooler of the vehicle. The fan at the TNO laboratory is not equipped with an additional air guide. The standard blades of the fan were directed as much as possible at the intercooler though. Measurements of the air intake temperature showed, however, that this temperature was about 10°C lower during the tests at the manufacturer than at TNO.

Vehicle 2

After the initial test on vehicle 2 the engine oil, the oilfilter and the airfilter were changed, and the vehicle was fuelled with reference diesel fuel. On advice of the manufacturer a 'heavy pre-conditioning' procedure was done. The test following these procedures showed a considerable improvement of the PM result from 0,045 g/km to 0,035 g/km, which is still outside the limit value though. It was decided not to undertake any further investigations on vehicle 2 though.

Vehicle 3

The initial test of vehicle 3 showed a PM result of more than twice the limit value. After another test, following a 'stabilization pre conditioning' procedure in which the result even worsened, it was decided to send this vehicle to the manufacturer as well. There all injectors were exchanged because the original injectors showed an incorrect yield. On return at TNO vehicle 3 showed a PM result of 0,018 g/km, which is well within the Euro 4 limit value. The manufacturer stated that this was an exceptional case and could be regarded as an incident.

It is remarkable that the NO_x emission results were not affected much by all the measures taken on all three vehicles. In all cases the NO_x emission varied between 0,20 g/km and 0,24 g/km.

In the 2005 year of the in use compliance programme it will be considered to test two more vehicles of this type to investigate whether these problems are of a more structural character.

The detailed analyses of the emission performance of vehicles from the same type (Figures 12,13,14 and 15) give another view of the emission performances of the vehicles tested. For each component vehicle 'Euro 3 B' showed the most stable results, and in all cases well below the limit values, indicating that Euro 3 technology has now become a well mature technology. These figures also give another perspective of the problems encountered with Euro 4 vehicle.

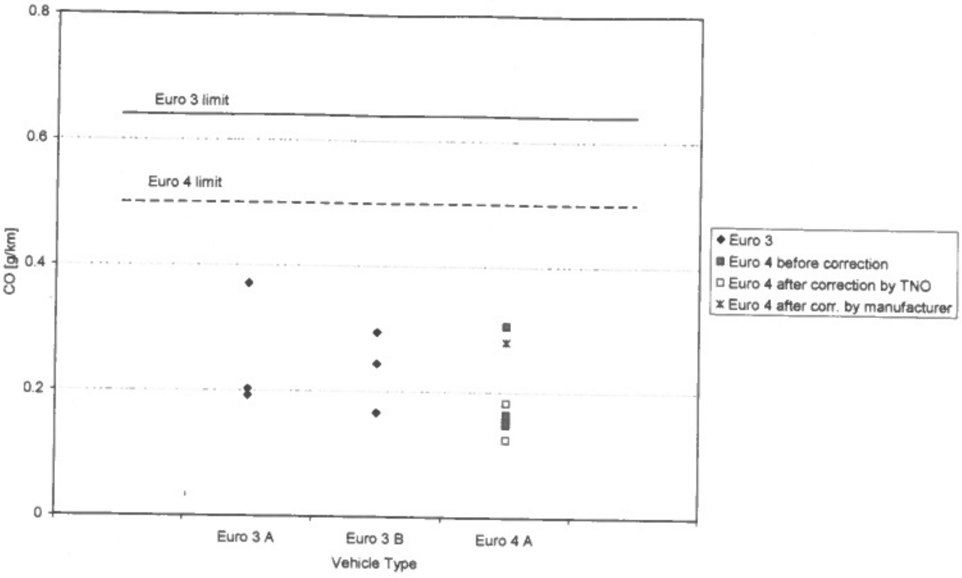


Figure 12 - CO-emission of individual diesel vehicles.

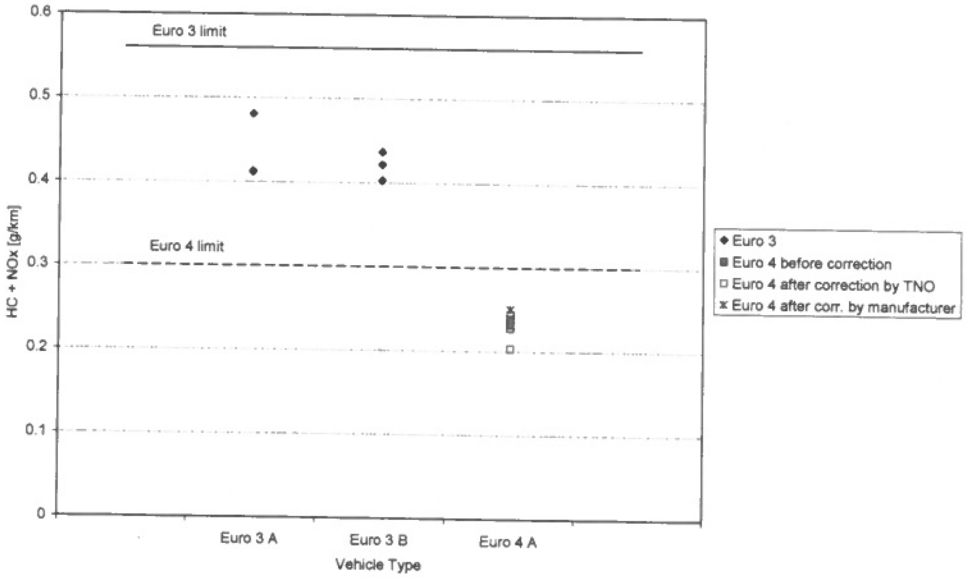


Figure 13 - HC+NO_x-emission of individual diesel vehicles.

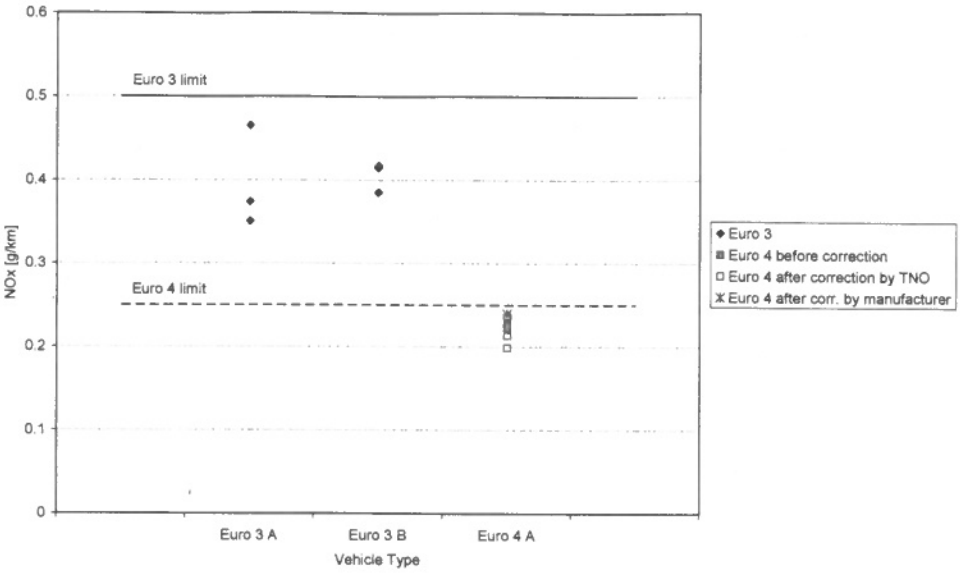


Figure 14 - NO_x-emission of individual diesel vehicles.

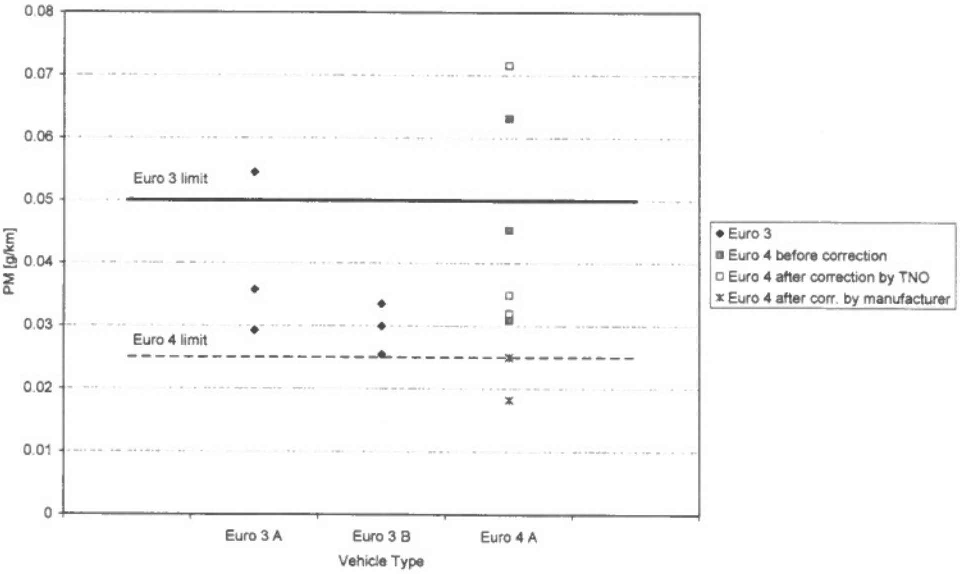


Figure 15 - PM-emission of individual diesel vehicles.

4.2 Cold start emissions

For the same reason as for petrol cars, the additional emissions due to a 20°C cold start were measured. Because of the problems encountered with the Euro 4 vehicle, only the Euro 3 vehicles were subjected to an additional UDC test with a hot start in order to be able to compare this result with the cold UDC test. The results are shown in Figures 16, 17, 18, 19 and 20.

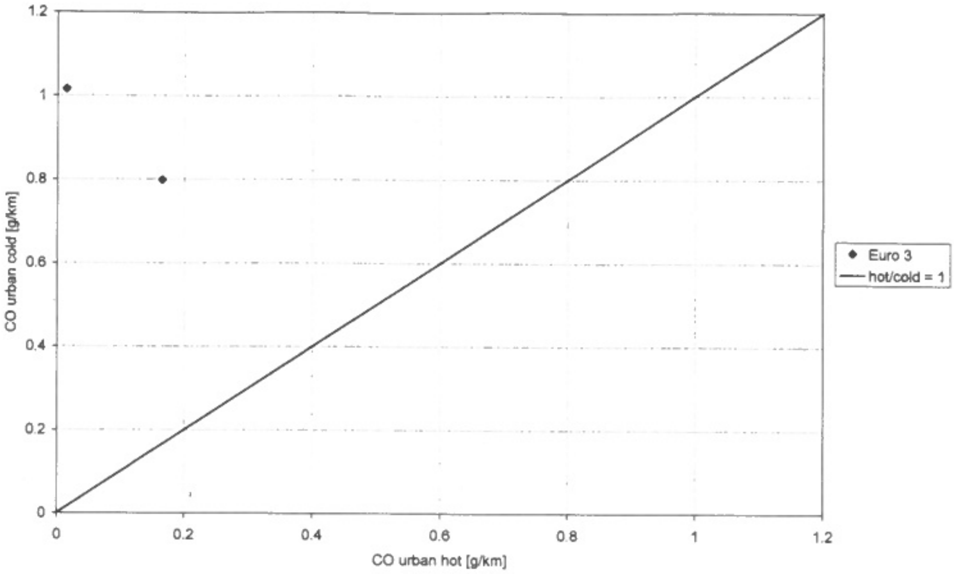


Figure 16 - UDC cold start emissions versus UDC hot start emissions for diesel vehicles: CO

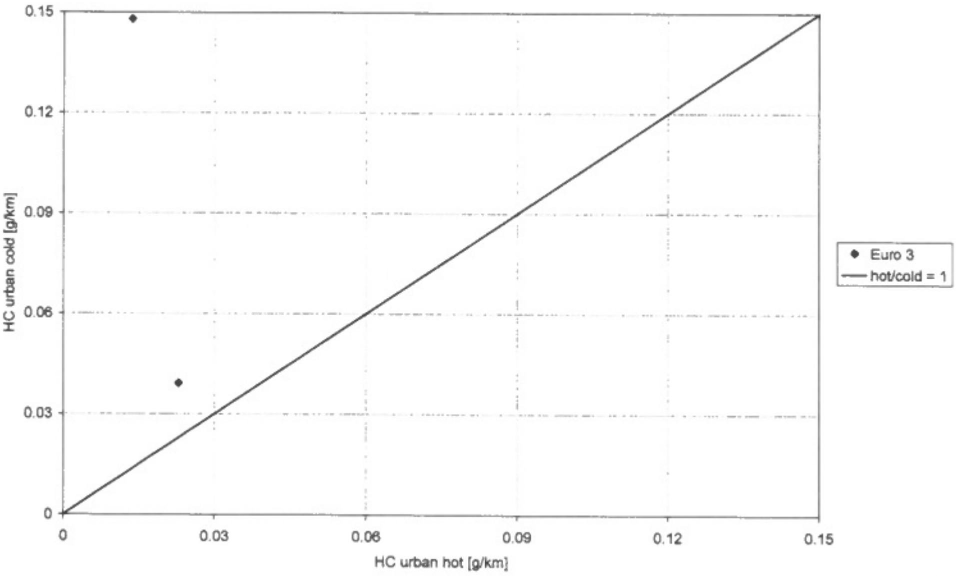


Figure 17 - UDC cold start emissions versus UDC hot start emissions for diesel vehicles: HC

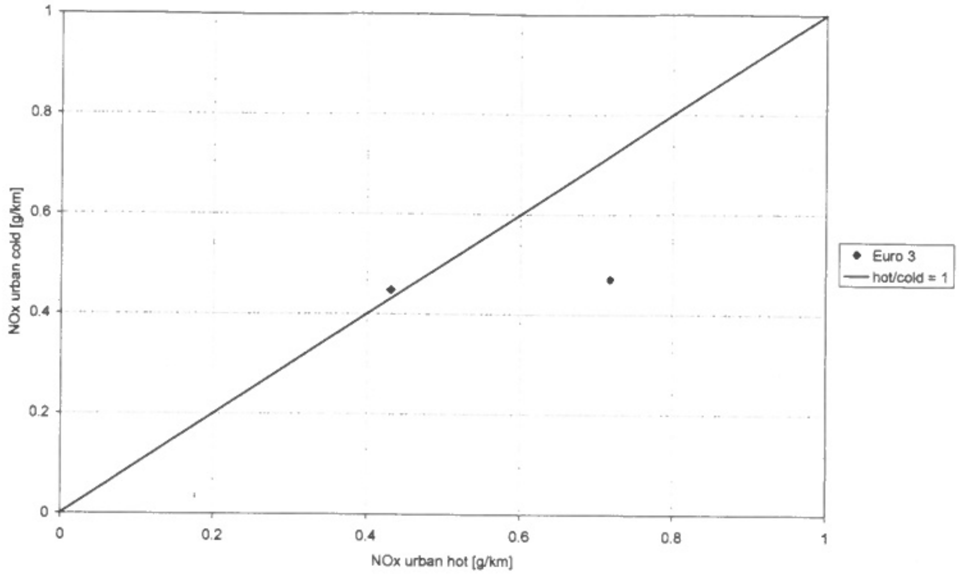


Figure 18 - UDC cold start emissions versus UDC hot start emissions for diesel vehicles: NO_x

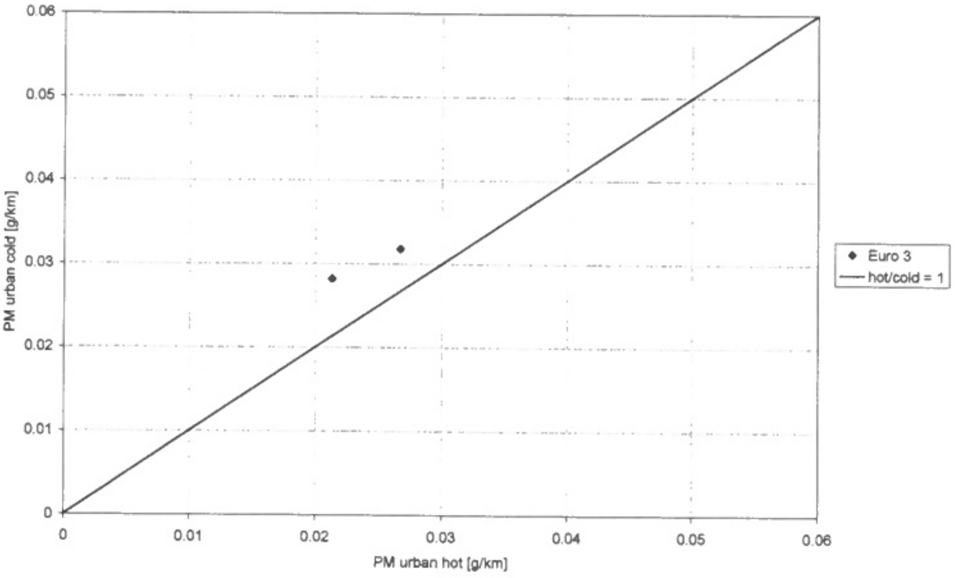


Figure 19 - UDC cold start emissions versus UDC hot start emissions for diesel vehicles: PM

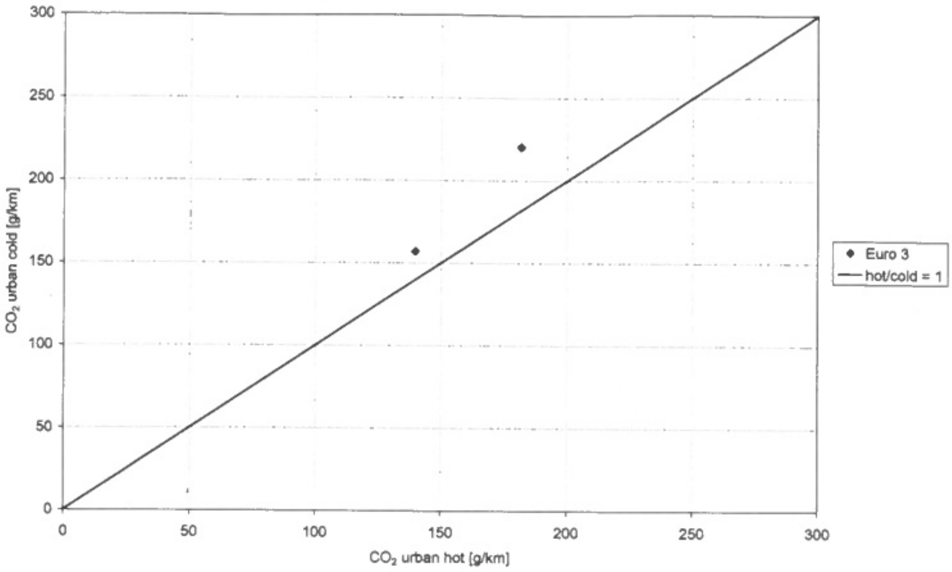


Figure 20 - UDC cold start emissions versus UDC hot start emissions for diesel vehicles: CO_2

From the cold start graphs it can be concluded that the HC and CO emissions of diesel cars when hot are very low, but the cold emissions vary a lot. The cause for this is (in analogy with petrol vehicles) the period until light-off of the catalyst (in this case an oxidation type), during which products of incomplete combustion are not oxidised in the catalyst before being emitted. After light-off of the catalyst emissions drop to almost zero. For PM there is a small cold start increase of emissions which indicates that the combustion properties of modern diesel engines appear to be optimal directly after cold start. This can not be firmly substantiated as only two vehicle types were measured, but agrees with results from 2002 and 2003.

For the two vehicles tested the NO_x emissions remain at the same level or even show a reduction by cold start. This is due to the lack of thermal aftertreatment system for NO_x in the tested vehicles that could be subject to heating up effects. The lower value is likely due to the lower intake air temperature during engine warmup. Future technology (NO_x-storage systems) will most probably be more affected by cold start, similar to the results affected by the oxidation catalyst heating.

The CO_2 emissions resulting from the cold start show consistent results. Both vehicles show an increase of 17%, likely caused by increased friction and heat losses directly after cold start. Fuel enrichment is no issue for diesel engines.

4.3 Summary of results for diesel vehicles

The results for the diesel vehicle types must be subdivided into the Euro 3 and Euro 4 class vehicle types.

The results for the Euro 3 vehicle types show that the technology has reached a level where the limits can be reached easily. Only one exception occurred in 2004, where one vehicle had a PM result of 10% above the limit value. As already mentioned in the 2003 report, the problems with Euro 3 diesel vehicles as encountered in earlier years of the in use compliance programme now definitively belong to the past.

As Euro 3 diesel vehicles are almost faultless nowadays, this can't be said for Euro 4 diesel vehicles however. Although only one of the first Euro 4 vehicles types that have become commercially available has been tested, the same scenario as for the early Euro 3 vehicle types seems to repeat itself, at least for vehicles without additional aftertreatment devices such as particulate traps or $DeNO_x$ systems. As the next legislative step tightens the limits considerably, the 'old' Euro 3 technology has been optimised even further to become Euro 4 technology. As a result, the first instance of this Euro 4 technology, as seen in the 2004 in use compliance programme, failed to meet the Euro 4 PM limits on initial test in all three instances. Furthermore this vehicle type appeared to be very sensitive to the maintenance condition and the test procedure followed. Especially pre conditioning and optimised drive wind cooling, as prescribed by a manufacturer, seem to influence the result considerably. As a vehicle in general only can meet the limits on a set of boundary conditions specified by the manufacturer, a vehicle will not automatically meet the limits in any other laboratory, even if this laboratory is officially equipped to perform type approval test procedures as prescribed by the European Union.

5 LPG passenger vehicles

In the Netherlands the third main stream fuel is LPG. LPG fuelled vehicles are available directly from vehicle manufacturers (OEM vehicles) or come as retrofit vehicles, where the LPG system has been built into a vehicle after it has been delivered.

5.1 Initial tests

In order to be granted with the incentives from the Dutch government in the form of road tax reduction, LPG retrofit vehicles have to meet the so-called G3 specifications. In relation to the limits this means that the emissions should be below 70% of the Euro 2 petrol vehicle limits of 1997. This implicates that the LPG vehicles have to be tested on the 'old' Eurotest including 40 seconds idling before the measurements start. In the current NEDC procedure the measurements start directly after the engine is started. Therefore the LPG G3 emission values can not be compared directly with emission values obtained with the current NEDC.

In 2004 two LPG vehicle types were selected in the In-Use Compliance programme, of which one OEM vehicle and one retrofitted vehicle. The OEM vehicle type was type approved by the manufacturer under Euro 3, the retrofit vehicle type fell into the G3 category.

Table 8 The emission limit values in force for the LPG vehicle types

Emission component	Euro 3 limit value [g/km]	LPG G3 limit value (=70% Euro 2) [g/km]
CO	2,3	1,54
HC	0,20	-
NO_x	0,15	-
$HC+NO_x$	-	0,35

The two vehicle types tested in 2004 are shown in Table 7.

Table 9 Vehicle types tested in 2004 (LPG)

Vehicle make	Vehicle type	Retrofit (LPG G3)	OEM (Euro 3)
Opel	Zafira Z1.8XE	✓ (Koltec)	
Volvo	S60 2.4 Bi-Fuel		✓

Both vehicle types were tested on the Eurotest twice: running on LPG and running on petrol. Both vehicles in the standard petrol specification fall into the Euro 3 category.

In Figure 21, the average emissions test results (for three vehicles tested per vehicle type) of each vehicle type are plotted in comparison with the LPG G3 and Euro 3 limits. Although the Euro 3 category does not have a limit value for $HC+NO_x$ emissions as the Euro 2 category did (and thus also LPG G3), to compare both categories the $HC+NO_x$ values have been added together for the Euro 3 vehicles.

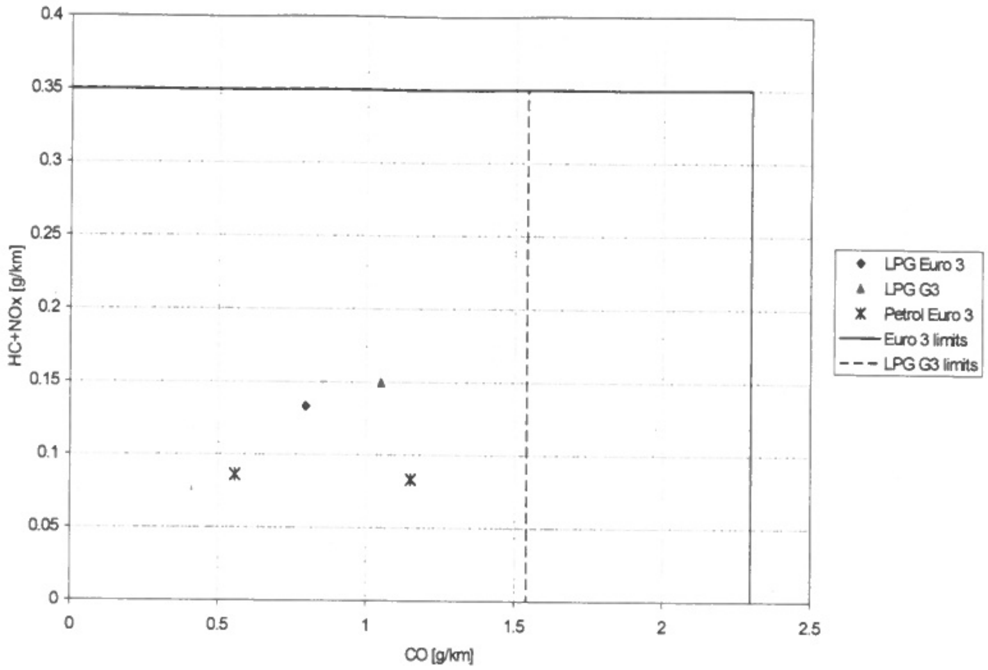


Figure 21 - Results of in-use LPG vehicle types during the standard type approval test procedure (average per vehicle type)

As can be seen in the figure, both vehicle types met the corresponding emission limits when running on LPG or on petrol. No specific problems were encountered during testing. Because of the small sample size and the different test procedures for LPG G3 and Euro 3, no general conclusions can be drawn here on the general emission performance of LPG G3 compared to LPG OEM Euro 3 or petrol Euro 3.

The individual results (see figure 22 show somewhat more scatter of the emission results though. One LPG G3 vehicle failed to meet the HC+NO_x limit. Because the average of the three vehicles was well within the limit value, this exceedance was regarded as an incident.

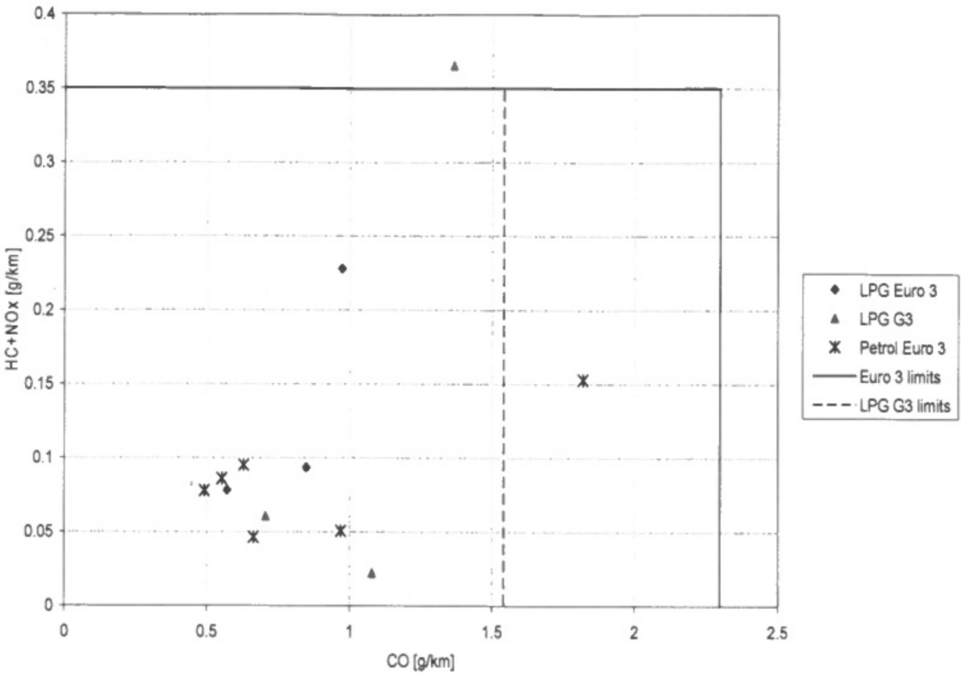


Figure 22 - Results of in-use LPG vehicle types during the standard type approval test procedure (individual results).

The detailed analyses of the emission performance of vehicles from the same type (Figures 23, 24 ,26 and 26) give another view of the emission performances of the vehicles tested. From these figures can be concluded that the OEM LPG has a somewhat more stable emission result than the retrofitted vehicle.

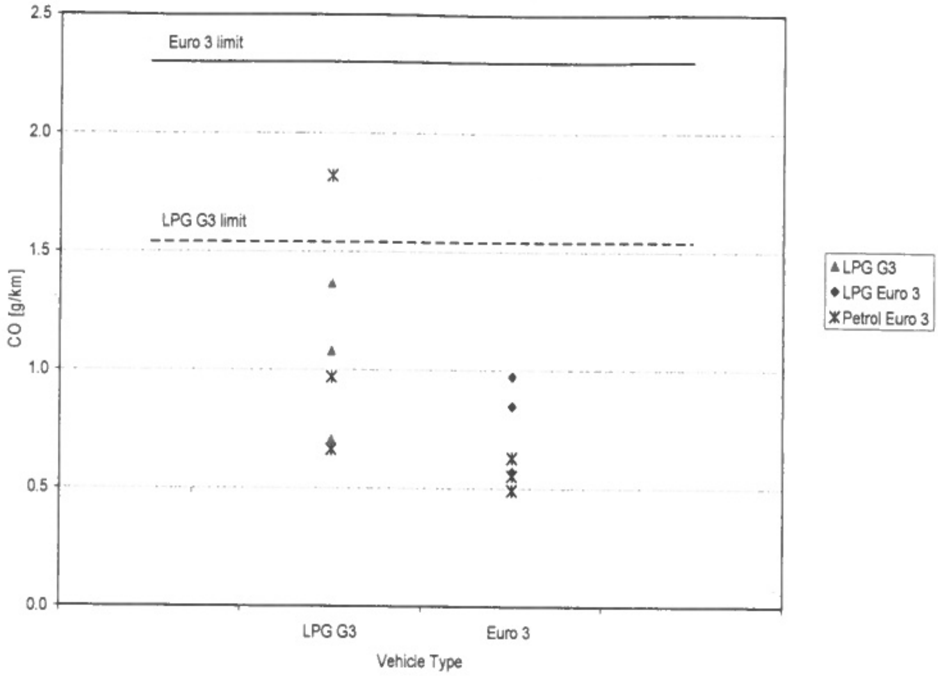


Figure 23 - UDC cold start emissions versus UDC hot start emissions for LPG vehicles: CO

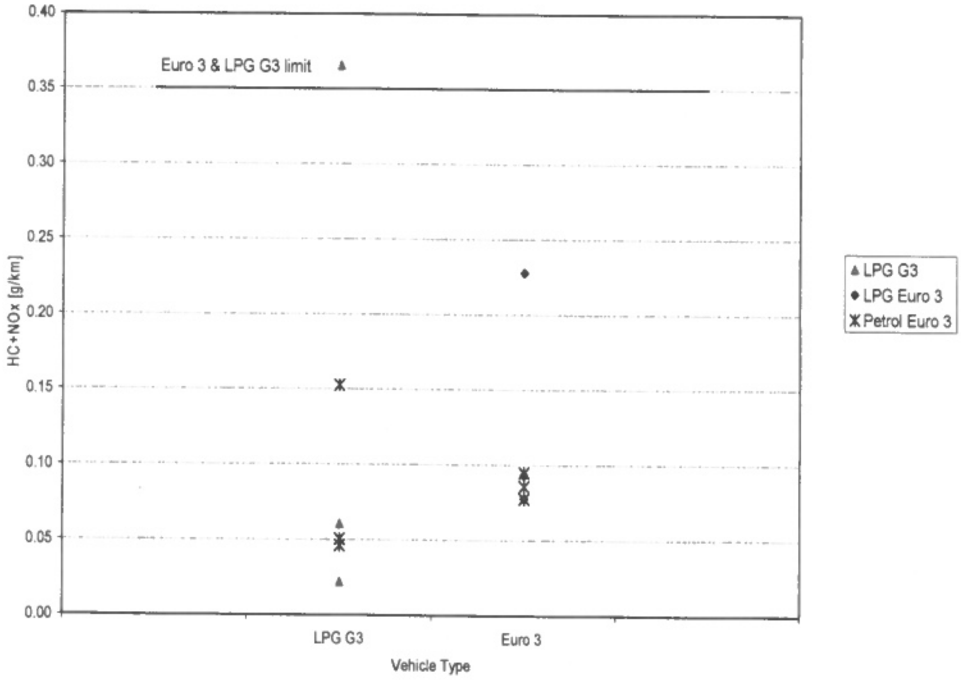


Figure 24 - UDC cold start emissions versus UDC hot start emissions for LPG vehicles: HC+NO$_x$

5.2 Cold start emissions

The additional emissions due to a 20°C cold start were measured as well for the LPG vehicles. For this purpose both vehicles were tested on the Euro 3 urban cold and the Urban hot cycle. The results are shown in Figures 25, 26, 27, 28 and 29.

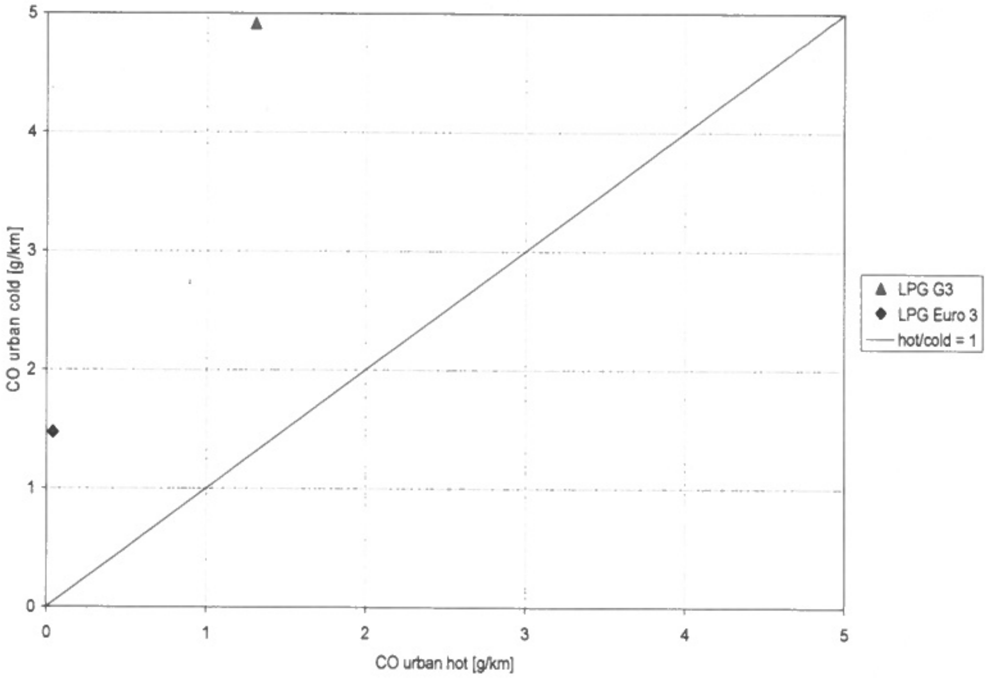


Figure 25 - UDC cold start emissions versus UDC hot start emissions for LPG vehicles: CO

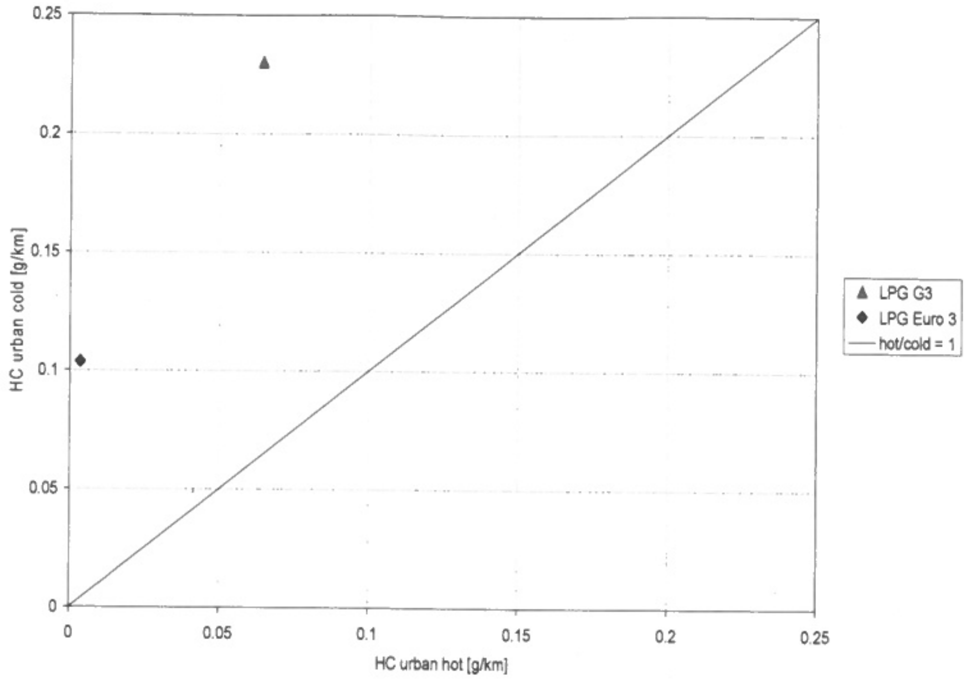


Figure 26 - UDC cold start emissions versus UDC hot start emissions for LPG vehicles: HC

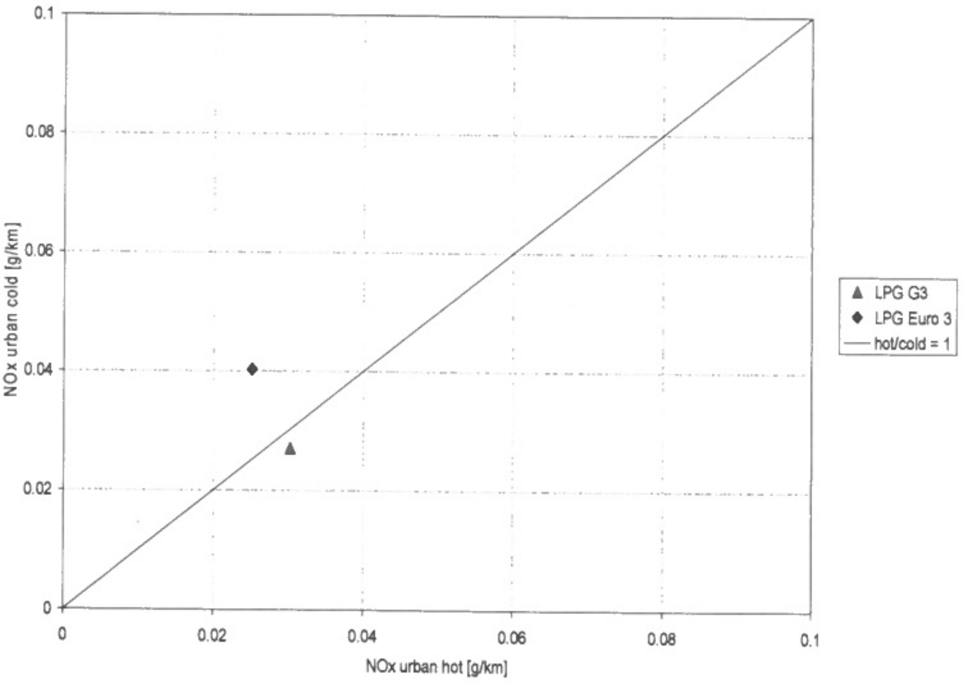


Figure 27 - UDC cold start emissions versus UDC hot start emissions for LPG vehicles: NO_x

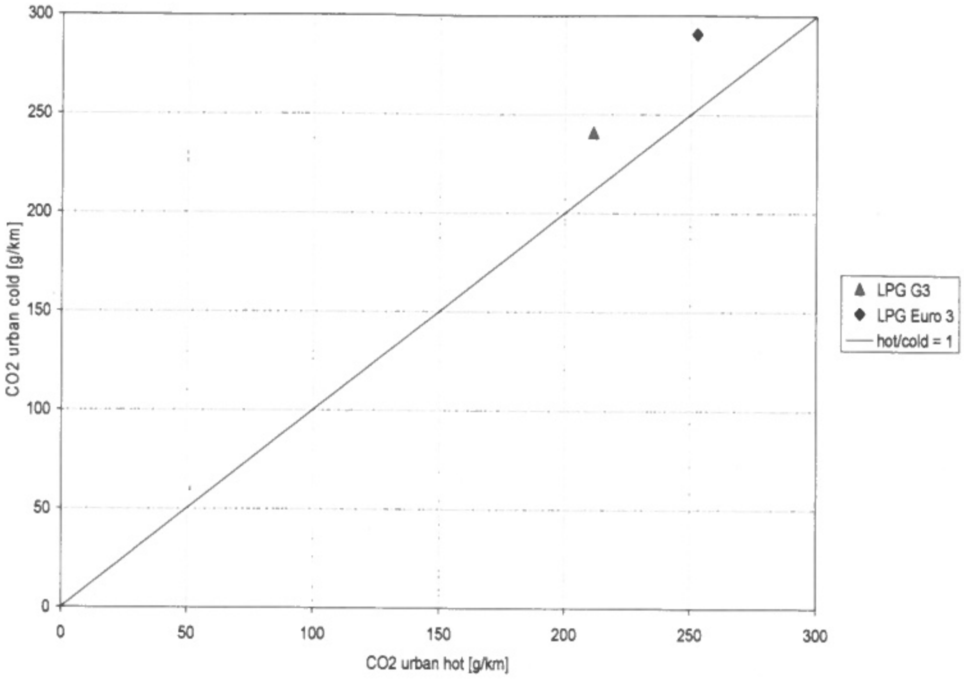


Figure 28 - UDC cold start emissions versus UDC hot start emissions for LPG vehicles: CO_2

For the cold start effect the same general conclusions can be drawn as for the petrol vehicles as discussed in chapter 3. For CO and HC the OEM LPG vehicle had a lower cold start effect than the retrofit LPG G3 vehicle. The NO_x cold start emissions were the lowest for the LPG G3 vehicle though. The increase in CO_2 emissions averaged 20%.

5.3 Summary of results for LPG vehicles

The two LPG vehicle types tested in 2004, one OEM Euro 3 vehicle and one retrofit G3 vehicle, both performed very well on an average basis. On an individual basis one failure of meeting the HC+NO_x limit can be reported for the retrofit G3 vehicle. When both vehicles are compared, the OEM vehicle has a somewhat more stable emission result and the lowest cold start effect for CO and HC. The retrofit G3 vehicle showed the lowest cold start effect for NO_x.

6 Real world emissions

An important objective of the Dutch In-Use Compliance programme is to gather information on the real-world emission behaviour of vehicles on the road. With changing situations on the roads, and vehicle technology being able to adapt to these changed situations, the data gathered using the European type approval procedure is more and more losing its value as representative emission data. These data were not really meant to be used for this purpose, but have been used as (a basis for) emission factors for a long time, since little else was available and originally they could be used for this purpose without much error. The increasing discrepancy between type approval testing and real-world emissions has been acknowledged by TNO and other European research institutes, leading to a demand for real-world test procedures (starting with real-world test cycles). These test cycles have their origin in a large amount of real-world recorded trip data, which have been "compressed" to short test cycles to be driven on a chassis dynamometer.

For the purpose of deriving real-world emission factors for the Dutch national situation, in fact two things are needed: 1) Dutch real-world driving cycles and 2) data of a representative Dutch vehicle sample. The second issue is easy to solve within the Dutch In-Use Compliance programme, since one of the main ideas behind the programme is exactly to test a sample that is representative for the Dutch fleet. The first issue is more difficult to address, since there is not yet a national full set of representative real-world driving patterns, although TNO Automotive is currently developing these cycles. It is expected that these cycles will be finished early 2005 so that they can be added to the 2005 programme.

The only option at this moment close to a national set, is a set of 11 different driving patterns that have been recorded on Dutch motorways in 1999 (Emissions and Congestion project) [Gense, 2001]. For the urban and rural part of real-world driving the Common Artemis Driving Cycles (CADC) are used. The CADC cycles have been developed in the European 5th Framework project Artemis in which all prominent European institutes participate. As a result, these cycles are considered representative for average European real-world driving.

In summary, it was decided to use the following cycles for measuring the real-world emissions of the Dutch car fleet:

1. the 'Emissions and Congestion' test cycles (11 different levels of highway traffic flow)
2. the Common Artemis Driving Cycles (CADC), for urban, rural and highway conditions

In practice this meant that from every vehicle type selected, one vehicle was additionally tested on set 1, and another one was additionally tested on set 2. The results from using both sets of test cycles will be further discussed in the following section.

6.1 Emissions and congestion

On behalf of the Transport Research Centre of the Dutch Ministry of Transport and the Dutch Ministry of Housing, Spatial planning and the Environment, TNO executed a research programme in order to determine the effects of traffic congestion on exhaust gas emissions and fuel consumption of road vehicles on motorways. The need for information on this topic occurred when policy makers wanted to know what the benefits for emissions could be of decreasing traffic congestion by using traffic management measures. As a result an extensive research programme was executed in 1999 and 2000 [Gense, 2001]. Important milestones in this project were the development of test cycles that represent Dutch motorway traffic and an extensive measurement campaign in which 19 vehicles were tested in the TNO laboratory on these test cycles. Table 6 shows the congestion categorisation used in the project.

Table 10 Congestion categorisation as used in the emissions and congestion study

Congestion category	Definition
1aa	Speed <10 km/h; 'stop and go'
1ab	Speed between 10 and 25 km/h
1a	1aa and 1ab combined, speed between 0 en 25 km/h
1b	Speed between 25 and 40 km/h
1c	Speed between 40 and 75 km/h
2a	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 100 km/h
2b	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 120 km/h
2c	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 100 km/h
2d	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 120 km/h
2e	Speed over 120 km/h, independent of traffic volume
3	Traffic jam 'avoidance' route

When the emission results were weighted for the share of different vehicle types in the Dutch vehicle fleet of 1998, the following average 'bathtub-shaped' emission correction curves were constructed for the national Dutch vehicle fleet. Driving pattern 2C is set at 100% (see Figure 29).

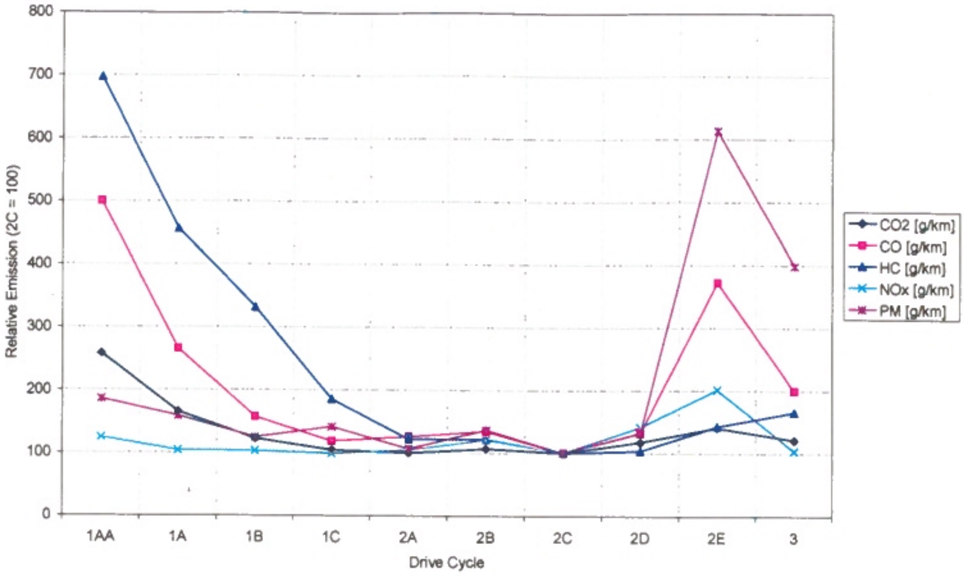


Figure 29 - Relative emission profile total Dutch fleet in 1998 (2C=100), including petrol, diesel and LPG vehicles.

The vehicle selection used in the study mentioned only consisted of cars up to Euro 2 and includes petrol, diesel and LPG vehicles. In order to gain more insight into the actual situation on the road and to make the predictions for the future more accurate, Euro 3 and Euro 4 vehicles from the selection in the recent years of the In-Use Compliance programme have been tested on these real-world motorway test cycles in order to update these curves. Figures 30-32 show the overall relative results for the 2001–2004 vehicle selection for indirect injection petrol (average of 36 vehicles), DI-petrol (average of 3 vehicles) and diesel (average of 14 vehicles), respectively. Due to the limited number of DI-petrol vehicles tested, the DI-petrol results are not expected to be statistically significant.

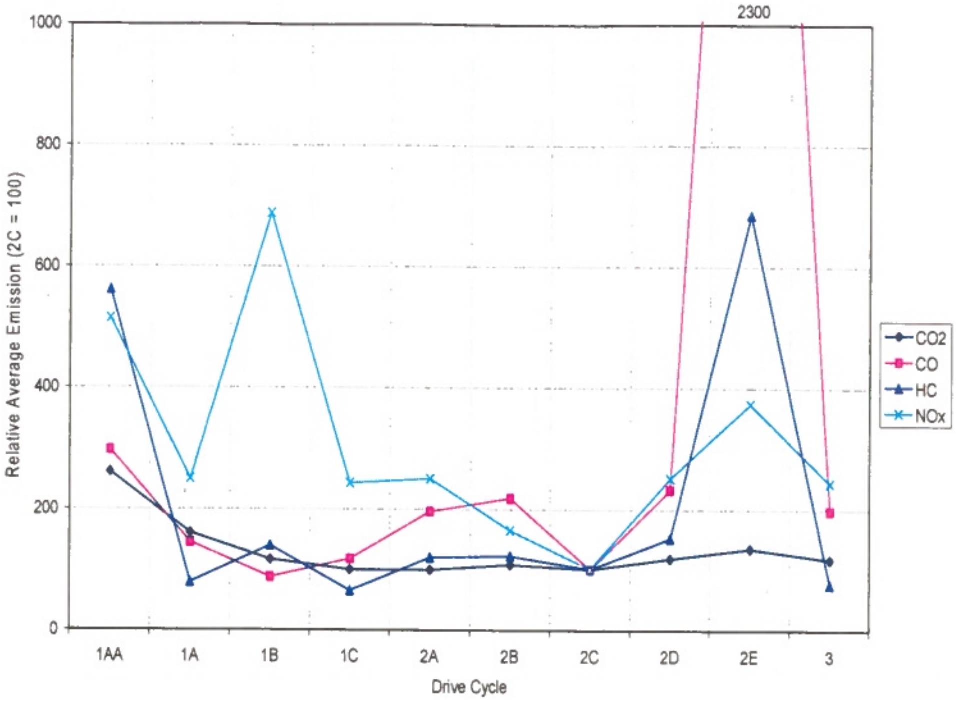


Figure 30 - Average emissions for Euro 3 and 4 petrol vehicles with indirect injection on the Emissions and Congestion driving cycles, relative emissions on the 2C cycle.

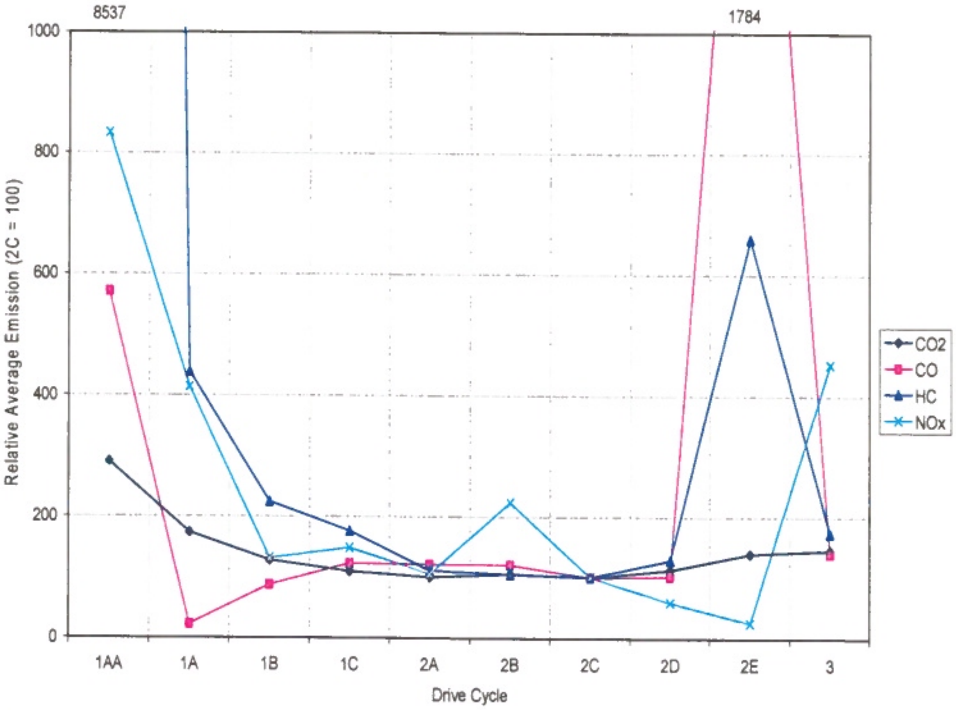


Figure 31 - Average emissions for Euro 3 and 4 petrol vehicles with direct injection on the Emissions and Congestion driving cycles, relative emissions on the 2C cycle

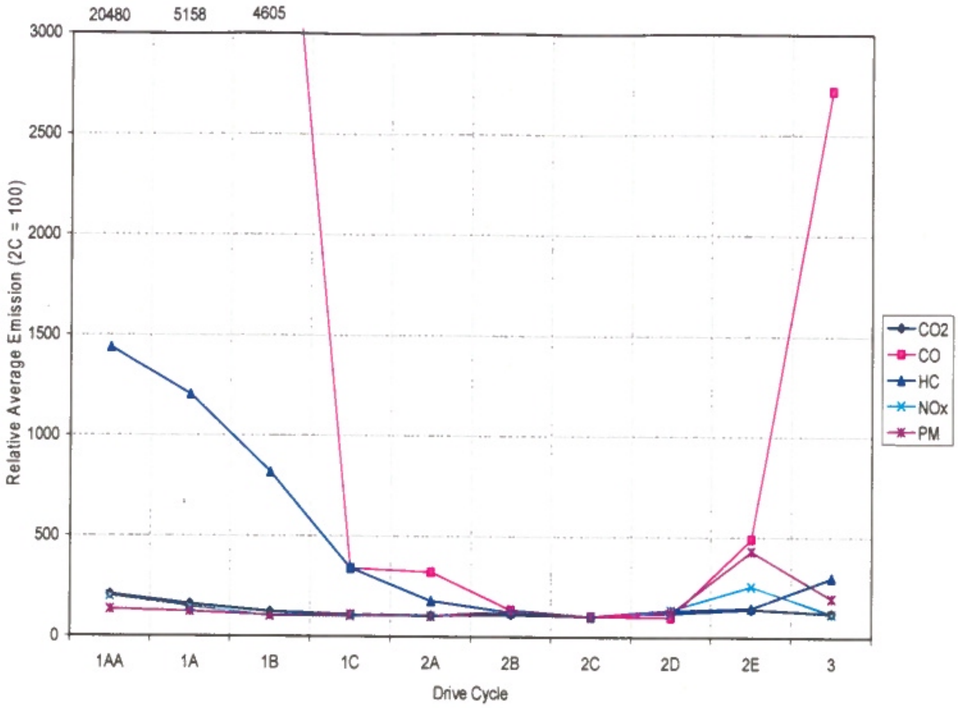


Figure 32 - Average emissions for Euro 3 diesel vehicles on the Emissions and Congestion driving cycles, relative emissions on the 2C cycle.

Based on the results for Euro 3 and 4 vehicles, the total Dutch fleet emission profile has been updated (Figure 33). The emission levels for the various vehicle types have been weighted for their share of the 2004 fleet.

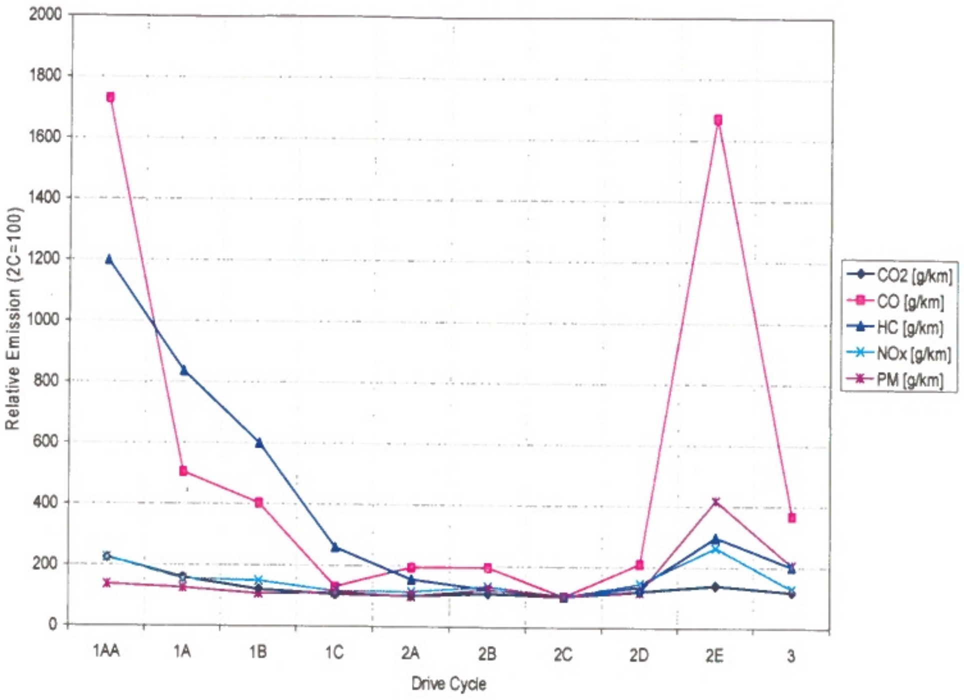


Figure 33 - Relative emission profile total Dutch fleet in 2004 (2C=100), including petrol, diesel and LPG vehicles

The relative values show an appreciable change with respect to the previous results (Figure 29). This is especially true for the considerable relative increase in CO and HC for the low speed cycles, and CO on the 2E (high speed) cycle.

The absolute values, however, are all reduced, some significantly (Figure 34). As certain emission components are reduced by a much lower factor on given drive cycles (especially CO), the emission level relative to the 2C cycle has increased. It can therefore be concluded that with the introduction of Euro 3 and 4, fleet emission levels are reduced under all conditions, but that this reduction is not the same under all driving conditions. The lowest reduction is seen by stop-and-go and high speed driving for CO and NO_x emissions.

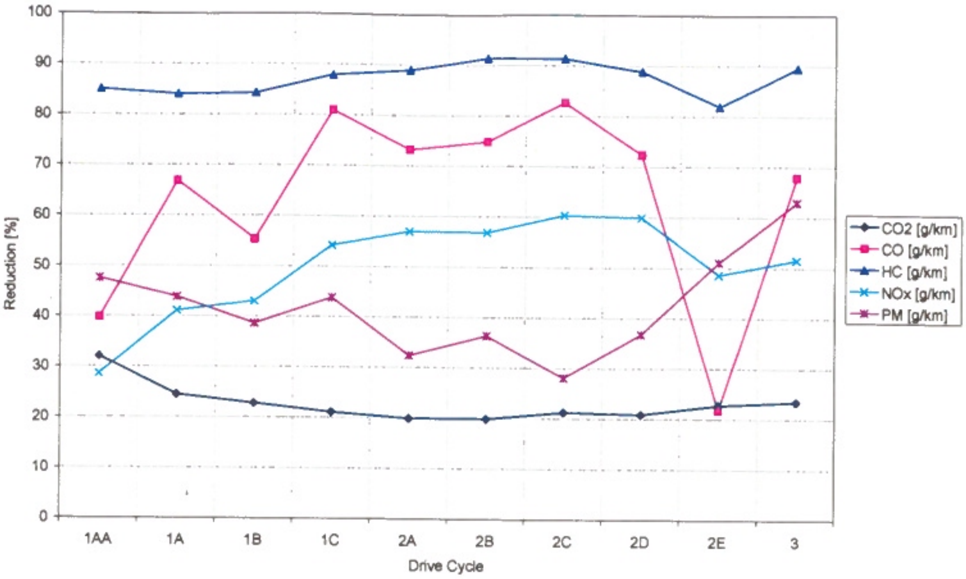


Figure 34 - Percentage reduction of the 2004 fleet absolute emission levels compared with the 1998 fleet.

DI petrol vehicles have been tested only in 2003 and 2004. Compared to multi-point vehicles, the HC emission is much higher on the 1AA and 1A cycles, while the NO_x is lower for the 2D and 2E cycles.

6.2 Common Artemis Driving Cycles

The Common Artemis Driving Cycles (CADC) are used for producing information on the real-world emission behaviour of cars in comparison to the Type Approval (TA) testing. The CADC consists of an urban part, an extra-urban part and a highway part.

Comparing the data from the CADC-cycles with the TA test data gives relevant information on the transient behaviour of vehicle emissions outside the TA test window. This information is essential for emission modeling purposes.

Figures 35-39 show the test results of the vehicle types from the 2002–2004 vehicle selection combined. The number of vehicles that have been tested in the framework of the In-Use Compliance programme on which these figures are based are:

Petrol Euro 3:	9 vehicles
Petrol Euro 4:	6 vehicles
Petrol DI (Euro 3 and Euro 4):	4 vehicles
Diesel Euro 3:	8 vehicles
Diesel Euro 4:	1 vehicle
LPG:	6 vehicles

The bars in the figures indicate the 1-σ values of the emissions produced assuming normally distributed values. The results will now be discussed per emission component.

The CO emission results, see figure 35, show very low levels on the CADC Urban cycle, the Euro 3 and Euro 4 diesel emissions being close to zero. The LPG results show higher CO emissions and a relatively large spread on the urban cycle. On the CADC road cycle, the petrol results go up and the spread increases as well. The diesel results remain very low and the LPG results are comparable to the petrol results. The results on the CADC Highway cycle show strongly elevated emissions for Euro 3 petrol vehicles, and a very large spread as well. This points to some major high load enrichment effects on several vehicle types. This effect is less present for the Euro 3 petrol, the DI petrol and the LPG vehicles.

Figure 36 shows the HC emission results on the CADC cycles. For the CADC Urban cycle the high Euro 3 diesel result is very remarkable. This is caused by two (out of 8) vehicles having significantly higher HC emissions than the other vehicles. This effect is also visible on the CADC Road cycle and to a less extent on the CADC Highway cycle. The other vehicle types show very low HC emissions, ranging from close to zero to 0,04 g/km.

For the NO_x results, see figure 37, the influence of vehicle technology and emission legislation clearly becomes visible. The diesel vehicle has as expected the highest NO_x emissions. Especially on the highway cycle the difference with petrol vehicles is very large. It is also clear that the step from Euro 3 to Euro 4 also has its impact on the real world NO_x emissions, although based on only one Euro 4 diesel vehicle it is too early to say whether or not the 50% reduction of the emission limit from Euro 3 to Euro 4 will result in the same reduction under real world circumstances. The DI petrol vehicles that have been tested emit more NO_x on the CADC Urban cycle than the petrol vehicles. This can be explained by the fact that the DI vehicles tested so far are calibrated for lean burn operation in the lower part of the engine map. Through the excess of air under lean burn operation, the NO_x emissions increase, which will happen especially in urban conditions. Under conditions with a higher engine load, such as road or highway, the engine returns to stoichiometric operation, and the NO_x emissions will be about the same as conventional petrol vehicles. The LPG vehicles show higher NO_x emissions than petrol vehicles. Especially on the CADC Highway cycle the LPG NO_x emissions are significantly higher than the petrol emissions.

The CO_2 emission results, see figure 38, are much influenced by the average weight of the vehicles that have been tested, so it is difficult to draw general conclusions at this time. What is clear though is that diesel vehicles generally have the lowest CO_2 emissions, followed by LPG vehicles. Conventional petrol vehicles have the highest CO_2 emissions. The advantage of DI petrol vehicles as claimed by several manufacturers has not become apparent, based on the vehicles tested in the In-Use Compliance programme.

The PM emissions have been measured on the CADC cycles as well, see figure 39. PM emissions are measured by default on diesel vehicles only. In 2003 the PM emissions from 3 DI petrol vehicles have been measured too. From the figures the difference between the petrol DI and the diesel results is immediately apparent. The Euro 4 diesel vehicle does not have a significantly lower PM emission compared to the Euro 3 vehicles, although the spread on the Euro 3 vehicles is relatively large. The vehicle in question is actually 'Vehicle 1' as discussed in section 3.1, and therefore did not meet the Euro 4 PM limits at the time the CADC was driven.

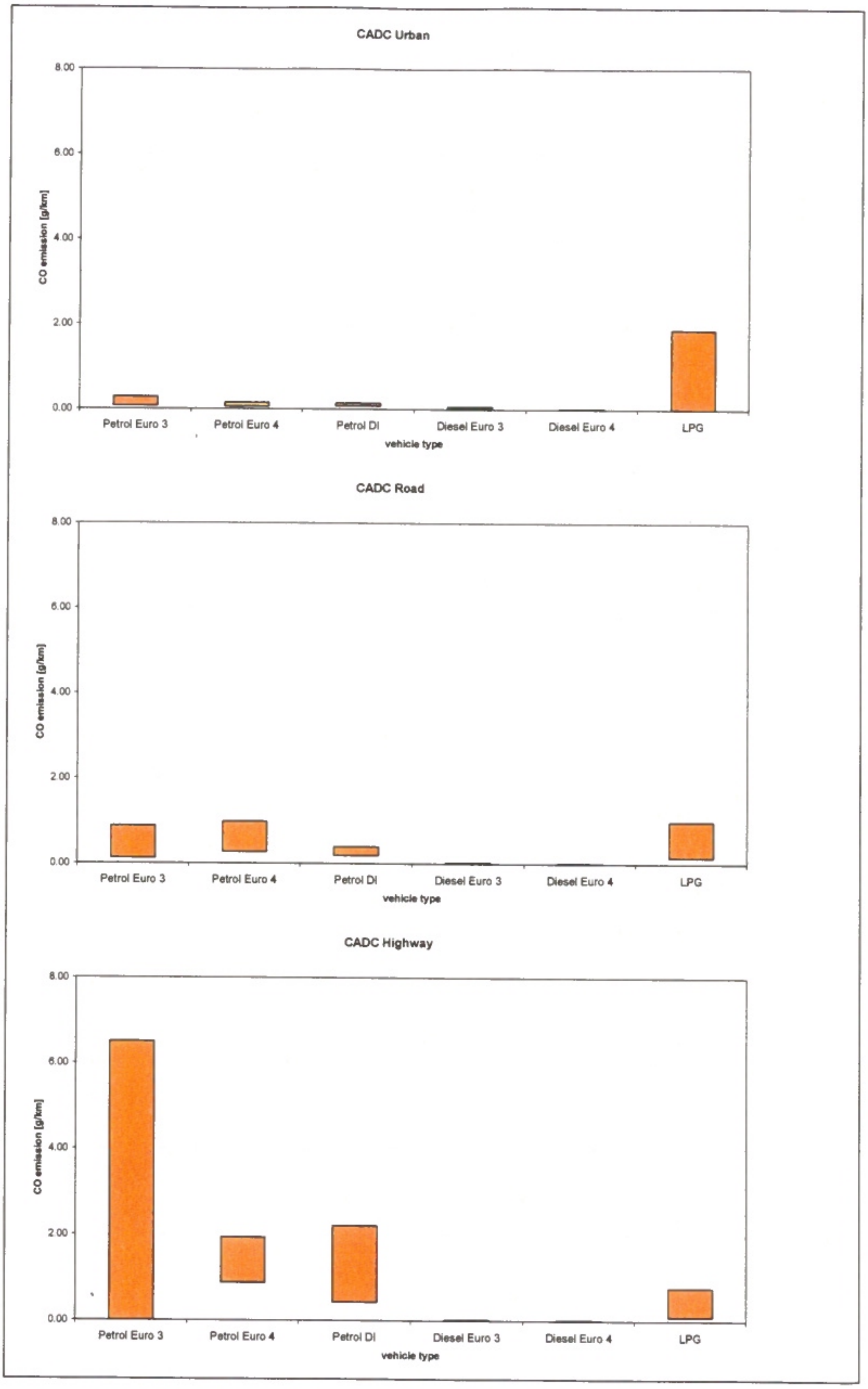


Figure 35- 1-σ CO emissions from the CADC cycles for several fuel and technology types (Note: only one Euro diesel vehicle type has been tested)

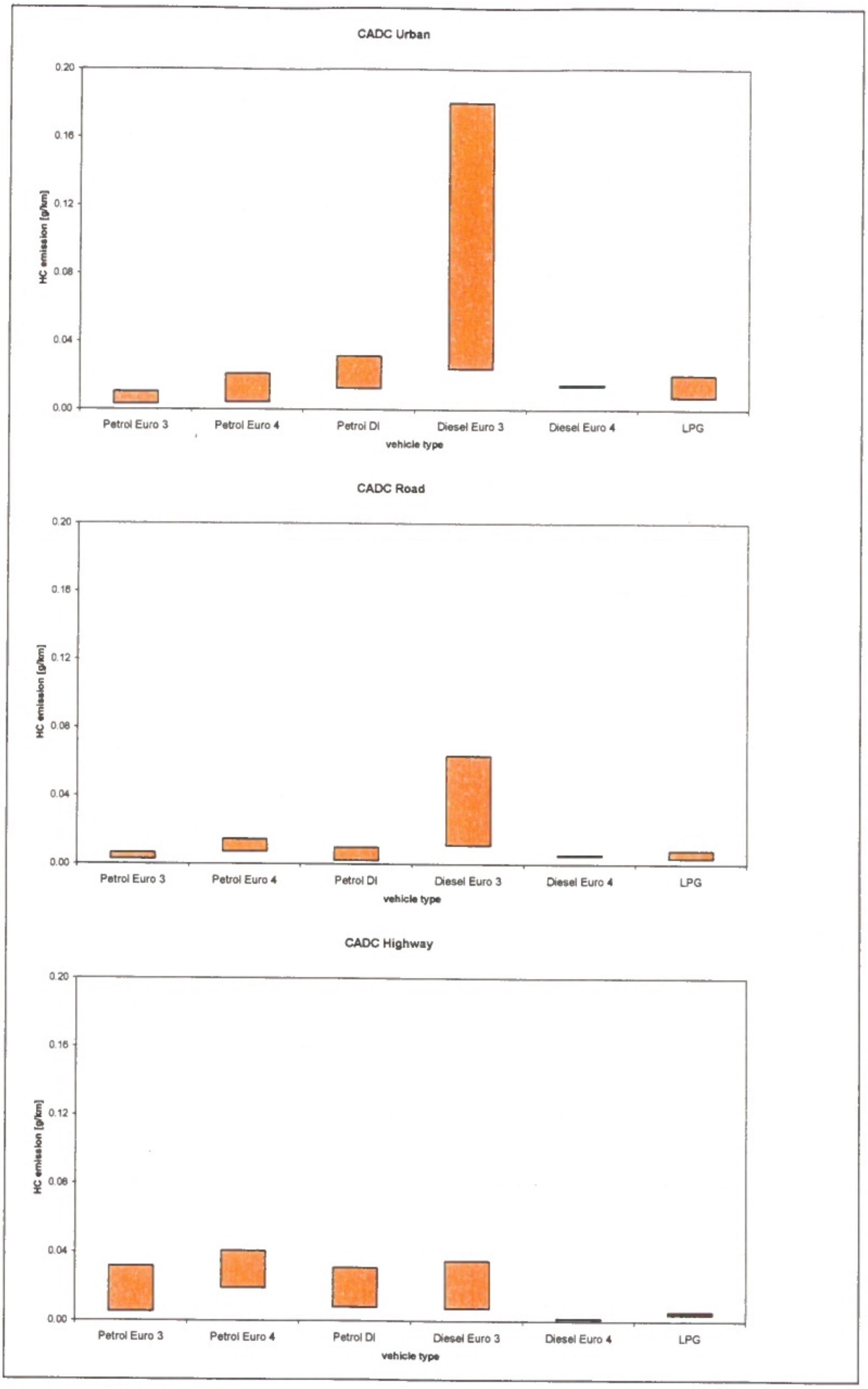


Figure 36 - 1-σ HC emissions from the CADC cycles for several fuel and technology types (Note: only one Euro diesel vehicle type has been tested)

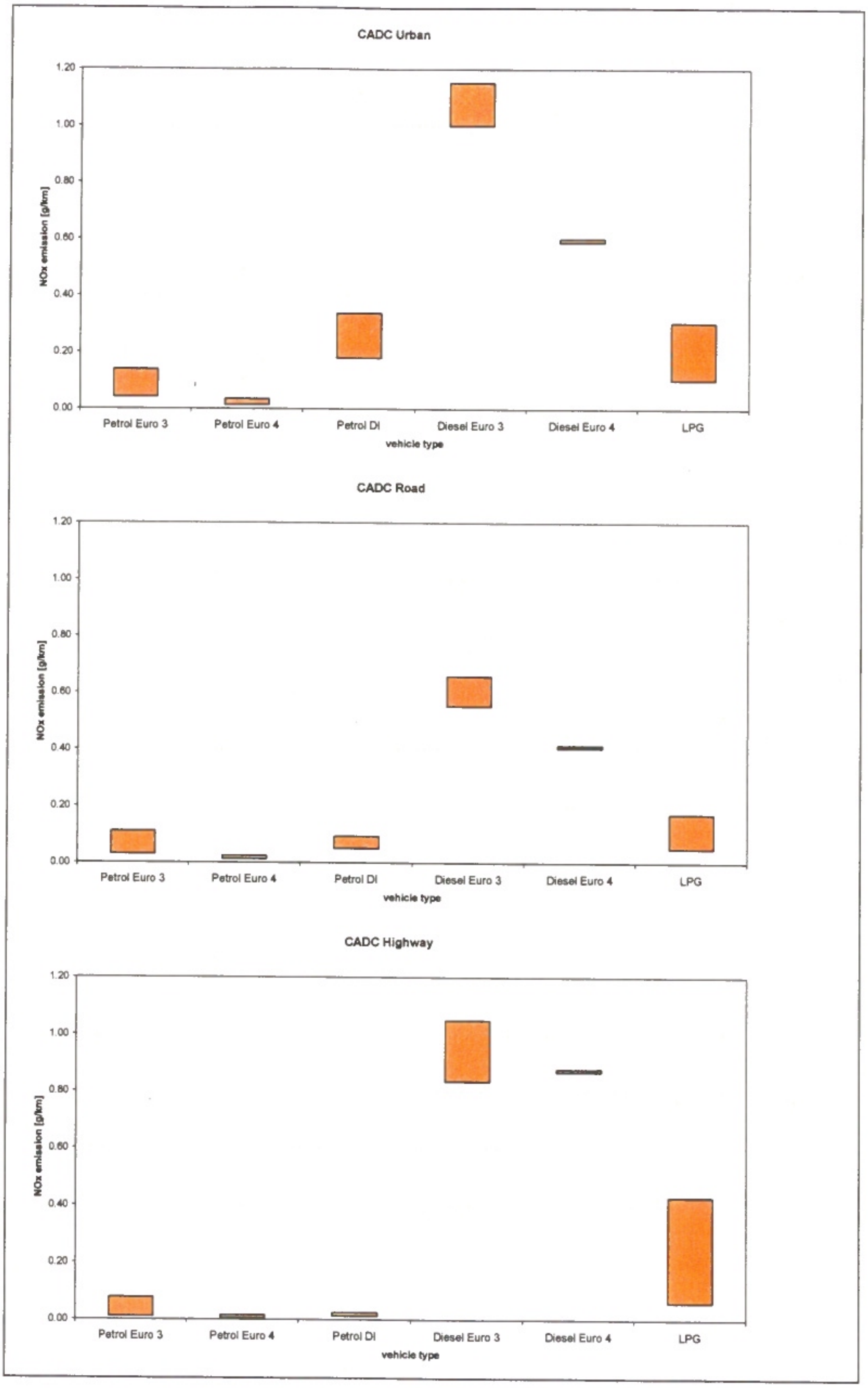


Figure 37 - 1-σ NO$_x$ emissions from the CADC cycles for several fuel and technology types (Note: only one Euro diesel vehicle type has been tested)

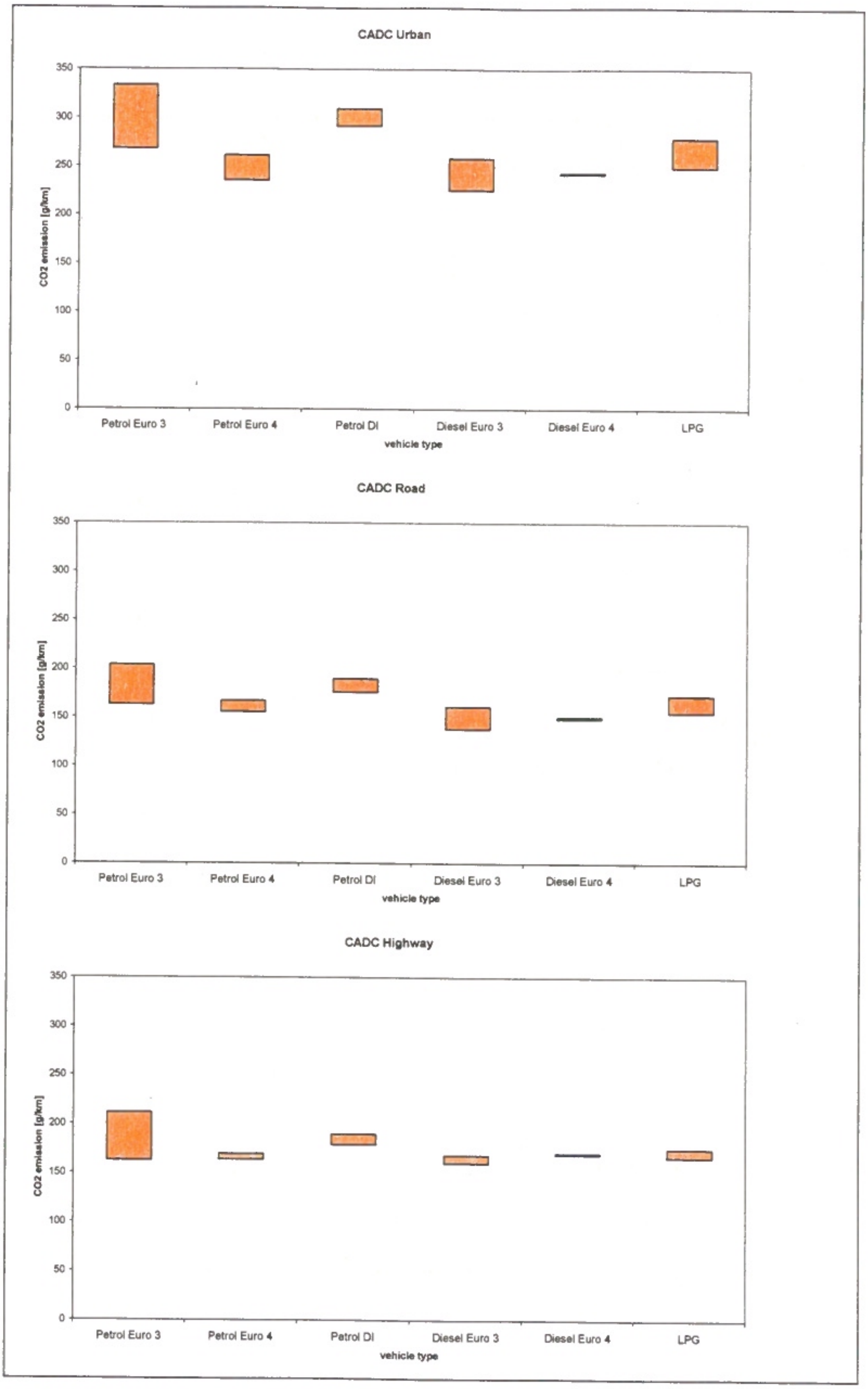


Figure 38 - 1-σ CO_2 emissions from the CADC cycles for several fuel and technology types (Note: only one Euro diesel vehicle type has been tested)

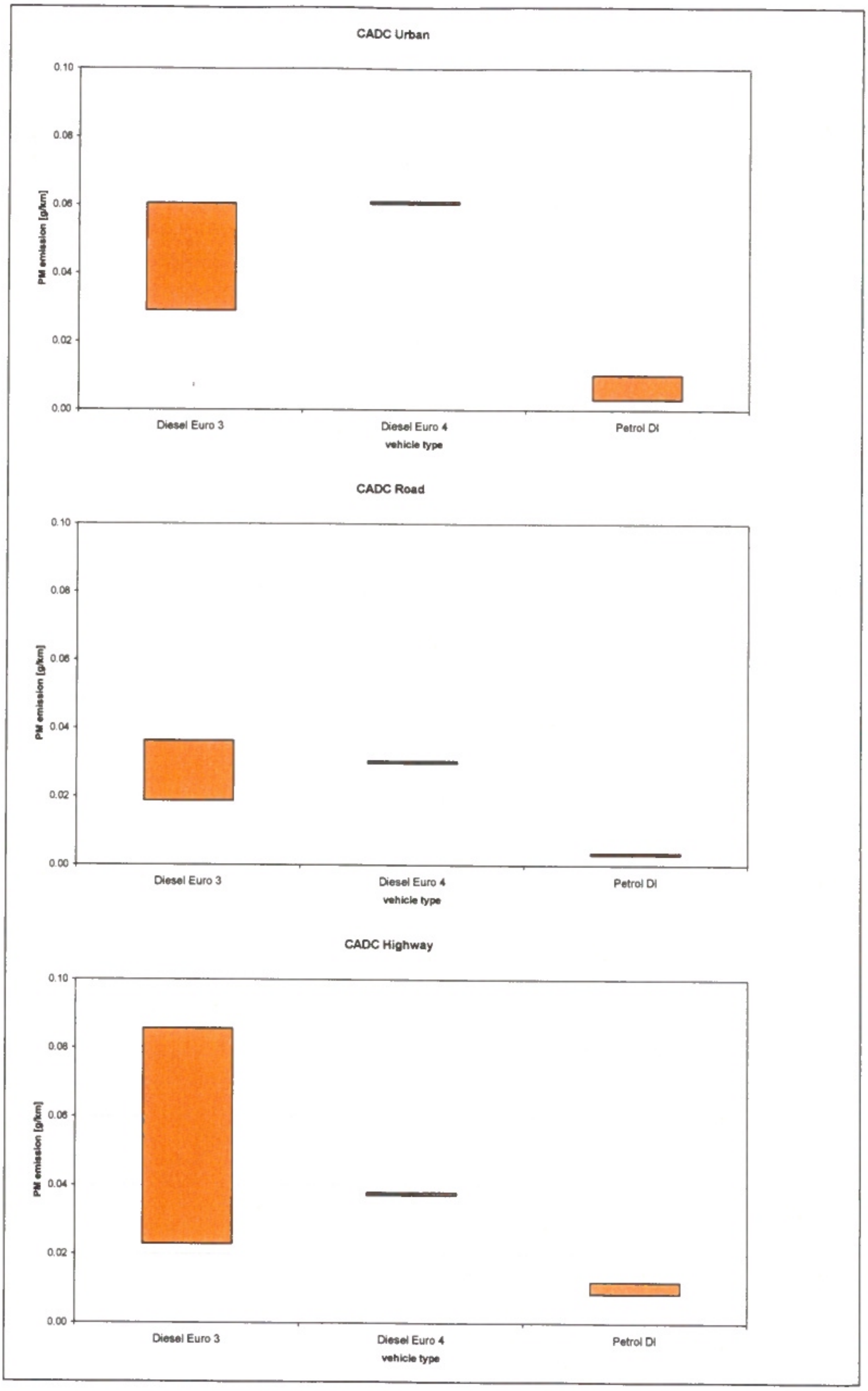


Figure 39 - 1-σ PM emissions from the CADC cycles for several fuel and technology types (Note: only one Euro diesel vehicle type has been tested)

6.3 Real world cold start emissions from average ambient temperature

During the previous years of the In-Use Compliance programme, a lot of emission data has been collected on real world cycles such as the CADC cycles. So far however, real world emissions under cold start conditions have been paid little attention to. Therefore in the 2004 In-Use Compliance programme a separate measurement campaign was set up for this purpose. It was chosen to drive the CADC urban cycle twice, with a cold start and with a hot start, because the additional cold start emissions will primarily be emitted under urban conditions as people leave their homes or work. The temperature that was chosen for the cold start was 9°C, the yearly average Dutch outside temperature. This temperature is also within the context of the calculations done by the 'Taakgroep Verkeer en Vervoer' (see section 11.1) [Klein, 2004]. Before the cold start test, the vehicles were conditioned at this temperature for at least 8 hours. 20 vehicles were selected to undergo the real world cold start test, see table 9.

Table 11 Vehicles selected for real world cold start test

Fuel	Vehicle make	Vehicle type	Euro 1	Euro 2	Euro 3	Euro 4
Petrol	Ford	Focus 1.6 16v		✓		
Petrol	Mazda	6 1.8				✓
Petrol	Nissan	Almera 1.4i		✓		
Petrol	Opel	Astra 1.6i	✓			
Petrol	Peugeot	307 SW 1.6 16v			✓	
Petrol	Suzuki	Alto 1.1			✓	
Petrol	Volkswagen	Polo 1.4i 16v		✓		
Petrol	Volkswagen	Touran 1.6 FSI				✓
Petrol	Volvo	V40 2.0			✓	
Diesel	[anonymous]*	[anonymous]*				✓
Diesel	Audi	A4 1.9 TDI		✓		
Diesel	Ford	Fiesta 1.8 D	✓			
Diesel	Opel	Astra 1.7 DTi			✓	
Diesel	Peugeot	306 1.9 D		✓		
Diesel	Renault	Megane 1.5 dCi			✓	
Diesel	Toyota	Picnic 2.2 TD		✓		
Diesel	Volkswagen	Passat 1.9 TDI			✓	
Diesel	Volvo	V70 2.4 D5			✓	
LPG	Alfa Romeo	147 1.6 T.S. 77kW			✓ (LPG-G3)	
LPG	Volvo	S60 2.4 Bi-Fuel			✓	

* In the light of the further discussions in this chapter, this vehicle type has been made anonymous because it is the only Euro 4 diesel vehicle that was tested in 2004.

The results of the cold start CADC urban test compared to the hot start CADC urban test are displayed in the next figures per emission component.

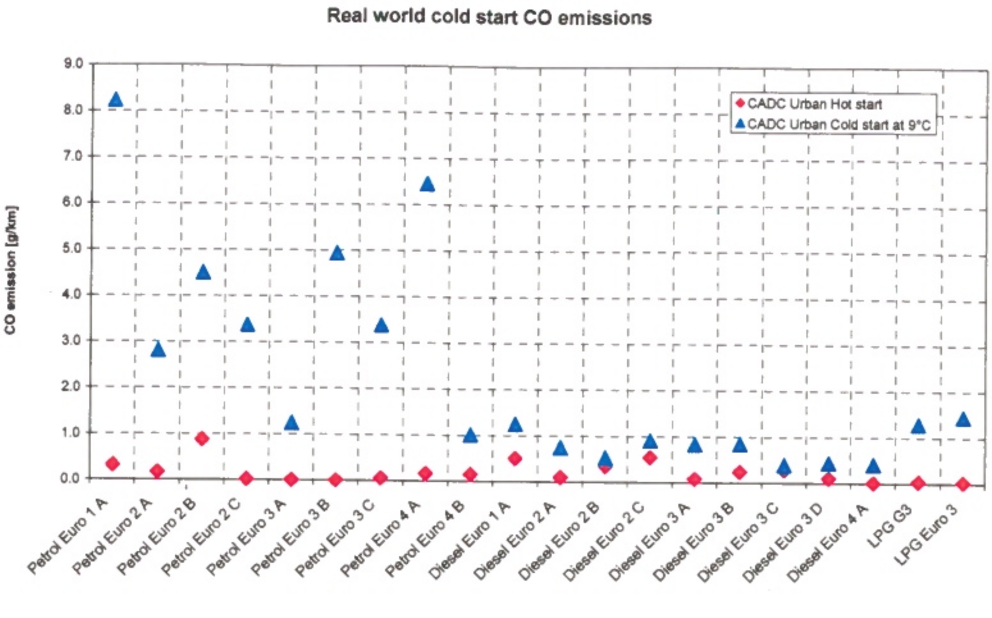


Figure 40 - CO emission results on the CADC urban cycle with a hot start and a cold start at 9°C

The cold start vs. the hot start CO emissions clearly show the difference in cold start behavior of the three fuel types petrol, diesel and LPG. Because of cold start enrichment and catalyst light off, the petrol and to a less extent the LPG vehicles, have the highest cold start effect. It is remarkable that there seems to be no trend in the decrease of the cold start effect at this temperature from petrol Euro 1 to Euro 4 vehicles. The Euro 1 vehicle indeed had the highest cold start emissions, but followed by a Euro 4 vehicle. In general the Euro 1 to Euro 4 cold start effect for petrol vehicles alternated between high and low values. The two LPG vehicles both showed a relatively low cold start effect.
Because of the low engine out emissions for diesel vehicles, their cold start effect for CO is very low. The light off of the oxidation catalyst, which was present on most vehicles tested, reduced the hot start emissions, but the effect is not as large as for the petrol vehicles.

In table 10, the cold start effects (grams per cold start) on the UDC cycle at 20°C and on the CADC Urban at 9°C are compared. For this purpose all data was used that was available in the emission database of the In-Use Compliance programme. It is important to note that from Euro 2 to Euro 3, the cold start procedure was changed. The old procedure included 40 seconds idling before the measurement started. For the new Euro 3 onwards procedure, the 40 seconds idling was dropped and the measurement started immediately after engine start. Therefore the emission results from using the new procedure are worse than from the old one.

For the UDC cycle much more data are available than the 20 vehicles tested on the CADC in 2004. In order to obtain a more robust dataset, the results from the 2003 study "Evaluation of the environmental impact of modern passenger cars on petrol, diesel, automotive LPG, CNG" [Hendriksen, 2003] were added to the dataset. Only Euro 3 vehicles were tested in this study, 6 per fuel type, so only the results for this category have increased in significance.

When both cold start effects are compared for CO petrol, as expected, the effect on the CADC Urban at 9°C is much higher than on the UDC at 20°C. At lower temperatures it takes more time for the catalyst to reach the light off temperature. During the warm up phase of the catalyst, the emissions are primarily 'engine out' emissions. Therefore the additional effect exists that due to driving a real world cycle, the engine out emission will increase strongly over the UDC cycle.

Furthermore it is remarkable that the CADC cold start effect for petrol vehicles does not decrease from Euro 2 to Euro 4, bearing in mind the small sample size for Euro 2 and Euro 4 and the strongly alternating cold start results.

For diesel vehicles, the CADC cold start effect varies from 1,5 to 3,5 grams per cold start. The LPG G3 vehicle showed a remarkable low cold start effect on the CADC Urban cycles, whereas the LPG Euro 3 cold start effect was more in range with the results on petrol vehicles.

Table 12 Cold start effect for CO on the UDC at 20°C compared to the CADC Urban at 9°C

Fuel	**Emission class**	**UDC 20°C [g/cold start]**	**CADC Urban 9°C [g/cold start]**	**Difference [%]**
Petrol	Euro 1	9.9 (n=220)	35.4 (n=1)	257%
	Euro 2	4.9 (n=74)	14.3 (n=3)	193%
	Euro 3**	5.4 (n=28)	19.0 (n=9)*	253%
	Euro 4	4.1 (n=19)	16.0 (n=2)	289%
Diesel	Euro 1	1.3 (n=31)	3.3 (n=1)	158%
	Euro 2	3.0 (n=64)	1.7 (n=3)	-42%
	Euro 3**	2.1 (n=22)	2.1 (n=10)*	-3%
	Euro 4	-	1.8 (n=1)	-
LPG	LPG G3	5.2 (n=8)	5.6 (n=1)	8%
	Euro 3**	5.8 (n=1)	13.8 (n=7)*	139%

* including the results from the study "Evaluation of the environmental impact of modern passenger cars on petrol, diesel, automotive LPG, CNG", [Hendriksen, 2003]

** For the Euro 3 onwards procedure, the 40 seconds idling has been dropped and the measurement is started immediately after engine start

The cold start results for hydrocarbons (HC) are displayed in the next figure.

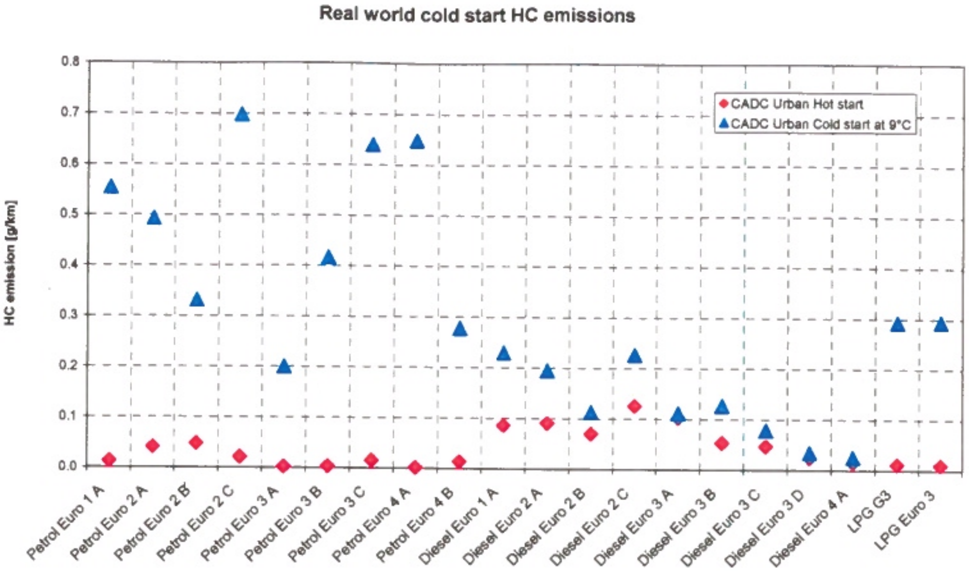


Figure 41 - HC emission results on the CADC urban cycle with a hot start and a cold start at 9°C

For the petrol vehicles, the same picture appears as for the CO emissions. The HC cold start results for Euro 1 to Euro 4 petrol vehicles alternate strongly, and the highest value that was measured was emitted by a Euro 2 vehicle, and not, as would be expected, by the Euro 1 vehicle. The LPG vehicles showed relatively low emission levels at cold start. The diesel vehicles had the lowest HC cold start emissions of all.

The comparison with the UDC cold start at 20°C is given in the table 11. Again as expected, the CADC 9°C values are much higher compared to the UDC 20°C values. It is remarkable that the CADC cold start effect appears to remain stable from Euro 1 to Euro 4 vehicles, in between 2 and 3 grams per cold start, although the effect has decreased on the UDC cycle. Again bearing in mind the small sample size for Euro 1, 2 and 4 and the strongly alternating cold start results, it might be concluded that the UDC cold start has been optimized for low emissions over the years, but the cold start at other (lower) temperatures and driving conditions not. It is clear however, that more vehicles need to be tested in order to be able to draw more robust conclusions.
The LPG vehicles show a similar behavior although the level of the cold start emissions is considerably lower. The diesel vehicles have low cold start emissions on both the UDC at 20°C as well as the CADC Urban at 9°C.

Table 13 Cold start effect for HC on the UDC at 20°C compared to the CADC Urban at 9°C

Fuel	**Emission class**	**UDC 20°C [g/cold start]**	**CADC Urban 9°C [g/cold start]**	**Difference [%]**
Petrol	Euro 1	1.7 (n=220)	2.4 (n=1)	44%
	Euro 2	1.2 (n=74)	2.1 (n=3)	76%
	Euro 3**	0.6 (n=28)	2.7 (n=9)*	322%
	Euro 4	0.6 (n=19)	2.0 (n=2)	247%
Diesel	Euro 1	0.1 (n=31)	0.6 (n=1)	340%
	Euro 2	0.6 (n=64)	0.4 (n=3)	-35%
	Euro 3**	0.2 (n=22)	0.1 (n=10)*	-40%
	Euro 4	-	0.1 (n=1)	-
LPG	LPG G3	0.6 (n=8)	1.3 (n=1)	125%
	Euro 3**	0.4 (n=1)	1.9 (n=7)*	365%

* including the results from the study "Evaluation of the environmental impact of modern passenger cars on petrol, diesel, automotive LPG, CNG", [Hendriksen, 2003]

** For the Euro 3 onwards procedure, the 40 seconds idling has been dropped and the measurement is started immediately after engine start

For CO and HC, new petrol vehicle types from 1 January 2002 must undergo an additional cold start test at type approval. This cold start test consists of four consecutive Urban Driving Cycles (UDC) starting at a temperature of -7°C. The emission limits are 15 g/km for CO and 1,8 g/km for HC. Of the petrol vehicles tested in 2004, only the two Euro 4 vehicles had to be type approved with the -7°C test. Since no -7°C test was done at TNO, the type approval values are mentioned in table 12, in which the test results are included too.

Table 14 Type approval values of the -7°C test compared to the measured values of the UDC at 20°C and the CADC Urban at 9°C

		-7°C Test (4*UDC) [g/km]* / [g/cold start]	UDC at 20°C [g/km] / [g/cold start]	CADC Urban at 9°C [g/km] / [g/cold start]
CO	Euro 4 A	5.4 / 87.2	2.0 / 8.0	6.4 / 28.1
	Euro 4 B	1.7 / 26.0	1.1 / 4.2	1.0 / 3.8
HC	Euro 4 A	0.55 / 8.8	0.13 / 0.52	0.65 / 2.9
	Euro 4 B	0.84 / 13.3	0.12 / 0.44	0.28 / 1.2

* Type approval values, limit for CO is 15 g/km and for HC 1,8 g/km

From this table can be concluded that both vehicles met the -7°C test at type approval by a rather large margin, especially for CO. Therefore it might be assumed that the manufacturers did not need to take measures, in addition to the measures needed to meet the Eurotest from 20°C, to meet these -7°C limits. The results also show the unpredictability of the cold start emissions, therefore more data is needed on the cold start behaviour at lower temperatures.

The cold start results for NO_x are displayed in the next figure.

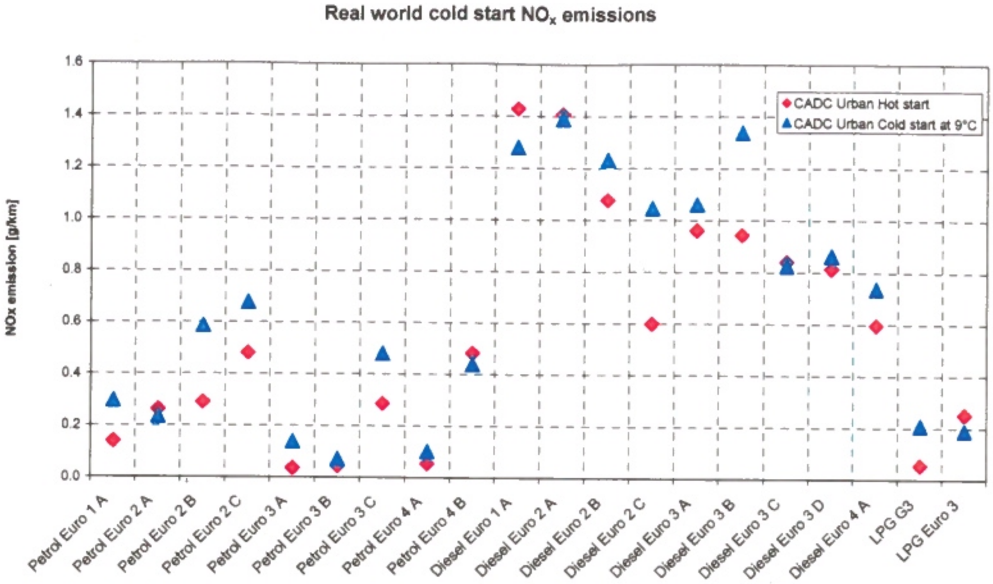


Figure 42 - NO_x emission results on the CADC urban cycle with a hot start and a cold start at 9°C

From this figure can be concluded that the hot and the cold start NO_x emissions lie more closely together than the CO and HC emissions did. In some cases the cold start emissions are even lower than the hot start emissions. This can be caused by the fact that the first part of the CADC Urban cycle requires a low load from the engine with consequently a low engine out NO_x emission. The last part of the CADC Urban cycle requires higher loads where the engine out NO_x emissions are higher too. Although the catalyst is working, this might overcompensate for the relatively low NO_x emissions from the first part of the cycle.

The comparison of the cold start effect for NO_x in general on the UDC cycle and the CADC Urban cycle is relatively low. Petrol, diesel and LPG vehicles show the same range of values.

Table 15 Cold start effect for NO_x on the UDC at 20°C compared to the CADC Urban at 9°C

Fuel	**Emission class**	**UDC 20°C [g/cold start]**	**CADC Urban 9°C [g/cold start]**	**Difference [%]**
Petrol	Euro 1	0.8 (n=220)	0.7 (n=1)	-8%
	Euro 2	0.4 (n=74)	0.7 (n=3)	73%
	Euro 3**	0.2 (n=28)	0.3 (n=9)*	51%
	Euro 4	0.2 (n=19)	0.0 (n=2)	-98%
Diesel	Euro 1	0.2 (n=31)	-0.7 (n=1)	-392%
	Euro 2	0.2 (n=64)	0.9 (n=3)	402%
	Euro 3**	-0.3 (n=22)	0.4 (n=10)*	242%
	Euro 4	-	0.6 (n=1)	-
LPG	LPG G3	0.2 (n=8)	0.7 (n=1)	351%
	Euro 3**	0.1 (n=1)	1.2 (n=7)*	1883%

* including the results from the study "Evaluation of the environmental impact of modern passenger cars on petrol, diesel, automotive LPG, CNG", [Hendriksen, 2003]

** For the Euro 3 onwards procedure, the 40 seconds idling has been dropped and the measurement is started immediately after engine start

The cold start PM emissions of the diesel vehicles has been measured as well

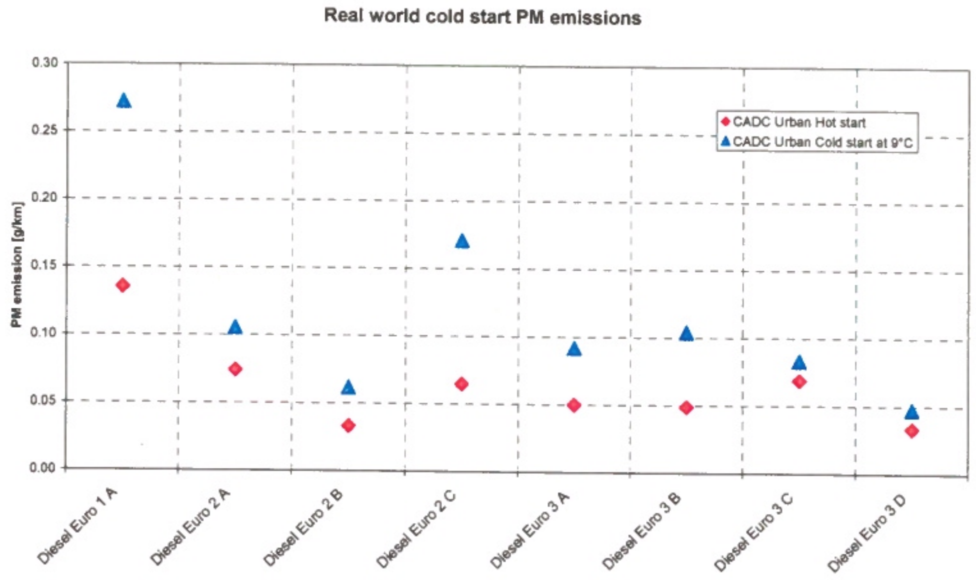


Figure 43 - - PM emission results on the CADC urban cycle with a hot start and a cold start at 9°C

Diesel vehicles clearly also have a cold start effect for PM emissions, which is caused by poor vaporization of diesel fuel under cold conditions. The amount of cold start emissions can vary a lot.

Table 16 Cold start effect for PM on the UDC at 20°C compared to the CADC Urban at 9°C

Fuel	Emission class	UDC 20°C [g/cold start]	CADC Urban 9°C [g/cold start]	Difference [%]
Diesel	Euro 1	0.14 (n=31)	0.61 (n=1)	333%
	Euro 2	0.06 (n=64)	0.25 (n=3)	310%
	Euro 3**	0.04 (n=22)	0.09 (n=10)*	121%
	Euro 4	-	0.22 (n=1)	-

* including the results from the study "Evaluation of the environmental impact of modern passenger cars on petrol, diesel, automotive LPG, CNG", [Hendriksen, 2003]

** For the Euro 3 onwards procedure, the 40 seconds idling has been dropped and the measurement is started immediately after engine start

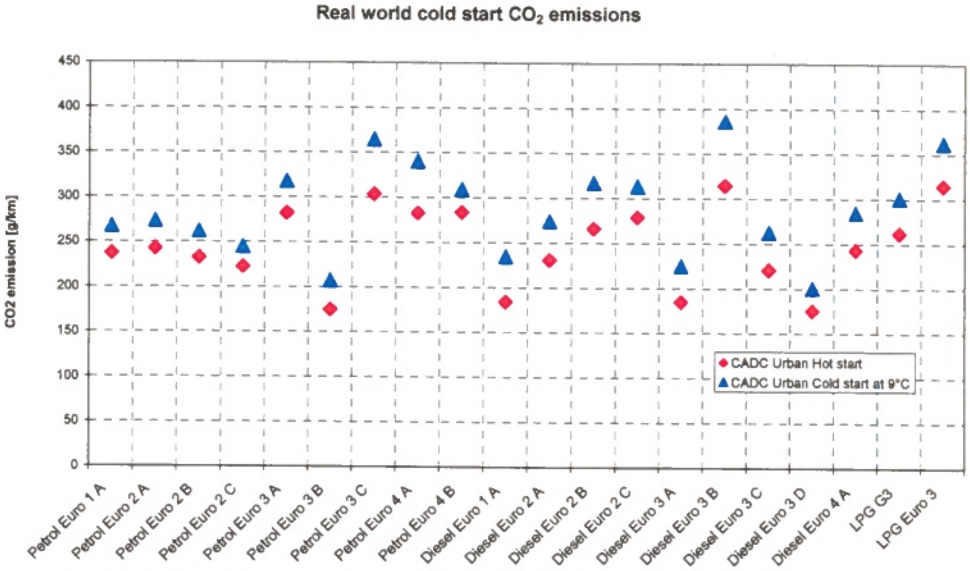


Figure 44 - CO_2 emission results on the CADC urban cycle with a hot start and a cold start at 9°C

The cold start emissions for CO_2 are not influenced by any catalyst light of effect. Only the increased friction at low temperatures and fuel enrichment are the cause of higher CO_2 emissions (and a higher fuel consumption). In general on a cycle of around 5 kilometres long, the CO_2 emissions are 15% to 20% higher than the warm emissions. Table 15 shows that this increase is about the same for the UDC cycle at 20°C and the CADC Urban cycle at 9°C. It could be that the lower starting temperature of the CADC Urban cycle is compensated by the increased speed of warming up of the engine due to the higher engine loads of the CADC Urban cycle over the UDC.

Table 17 Cold start effect for CO_2 on the UDC at 20°C compared to the CADC Urban at 9°C

Fuel	**Emission class**	**UDC 20°C [%]**	**CADC Urban 9°C [%]**	**Difference [%]**
Petrol	Euro 1	13 % (n=220)	13 % (n=1)	-5%
	Euro 2	16 % (n=74)	12 % (n=3)	-25%
	Euro 3**	15 % (n=28)	14 % (n=9)*	-4%
	Euro 4	18 % (n=19)	15 % (n=2)	-21%
Diesel	Euro 1	16 % (n=31)	27 % (n=1)	74%
	Euro 2	18 % (n=64)	16 % (n=3)	-6%
	Euro 3**	19 % (n=22)	20 % (n=10)*	2%
	Euro 4	-	17 % (n=1)	-
LPG	LPG G3	17 % (n=8)	15 % (n=1)	-14%
	Euro 3**	15 % (n=1)	15 % (n=7)*	-3%

* including the results from the study "Evaluation of the environmental impact of modern passenger cars on petrol, diesel, automotive LPG, CNG", [Hendriksen, 2003]

** For the Euro 3 onwards procedure, the 40 seconds idling has been dropped and the measurement is started immediately after engine start

6.4 Summary of the real world cycles

In 2004 the real world tests consisted of the following three parts:

- The emissions and congestion cycles
- The Common Artemis Driving Cycles (CADC)
- The real world cold start effect

The emission tests performed within each of these parts have generated a lot of useful information that has been added to the TNO emission database to improve the statistical foundation of the emission characteristics. Especially the real world characteristics of vehicles of the Euro 2 and Euro 3 category are sufficiently represented in the TNO database now. For the Euro 4 category, especially diesel, the number of vehicles tested is too low yet in order to create a general picture of their emission characteristics.

The emission results under real world cold start emissions show that the individual results vary a lot, especially for the components CO and HC. A statistical sound cold start effect under real world conditions therefore can not be determined yet with these results.

7 Durability

In order to assess the stability of emission levels during the lifetime of the vehicle, measurements have been performed on selected vehicles at various times during the vehicle life. This provides an indication of the increase or reduction of a vehicle's emission due to wear caused by continual use.

In 2004 the durability test fleet consisted two vehicles:
1 Volkswagen Passat TDI 74 kW Euro 3
2 Volvo V70 D5 Euro 3
These vehicles are the first ones where the CADC cycles have been used to assess emissions durability.

In 2003 an Volkswagen Passat TDI 66kW and a Ford Mondeo D were also subjected to durability tests, however these vehicles were discontinued in the test programme due to vehicle availability.

The tests during the lifetime of the Volkswagen Passat TDI 74 kW were conducted at the intervals shown in Table 16.

Table 18 Odometer readings and date of durability tests for the VW Passat TDI 74kW.

Test Date	Odometer reading
21-10-2003	46 245 km
26-08-2004	77 667 km
23-12-2004	91 002 km

The tests during the lifetime of the Volvo V70 D5 were conducted at the intervals shown in Table 17.

Table 19 Odometer readings and date of durability tests for the Volvo V70 D5.

Test Date	Odometer reading
19-06-2003	29 149 km
05-05-2004	70 555 km

The emission results over the test duration are displayed in Figures 46 and 47.

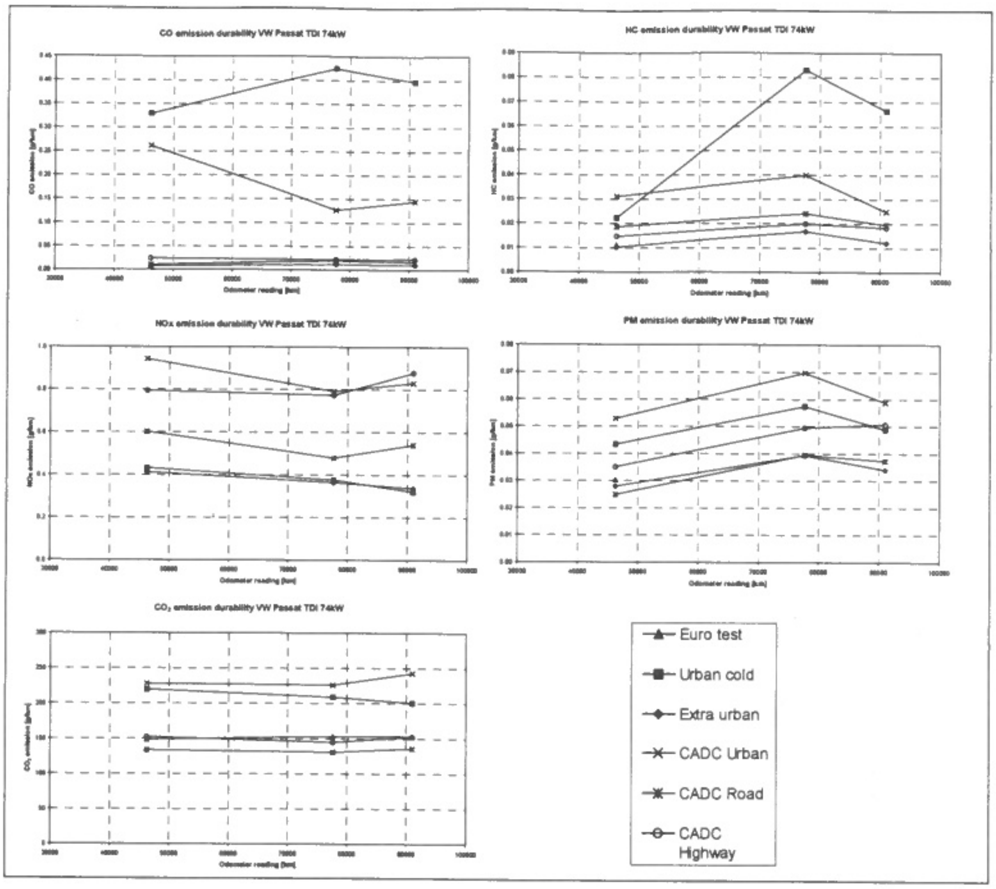


Figure 45 - Emissions of a Volkswagen Passat TDI 74kW over its lifetime

The NO_x and PM emissions during the lifetime of the Volkswagen Passat TDI 74kW seem to have a correlation with the exchange interval of the belt, that drives the camshaft that operates the valves and the unit injectors. This belt was replaced at 90.000 km. From the first measurement to the second, the NO_x emissions decrease and the PM emissions increase. This is possibly caused by lengthening of the belt during it's lifetime that changes (retards) the injection timing. As a result the NO_x emissions decrease and the PM emissions increase. After the replacement of the belt, the injection timing was set again at its original value. The emission test thereafter showed as expected that the NO_x emissions increased again, and the PM emissions decreased. Possibly because of some injector wear and contamination, the PM value does not return to it's value at the first measurement.
The CO and HC emissions more or less follow the same pattern as the PM emissions, except that these values stay low under any circumstance.

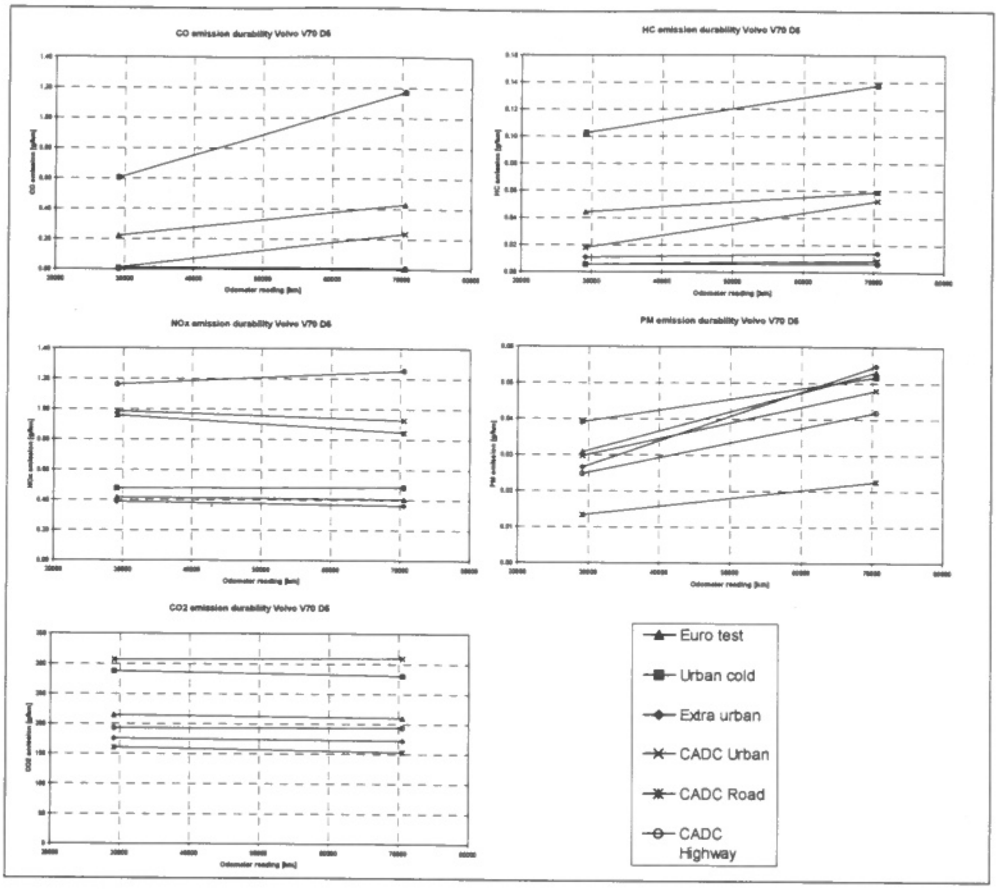


Figure 46 - Emissions of a Volvo V70 D5 over its lifetime

From this figure can be concluded that the CO, HC and PM emissions of the Volvo V70 D5 increased significantly over it's lifetime. At the second test, the PM emission on the Eurotest even exceeded the Euro 3 limit value of 0,05 g/km. Since the engine is equipped with common rail fuel injection, where the injection timing is not determined by a belt, and because the NO_x emissions appear to be very stable, a change of injection timing is not a likely cause of the increase of the PM emissions. More likely causes are wear of the injectors or contamination of the injectors. The tests that are planned for 2005 will show whether the emissions will deteriorate further or will stabilise.

8 Chip-tuning

8.1 Introduction to chip-tuning

Chip-tuning nowadays is a popular way of performance enhancement of road vehicles. Chip-tuning is an operation that includes all types of electronic modifications of an engine management with the purpose of improving the vehicles performance. The modifications are mostly easy to install (even by the vehicles owner) and are relatively cheap alternatives to a higher powered version in a vehicle range. Especially modern electronically controlled turbocharged engines are very suited for chip-tuning. The reason for this is that turbo charged vehicles generally have the possibility to increase the amount of air available for combustion, which allows for the increase of the amount of fuel to inject and therefore increases engine power and torque. These changes in air and fuel amount can be achieved by reprogramming the electronic motor management of the engine to increase turbo pressure and fuel injector timing. If the air/fuel ration would be constant for all engine load settings, chip-tuning would be an easy and reliable operation, involving linear changes in some parameters stored in the engine management computer. The only reservation that would have to be made in relation to chip-tuning would be some concern about the durability of the engine since it (in some cases) was not developed for the increased power and torque generated.

In practice the air/fuel ratio is far from constant and largely depends on a large variety of parameters like, engine speed, coolant temperature, throttle position etc. Next to the amount of fuel injected in relation to the amount of combustion air available, the timing of the injection of the fuel is variable and very critical. All parameters have strong influence on the exhaust gas quality and fuel consumption of the vehicle. Car manufacturers execute extensive development programmes on optimising these parameter settings which leads to complex software in the vehicles engine management computer. This implicates that a chip-tuner will have to execute intensive research in order to make his product equivalent in environmental performance to the factory setup. But as can be expected, chip-tuners can have different perspectives. With differences in Dutch market prices of about Euro 2000,- between the standard and high powered engine listed variant (+30% power and torque), chip-tuning can be a profitable business. Prices for chip-tuning vary from about 70,- Euro to about 1000,- Euro, which implicates large differences between types of chip-tuning being sold.

The estimates vary, but it is assumed that up to 25% of new sold diesel cars in the Netherlands are equipped with chip-tuning. All systems are retrofit and therefore are not part of type approval or vehicle related taxation schemes (except for VAT). The Dutch taxation scheme (high luxury tax on vehicles and lease vehicle value added to the income) favours after market power increase above “new sold” high power. With this popularity of chip-tuning there is a concern that chip-tuning cars could lead to a significant increase of the total Dutch emission emitted annually. Since chip-tuning is applied outside of the European Type Approval process (after market) there is no insight into the actual emission performance of these modified vehicles and the consequences for the Dutch air quality. Therefore it was decided to test one vehicle with three typical levels of sophistication of chip-tuning with prices of 70,- , 400,- and 950,- Euro within the framework of the In-Use Compliance programme. The technical description of all three is presented below.

8.2 Description of versions of chip-tuning tested

The vehicle used for these tests was a Volkswagen Passat 1.9 TDI 74kW Euro 3, which is a typical vehicle type that is often fitted with chip-tuning, since it's the low powered version of the 1.9 TDI engine, with the 96 kW version of the same base engine being 1700,- Euro more expensive. Consequently, the vehicle was equipped with the following three types of chip-tuning.

Chip-tuning #1 : fuel temperature modification

The first chip-tuning tested does not actually deserve the title “chip-tuning”. It's a small box containing a resistor that is fitted in the engine compartment between the fuel temperature sensor and the Electronic Control Unit (ECU) and thereby bypasses the fuel temperature sensor. The resistor generates a fixed value that simulates a high fuel temperature all the time (independent of actual fuel temperature) given by the fuel temperature sensor. The ECU then ‘thinks’ that the fuel has a higher temperature (and therefore a lower density) than it really has, and therefore decides to increase the amount of fuel to be injected. As a result the maximum power and torque increase by a few percent.

The consequences of this approach are that the power increase is at it's maximum when the actual fuel temperature is at it's lowest, directly after a cold start. In modern diesel engines fuel temperatures can rise towards 80°C (because of ultra high injection pressures and fuel backflow from the injectors), which is the cause for the fuel temperature to be thermostatically regulated (in the fuel filter). The effect of this technical set-up is that whenever the engine is at operating temperature, the actual power increase under normal running conditions is limited. This set-up leads to the delicate factory engine (software) calibration being “fooled” all the time and therefore the injection amount, the injection timing and the combustion air amount being principally not optimal all the time. At cold start the error is at it's maximum.

Chip-tuning #2: External digital signal manipulation

The second type of chip-tuning tested is of a more sophisticated kind. The signal line between the ECU and the injector control unit is interrupted, feeding the signals into an external signal-processing unit. In this so-called “power box”, the signals to the injector control unit are modified regarding fuel amount and injection timing. But since the signal transfer is via a digital CAN-bus, the signal of for instance the turbo pressure control can be modified as well. In principle this set-up is very flexible and enables a rather good adoption of the engine settings.

The current digital CAN-bus approach of “power boxes” is much more sophisticated than earlier ones on analogue rotary pump injector systems (early TDI engines). These analogue power boxes just boosted the signal to the injector pump depending from the throttle position only. Injection timing and turbo pressure were not modified, leading to visible smoking of the vehicles because of lack of combustion air at high loads.

Power boxes are very popular because they can be fitted easily to an engine in a few minutes and therefore can also be removed easily when going to the workshop (in case of roadworthiness tests) or when changing cars. The performance of the power boxes however is largely dictated by the amount of work the developer of the system has put into the software. If the developer can take into account the levels of freedom the CAN-bus manipulation basically offers, the system can be rather well balanced. For doing this job right he needs high level diesel technology knowledge and test facilities. The amount of work that has been put in the power box will therefore automatically be reflected in the price of the power box.

Chip-tuning #3: Internal digital signal manipulation

The third chip-tuning tested basically has the same principle of chip-tuning #2, but instead of manipulating the signal from the ECU to the injector control unit, the ECU itself is modified. This involves reprogramming the EPROM in the ECU that contains the calibration software. This kind of chip-tuning is even more flexible than the (external) digital power-box, because all parameters of the engine calibration can be changed. Changing the parameters correctly demands a large amount of knowledge from the developer. Therefore chip-tuning #3 does not necessarily have to be better than the power-box. Only in combination with a high development effort, chip-tuning #3 will reveal the extra potential of an engine.

The advantage of chip-tuning #3 is that no additional connections and hardware are needed which increases the reliability of the chip-tuning. On the other hand, the ECU has to be opened and the new EPROM has to be welded in, which is a delicate operation that should only be executed by qualified personnel. The latest ECU's allow the EPROM's to by reprogrammed externally via the OBD connector, but industry is disabling this option gradually in order to prevent "easy" chip-tuning. The external reprogramming was initially foreseen to enable workshops to load manufacturers software updates into the ECU, but is now being misused for chip-tuning. The "disablement" of the manufacturers is utilised by limiting the amount of allowed software updates (to for instance max. 2) or disabling the option of reprogramming via the OBD connector. Official factory software updates will have to take place by opening the ECU again and using dedicated connectors and password protection.

Chip-tuning #3 is supplied by a wide variety of after market suppliers and is generally fitted to the vehicle by this supplier, because of the welding in the ECU or the need for a dedicated OBD reprogramming tool. The market prices vary from 400 Euro to over 1000 Euro.

The chip-tuning tested by TNO was supplied by the importer of the vehicle. It can be bought as a (BPM free) after market extra and is available at the VW dealerships in the Netherlands, together with a full warranty of the vehicle (in most cases). The software application itself is developed by a company that is closely linked to VW's sport activities, which gives this company direct access to the calibration engineers and software of original vehicle. The result is a fully dedicated software update for each individual vehicle type (up to the level of production month and accessories configuration). As such it can be regarded as an official importer approved way of chip-tuning.

8.3 Emission tests

In order to assess the effects of all 3 types of chip-tuning regarding their environmental performance, TNO has set up a dedicated test programme. This programme involved the execution of emission tests using the standard European Type Approval procedure

(Eurotest) and a broadly accepted real world test procedure (CADC, Common Artemis Driving Cycle). The results of these tests are shown in the next figures.

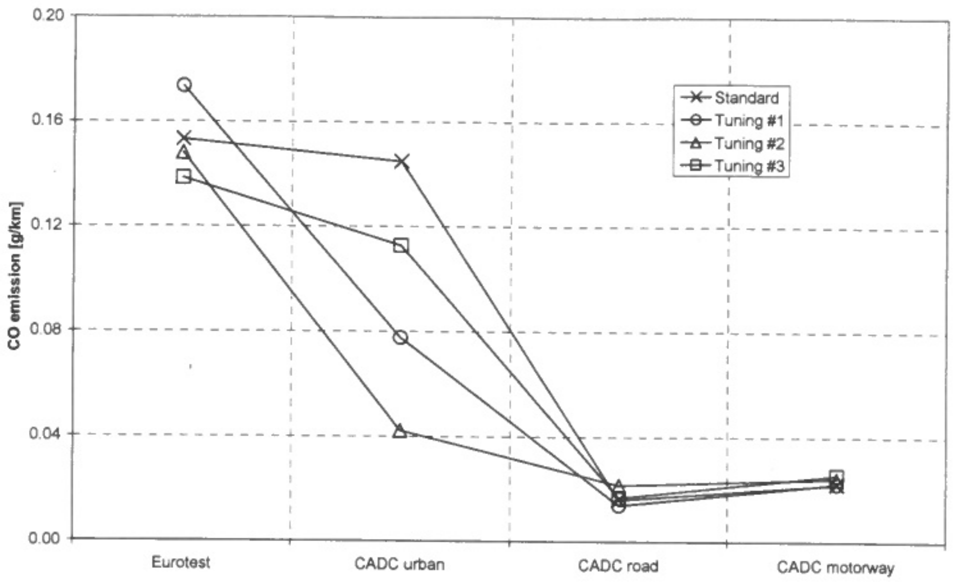


Figure 47 - Effect of chip-tuning on CO emissions, Eurotest and CADC cycles

For CO the largest effects occur on the Eurotest and the CADC urban cycle. The emission values on the Eurotest are well below the 0,64 g/km however. The CO emissions on the CADC urban cycle are significantly lower for all three types of chip-tuning. On the CADC road and motorway cycles no remarkable differences are observed, the CO emissions are very low in all cases.

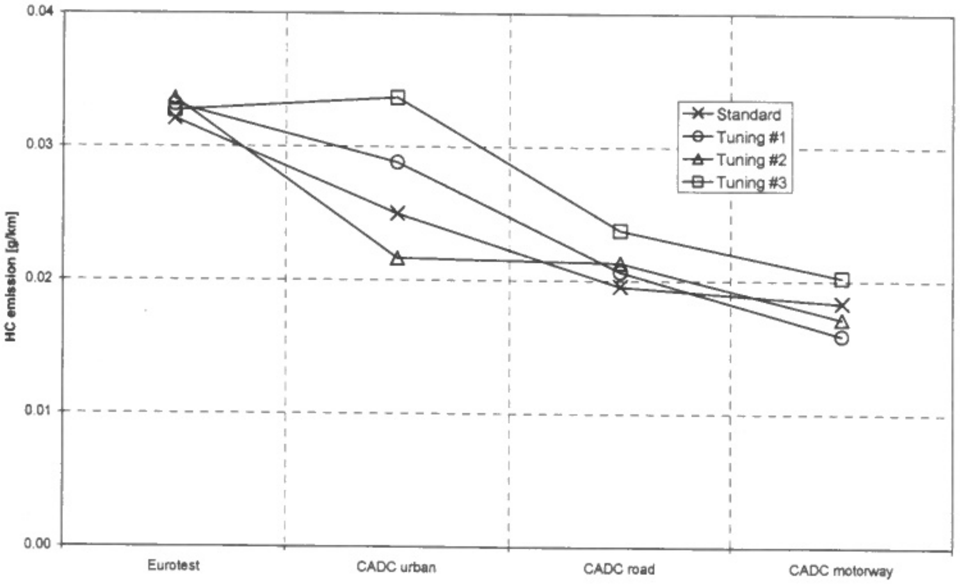


Figure 48 - Effect of chip-tuning on HC emissions, Eurotest and CADC cycles

Under any circumstances, the HC emissions measured are very low and the largest effects are seen on the CADC urban cycle. On all CADC cycles, Tuning#3 has the highest HC emissions though.

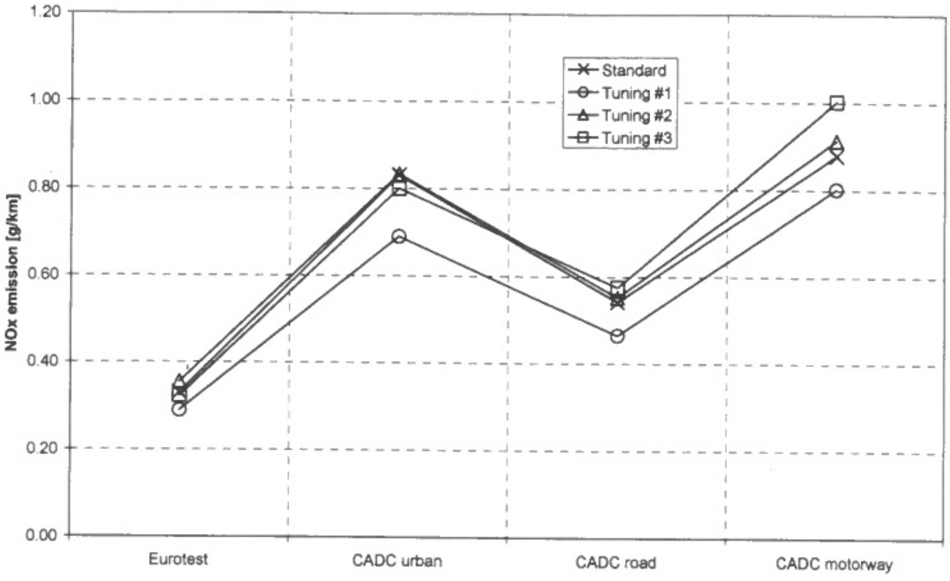


Figure 49 - Effect of chip-tuning on NO_x emissions, Eurotest and CADC cycles

The results for the NO_x emissions are more distinctive. It can be seen that on all cycles Tuning #1 has significantly lower NO_x emissions, up to -17% on the CADC urban cycle. This can be explained by the fact that Tuning #1 only increases the amount of fuel to inject by extending the duration of the injection of fuel. The injection timing is not being advanced and as a result the average injection timing retards. When the injection is retarded, the combustion peak pressures and temperatures drop, resulting in a lower production of NO_x, but on the contrary a higher production of PM as resulting from this retarding.

Tuning #2 and #3 show little or no effect on the NO_x emissions on the Eurotest, the CADC urban and road cycles. The more integrated approach where all engine parameters are optimised towards higher maximum power shows that under these mediate driving conditions a chip tuned car's emissions can be quite close to the standard car. With the request for more engine power (on the motorway) the NO_x CADC motorway emissions for Tuning #3 were higher than the standard car though, making more use of the high power and torque setting at elevated throttle positions. In all cases no exceedances of the Euro 3 NO_x limit were measured.

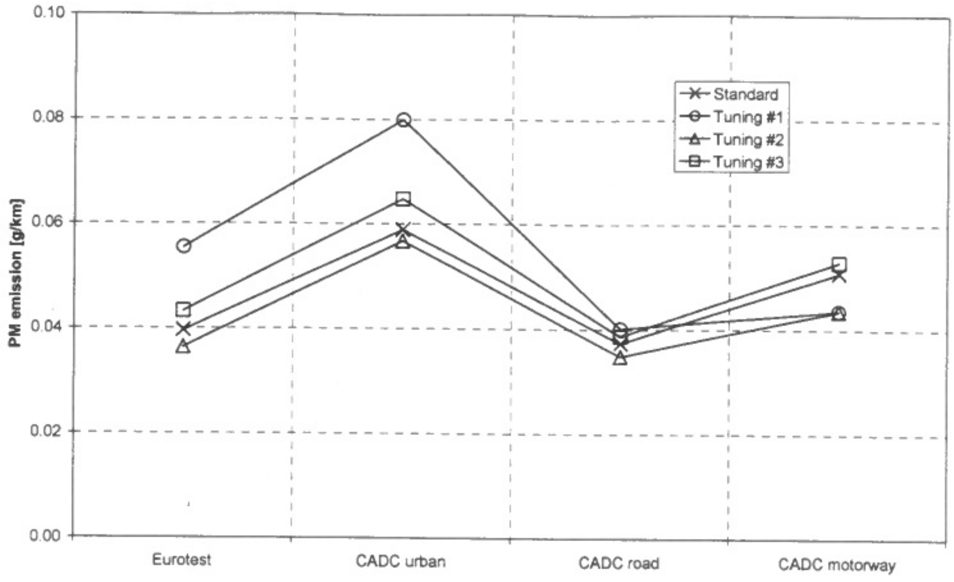


Figure 50 - Effect of chip-tuning on PM emissions, Eurotest and CADC cycles

As can be expected, mainly linked to the retarding of the average injection timing, the PM emissions of Tuning #1 increase significantly up to 40% on the Eurotest and the CADC urban cycle. The result on the Eurotest even exceeds the Euro 3 limit value of 0,05 g/km. No increase of the PM emissions on the CADC road cycle was observed, and on the CADC motorway cycle the PM emission even decrease, probably due to the calibration being off.

The large increase in emissions of Tuning #1 may be explained by the fact that this type of tuning has the largest effect at the moment the fuel is at it's coldest, which occurs during testing directly after the cold start of the Eurotest. The CADC test is started with a warm (not hot) engine. With the fuel therefore already at an elevated temperature, the tuning remains limited when compared to cold fuel. During the driving of the CADC the fuel heats up even further, further limiting the effect of the tuning. Tuning #3 showed on all cycles an increase of the PM emissions of 4% to 10%. On the other hand, Tuning #2 emitted up to 14% less PM on all cycles. These effects are typically caused by certain choices in the recalibration regarding drive ability, fuel consumption and maximum power/torque.

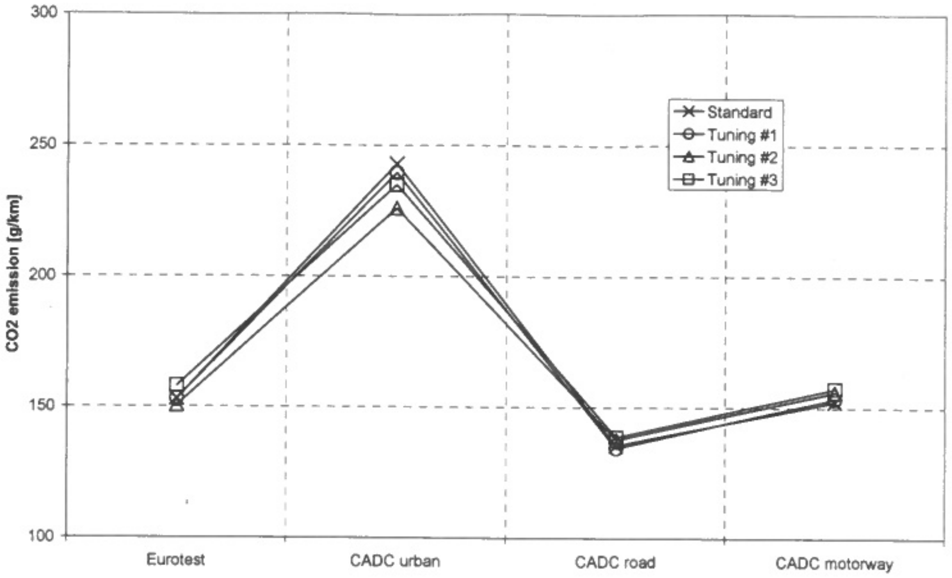


Figure 51 - Effect of chip-tuning on CO_2 emissions, Eurotest and CADC cycles

The effects of chip-tuning on CO_2 emissions (and fuel consumption) are small. The differences measured range from -2% to +3%. Tuning #2 emitted 7% less CO_2 on the CADC urban cycle though.

8.4 Summary of chip-tuning

When the results of the tests with chip-tuning are summarised, a distinction between 'simple' and 'sophisticated' types of chip-tuning must be made. The tests have shown that the largest effects occur with the simple Tuning #1, where by means of "fooling" the ECU, the amount of fuel injected is increased. Since no adaptations to the injection timing are made, the change in fuel amount and injection duration has its effects on the NO_x (decrease) and PM (increase) emissions.

The effects measured on the more sophisticated Tuning #2 and #3 are of a lower magnitude, and in many cases the emissions remained close to the level of the standard vehicle.

It is important to note that the circumstances under which the various forms of chip-tuning were tested were kept equal. All tests were carried out with the same Eurotest and CADC cycles. It is to be expected though that higher powered vehicles will in practice tempt a driver to a more 'sporty', dynamic driving pattern, that consequently will lead to higher emissions of NO_x and PM.

The actual effect for the consumer (power-and torque increase) has not been quantified. It could however be observed that the subjective feeling was that Tuning #2 gave the highest amount of extra power, because of the sharp increase in acceleration (torque) at about 1800 rpm. The setting of Tuning #3 was less "aggressive", but the actual maximum achievable acceleration was slightly better than Tuning #2. Tuning #1 only showed increased acceleration with a cold engine.

The driveability of the three variants was quite different as well. Compared to the standard vehicle, Tuning #1 had poor cold start drive-ability and unsmooth power display at constant speed. Tuning #2 also was unsmooth to drive after cold start, but when warm had a good driveability. The drive-ability of Tuning #3 was at the same level of the standard vehicle (not taking into account the additional power and torque).

9 Emissions on four Dutch real world highway cycles

As already described in section 6.1, much work on emissions from passenger cars under real world highway situations has been done in the 'Emissions and congestion' project [Gense, 2001]. The ten driving cycles that were developed in this project have been part of the In-Use Compliance programme for several years now. However the need for a more refined set of driving cycles within the speed range of 80 to 100 km/h became apparent in recent years. Especially situations with a speed limit of 80 with trajectory speed limit enforcement became subject of much public and political attention. For this reason TNO decided to develop four more driving cycles that address these specific situations. These cycles were developed within the framework of the "Driving cycles" target funding programme in 2003 and 2004. An extensive description of the development of these cycles is given in [Elst, 2005].

The four driving cycles that were developed can be described as follows:

Table 20 Characterisation of additional Dutch real world highway cycles

Cycle no.	**Speed limit [km/h]**	**Traffic characterisation**	**Speed limit enforcement**	**Location of recorded traffic data**
80FF	80	Free flow	Trajectory speed limit enforecement	A13, Delft - Rotterdam
80MI	80	Medium interaction	Trajectory speed limit enforecement	A13, Delft - Rotterdam
100FF	100	Free flow	High density speed radars	A9, Schiphol - Amstelveen
100MI	100	Medium interaction	High density speed radars	A9, Schiphol - Amstelveen

The characterisation, in terms of average speed and dynamics [RPA], of these four cycles is displayed in the next figure.

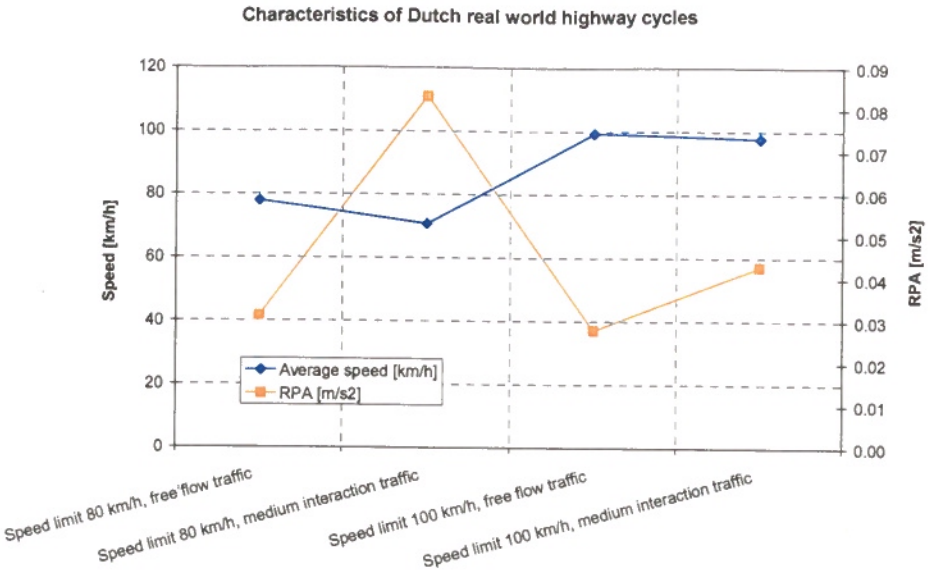


Figure 52 - Characteristics of Dutch real world highway cycles

As can be concluded from this figure, the differences between the 80 Medium Interaction (MI) cycle and the 80 Free Flow (FF) cycle are greater than the differences between the 100MI and the 100FF cycles. Apparently the type of speed limit enforcement and the speed limit itself has much influence on the traffic flow.

The emissions on these four driving cycles were measured on 20 vehicles, the same that were already selected for the real world cold start tests. The vehicles are listed in table 9. The results of the emission measurements are given in the next figures.

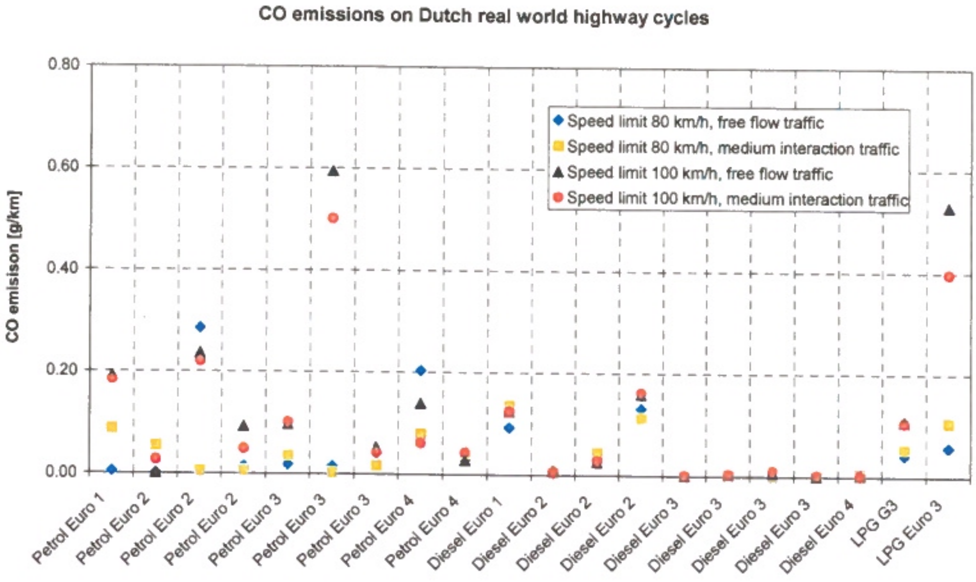


Figure 53 - CO emission results on the Dutch real world highway cycles

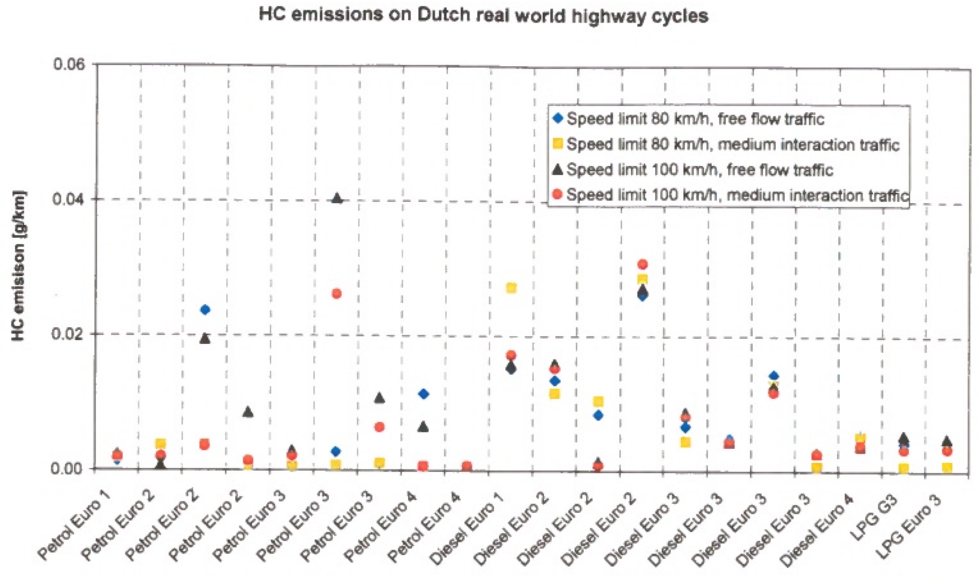


Figure 54 - HC emission results on the Dutch real world highway cycles

The vehicles tested emitted very low levels of CO and HC emissions on these driving cycles. It is difficult though to observe a general trend on CO and HC emissions from these figures. Given the low priority of CO and HC within the framework of urban air quality management, no further attention will be given to these pollutants at this point.

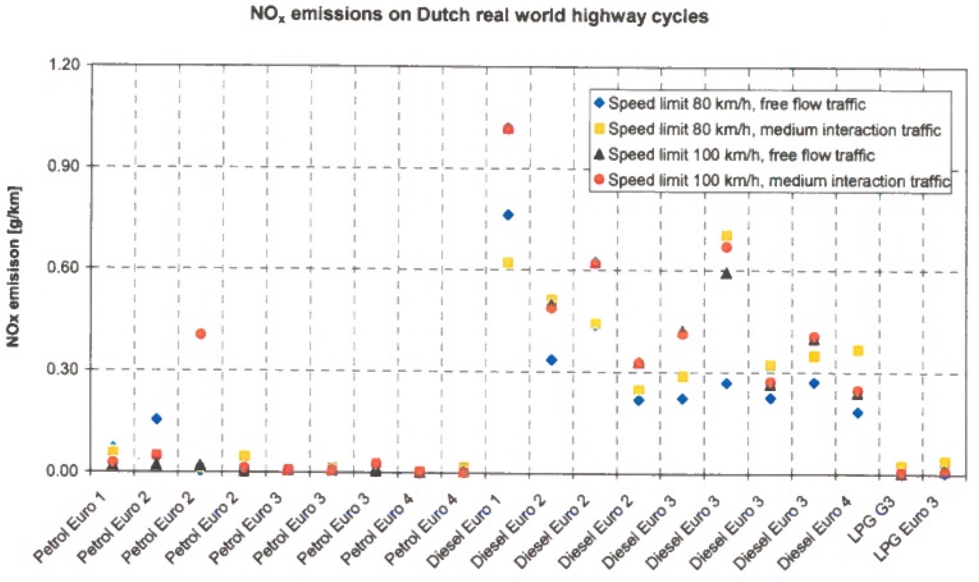


Figure 55 - NO_x emission results on the Dutch real world highway cycles

The NO_x emissions as displayed in the previous figure show a familiar pattern, the NO_x emissions of diesel vehicles being the highest and decreasing with the Euro-classes. The NO_x emissions on all cycles for the petrol and LPG vehicles are very low though.
In most cases the vehicles have the lowest emissions on the 80FF cycle, followed by the 100MI cycle. This is especially the case for the diesel vehicles, which also have the highest absolute emission levels. The emissions on the 80MI cycle, with the highest

driving dynamics, are in most cases higher than the emissions on the 80FF cycle. This is not the case for the 100FF and 100MI cycles. Apparently the higher speed is more dominant than the differences in driving dynamics.

For the PM emissions of the diesel vehicles, the results are as follows:

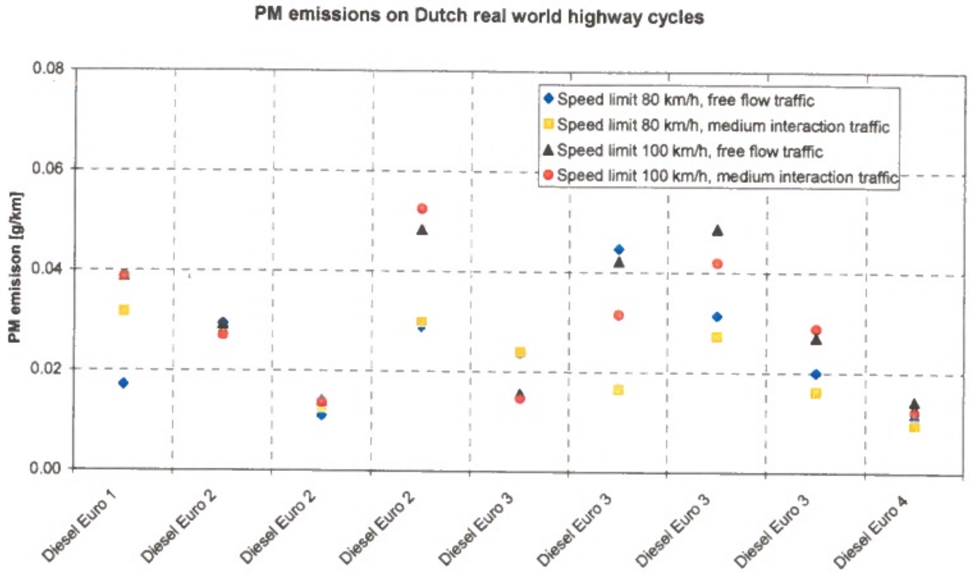


Figure 56 - PM emission results on the Dutch real world highway cycles (diesel vehicles)

Since no clear patterns appears in the absolute PM emissions from the diesel vehicles, the emissions have been ranked too, see the next table. Despite the absolute differences between the cycles are small, in general the 80MI cycle seems to have the lowest emissions, especially for the most modern diesel vehicles. The NO_x – PM trade off clearly plays a role here. Because of the higher power demand on the 80MI cycle, the engine management will advance the ignition timing. As a result the NO_x emissions go up, and the PM emissions decrease. The differences between the 100FF and the 100MI cycles are relatively small, especially for the modern diesel vehicles.

The CO_2 emissions have been measured as well.

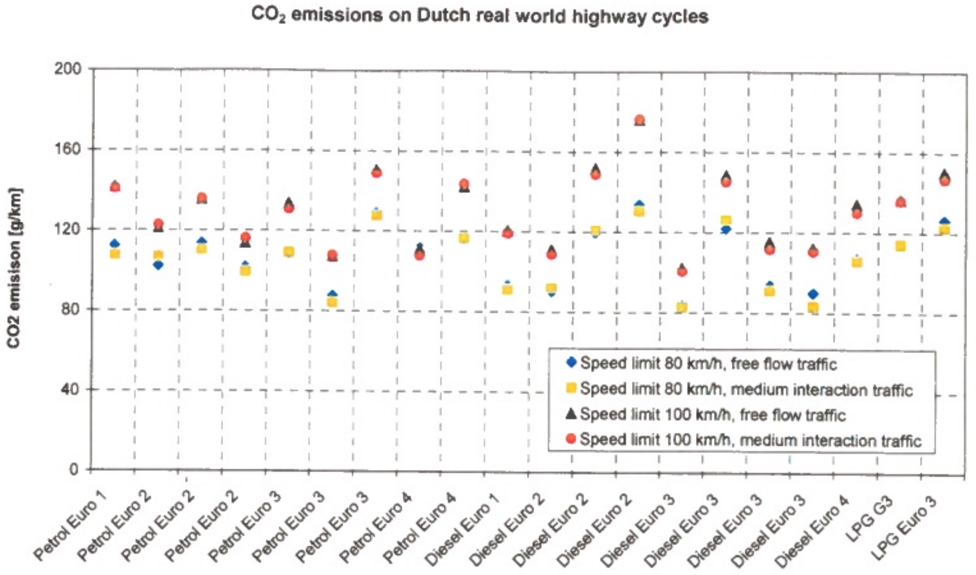


Figure 57 - CO_2 emission results on the Dutch real world highway cycles

From this figure can be concluded that the CO_2 emissions (and fuel consumption) for the 80 km/h and the 100 km/h cycles can be clearly distinguished from each other. The difference amounts to approximately 15% for the petrol and LPG vehicles and 20% for the diesel vehicles that were measured. The differences between the Free Flow and the Medium Interaction cycles averaged 1%.

In areas where highway traffic contributes to the local air quality problems, imposing a speed limit of 80 km/h and/or enforcing the limit (80 or 100 km/h) strictly (e.g. by means trajectory speed limitation) could be a means for improvement of the air quality. In practice this could mean imposing a 80FF or 100FF situation where currently a 100MI situation exists. Since this issue is very complicated though, it will not be further discussed in this report, but will be referred to the report *"Quickscan optimal speed limit on Dutch highways"* [Riemersma, 2004]. As an aid though for the interpretation of the test results, the next table gives a simplified overview of the differences in NO_x and PM emissions for the 100MI cycle compared to the 80FF, 80MI and 100FF cycles per vehicle type tested.

Table 21 Differences in NO_x and PM emissions for the 100MI cycle compared to the 80FF, 80MI and 100FF cycles

	NO_x			PM		
	80FF	80MI	100 FF	80FF	80MI	100 FF
Petrol Euro 1 A	--	--	+			
Petrol Euro 2 A	--	o	++			
Petrol Euro 2 B	++	++	++			
Petrol Euro 2 C	++	--	++			
Petrol Euro 3 A	o	-	-			
Petrol Euro 3 B	o	--	-			
Petrol Euro 3 C	++	-	++			
Petrol Euro 4 A	++	o	++			
Petrol Euro 4 B	--	--	--			
Diesel Euro 1 A	+	+	o	++	+	o
Diesel Euro 2 A	+	o	o	o	o	o
Diesel Euro 2 B	+	+	o	+	o	o
Diesel Euro 2 C	+	+	o	+	+	o
Diesel Euro 3 A	+	+	o	--	--	o
Diesel Euro 3 B	++	o	+	-	+	-
Diesel Euro 3 C	+	-	o	+	+	-
Diesel Euro 3 D	+	+	o	+	+	o
Diesel Euro 4 A	+	-	o	+	+	-
LPG G3	+	--	+			
LPG Euro 3	++	--	-			

Legend: ++ much less emissions (> -50% difference); + less emissions (-10 to -50% difference); o neutral (-10 to +10% effect); - more emissions (+10 to +50% difference); -- much more emisisons (> +50% difference)

This table shows that for the petrol and LPG vehicles tested the effects on the NO_x emissions that were measured could be either very positive or very negative, though the positive effects occur more often, especially for the 100FF cycle compared to the 100MI cycle. For the diesel vehicles it is clear that without exception the 80FF cycle has much lower NO_x emission levels than the 100MI cycle. The comparison of the 100FF and 100MI cycles for NO_x emissions of the diesel vehicles tested, the differences are in most cases rather small. The PM emissions of diesel vehicles tested show more variation than the NO_x emissions, but the same picture emerges as for the NO_x emissions, the 80FF cycle showing the largest emission decrease compared to the 100MI cycle than the 100FF cycle.

This leads to the more generalised conclusion that the 80FF cycle is the traffic regime that is to be preferred from an emissions point of view over the 100FF cycle. Especially the effect for NO_x emissions from diesel vehicles seems significant, and in combination with the fact that this vehicle category has the largest absolute emission levels too for both NO_x and PM, the effect of imposing a 80FF traffic regime can have an effect on the air quality as well. It is difficult at this point to attach a percentage to the amount with which the emissions could be reduced however. This strongly depends on the reference situation (speed limit regime, congestion) and the vehicle fleet composition. But also the emission test results show a variation of such kind that it is impossible to calculate any statistical significant emission factors for each vehicle class (e.g. diesel Euro 4), for use in air quality modelling. Before this can be done, the number of vehicles per vehicle class that have been tested on these cycles must be increased. Therefore an extension of the number of emission tests with the new Dutch real world highway cycles has been planned for 2005.

10 Emission measurements for the EU 5th Framework project OSCAR

In 2004 TNO Automotive participated in the EU 5th Framework project OSCAR. The work of TNO Automotive in OSCAR is co-financed by the Dutch Ministry of Housing, Spatial Planning and the Environment as part of the 2004 contract for the In-Use Compliance programme. A description of the project and the contribution of TNO Automotive is discussed in the next sections, and adapted from [Boulter, 2005].

10.1 Introduction to OSCAR

OSCAR is a European Commission 5th Framework project which will deliver a tool to enable users to evaluate road traffic-related air pollution, and to identify suitable impact reduction options. The tool (the OSCAR 'Assessment System') will be designed primarily to address the management of local air quality during periods of traffic congestion. The development of a tool which can be applied across Europe requires an understanding of the similarities and differences between road traffic patterns, emissions and air pollution levels in different urban areas of different geographical regions. Consequently, measurement campaigns have been conducted in four 'main' European cities - Athens, Helsinki, London and Madrid - as part of the development of the OSCAR System. These campaigns have provided new data relating to the following:

- Driving patterns, vehicle operation conditions and traffic characteristics on main urban roads.
- Exhaust emissions associated with different levels of congestion.
- Roadside and urban background concentrations of nitrogen oxides (NO_x), nitric oxide (NO), nitrogen dioxide(NO_2), particles with a diameter of less than 10µm (PM_{10}), and particles with a diameter of less than 2.5µm ($PM_{2.5}$).
- Meteorological parameters.

Improved emission and air pollution models will be created from these measurements, and these will subsequently be incorporated in the OSCAR Assessment System. Relevant data from three 'supplementary' cities will also be incorporated. The Assessment System approach will be validated and verified by application in the main and supplementary cities.

10.2 Aims of vehicle emission measurement and modelling in OSCAR

An important element in the development of the OSCAR Assessment System is an improved understanding of driving characteristics, vehicle operation and exhaust emissions at low speeds, which should lead to improvements in the modelling of emissions associated with different levels of congestion.

In OSCAR, new exhaust emission measurements have been conducted on 20 passenger cars, see section 10.4. However, for the OSCAR system to be applicable consistently on a European level, these new measurements would not, on their own, be sufficiently extensive. Hence, the emissions work has not been designed to provide a completely new emission model, but rather to supplement and improve the underlying data and methodologies of existing models. The usefulness of the emission measurements conducted in OSCAR was therefore maximised by ensuring that they conformed to the current needs of emission model developers. In particular, the measurements had to be compatible with the structures of the latest emission models being developed in Europe. The specific objectives of the emissions work were:

- To characterise driving patterns in the four main cities, based on measurements of vehicle operation and traffic conditions.
- To improve existing emission databases by measuring emission factors for slow-moving and stationary traffic.
- To develop an Emissions Module for use in the OSCAR system which improves existing models.
- To develop a best practice for determining congestion-related emission factors.

10.3 Development of the OSCAR driving cycles

One of the objectives of OSCAR is to improve low-speed emission factors for road vehicles, and to develop a method which would allow users to distinguish between different levels of traffic congestion in a pragmatic way. There were two principal tasks associated with these objectives:

1 To measure emission factors for different levels of congestion
2 To develop an emissions module for use in the OSCAR system

The driving cycles in OSCAR were developed by TRL. They should reflect varying degrees of congestion on main roads in large urban areas, and to improve existing approaches to defining different levels of congestion from a perspective which is likely to be meaningful in terms of vehicle emissions. The process of constructing driving cycles has a direct bearing on the way the emissions data can be used in a model. In order to estimate emissions using a model, there must be a means by which the model user can compare the parameters which describe typical vehicle operation associated with a given scenario to the cycles over which emissions are measured. One or more intermediate variables must be used to link the two, and these must be meaningful in terms of emissions. Many emission models have used average speed as the sole intermediate variable.

The stages of the methodology for the development of the OSCAR driving cycles were as follows:

I. Vehicle operation patterns, road conditions and traffic conditions were recorded on specified links in each of the four main cities Athens, Helsinki, London and Madrid.
II. The power characteristics of each driving pattern were determined.
III. Relationships were established between traffic speed and density, and the power-based cycle parameters.
IV. The real-world driving patterns were grouped according to these two sets of parameters.
V. Representative driving patterns were selected from the different groups, and used to construct driving cycles which reflected driving in all cities for given road and traffic conditions.

An extensive description of the work done by TRL can be found in [Boulter, 2005]. At this point, some milestones of the development will be highlighted.

For each driving pattern measured on urban roads in OSCAR, the 1-hour average traffic density (v/km, again based on LDV equivalents) was calculated for the corresponding period. The traffic density value was calculated as the 1-hour average traffic flow divided by the 1-hour average speed. Average link speed was plotted against traffic density for these links, as shown in figure 58. Each point in figure 58 represents a single driving pattern. The plot indicates that, in relation to traffic density, the traffic on different links with different speed limits do, in general terms, behave similarly (for example, the data for different cities sometimes appear to follow the same general curve). However, it was not known what the most significant influences on driving patterns had been during the OSCAR measurements, and that the similarity was likely to be strongly influenced by unrecorded parameters, such as the phasing of the traffic signals.

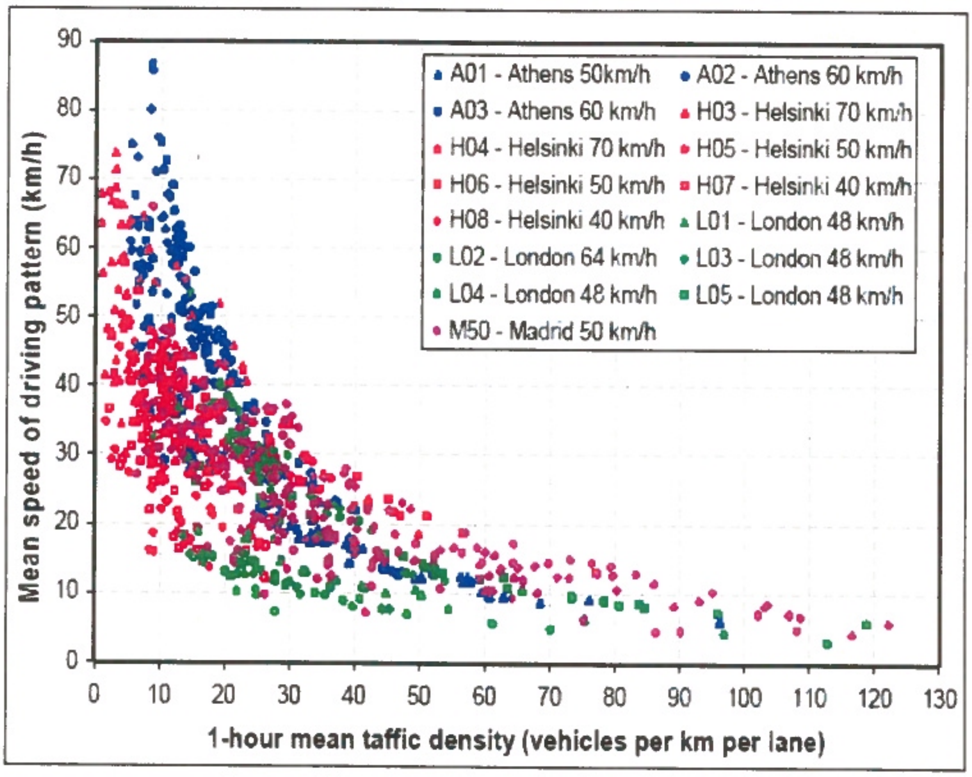


Figure 58 - Average link speed as a function of traffic density on urban roads (speed limit <=70 km/h) in each of the four main OSCAR cities

Driving cycles were constructed to represent each of the six regions C to H of figure 59 Cycles were not developed for regions A and B, as OSCAR is primarily concerned with low speeds. For each of regions C to H, the average values of speed, RPA, power, and number of power peaks per km were determined. Typical driving patterns were selected for each box by virtue of their proximity to these average values. The driving patterns from each region were then combined to form a driving cycle for that region to be used on the chassis dynamometer. The parameters of the driving cycle (average speed, average engine speed, RPA, etc) were within one standard deviation of the region average in each case. Original gear selections were retained.

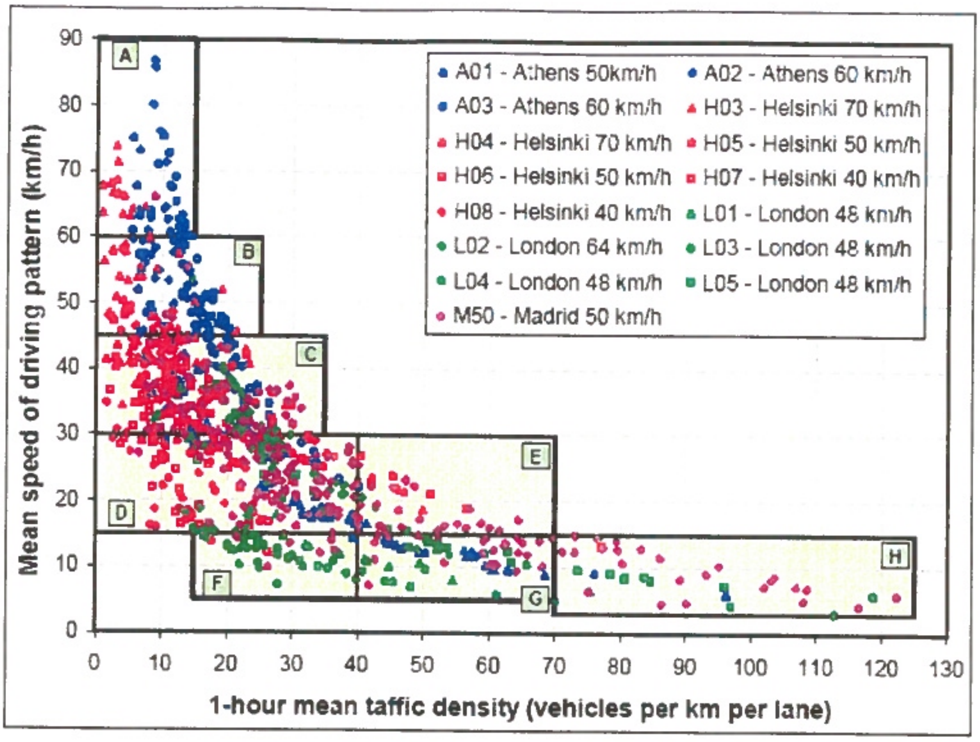


Figure 59 - Average speed and traffic density regions. Traffic speeds and densities are hourly averages

The characteristics of the OSCAR driving cycles are summarised in table 22. Cycles C, D2, E, F, G1 and H1 correspond to typical driving conditions for the associated boundary conditions. Four additional cycles were developed where the data allowed. These were:
D1 – low number of power peaks
G2 – high number of power peaks
H1 – medium number of power peaks
H3 – very high number of power peaks

Although these additional cycles allow the user some flexibility in the modelling, the cycles do not reflect the typical driving for the associated region, and can only be referenced via the speed/density criteria plus a subjective descriptor (e.g. 'smooth flow', 'interrupted flow with high accelerations'). This will be addressed during the emission modelling phase. Some traffic situations (and vehicle operation conditions) may not be adequately covered by the OSCAR database, though some of these are considered to be unlikely (e.g. high speed and high traffic density).

Table 22 Characteristics of OSCAR driving cycles

Cycle	Distance [km]	Duration [s]	Average speed [km/h]	Maximum speed [km/h]	RPA [m/s^2]	% of time idling
C	3.98	402	35.6	70.8	0.212	12
D1	2.70	430	22.6	46.7	0.163	21
D2	2.33	364	23.0	54.7	0.224	20
E	2.05	372	19.9	54.7	0.247	33
F	1.60	424	13.6	49.0	0.244	50
G1	1.56	456	12.3	40.2	0.221	38
G2	1.12	351	11.5	51.5	0.277	32
H1	0.80	371	7.8	31.0	0.169	35
H2	0.95	425	8.1	30.6	0.242	42
H3	0.85	375	8.2	38.6	0.270	41

10.4 OSCAR emission measurements

The derived OSCAR driving cycles were supplied by TRL to TNO Automotive, where the emission tests were conducted on a chassis dynamometer. A total of 20 vehicles was included in the test programme, the same as used for the real world cold start tests (section 5.3) and the real world highway cycles (section 9). The vehicles are listed in table 9 in section 5.3. The primary goal of these emission measurements was to expand existing emission databases for slow-moving and stationary traffic on which the emissions will be modelled. Therefore the objective of OSCAR is not to judge on the individual emission results that have been measured at TNO. To give an impression of the emissions measured though, the results for NO_x and PM, the most important for air pollution, are given in the next figures.

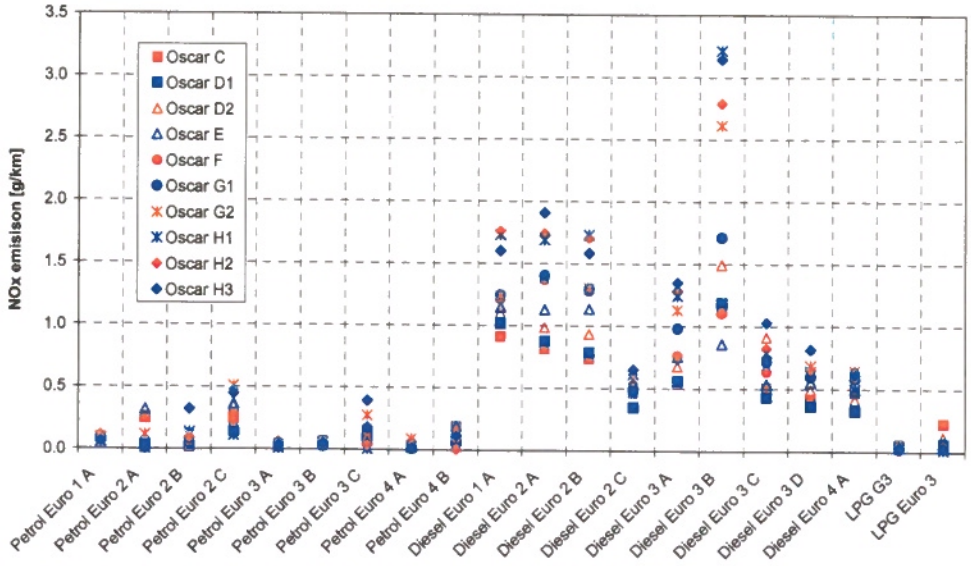


Figure 60 - NO_x emissions on the OSCAR driving cycles

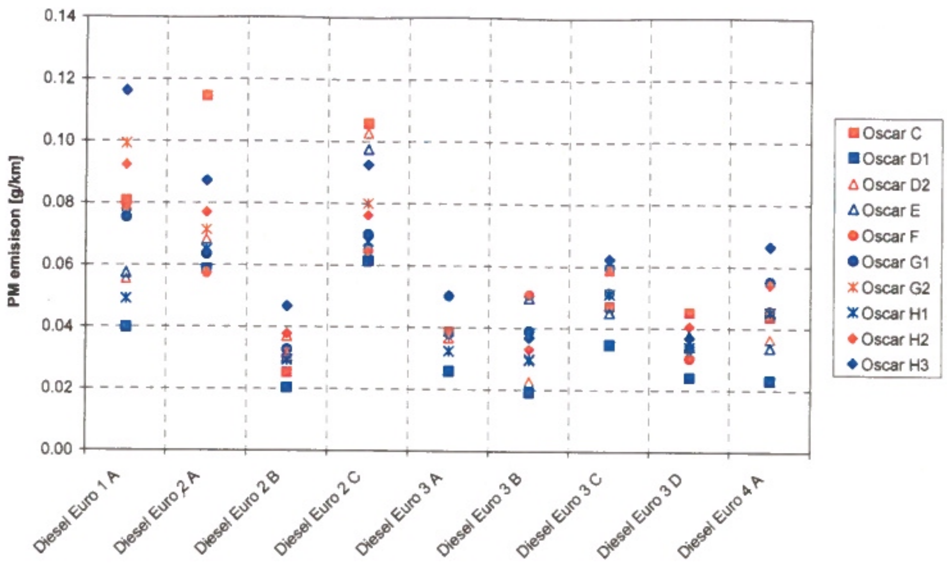


Figure 61 - PM emissions on the OSCAR driving cycles (diesel vehicles)

Based on these figures the following general observations can be made:

- For NO_x of diesel vehicles the highest emissions appear on the G2, H1, H2 and H3 cycles. These cycles represent highly congested traffic at low speeds and a high percentage of idling.
- For the NO_x of petrol and LPG vehicles it is more difficult to draw general conclusions. For some vehicles the 'congested' cycles have the highest emissions, but for other vehicles the 'free flow' cycles have the highest NO_x emissions. Some vehicles have such low emissions that the various OSCAR cycles can hardly be distinguished from each other. It is remarkable too that the emission levels of the petrol vehicles do not vary a lot over the emission classes.
- The PM results for the diesel vehicles show a lot of variation in terms of absolute levels of the emissions, but also in which cycle has the highest (or lowest) emission. This differs per vehicle.

In order to gain more insight in the emission results, the following tables have been made. In these tables the OSCAR cycles have been ranked per vehicle according to the emission on the cycles (1 = highest emission, 10 = lowest emission). The colours are used to accentuate to tables, where red represents the three highest cycles per vehicles, green the three lowest and orange the four intermediate cycles.

For the petrol NO_x emission, this approach results in the following table.

Table 23 Ranking of OSCAR cycles for NO_x emissions of petrol vehicles

	OSCAR driving cycle									
	C	D1	D2	E	F	G1	G2	H1	H2	H3
Petrol Euro 1 A	6	4	9	5	2	3	7	10	1	8
Petrol Euro 2 A	2	5	3	1	10	7	4	8	9	6
Petrol Euro 2 B	10	8	9	7	6	5	3	2	4	1
Petrol Euro 2 C	5	8	4	3	7	9	1	10	6	2
Petrol Euro 3 A	5	9	7	4	2	6	3	10	1	8
Petrol Euro 3 B	1	8	3	6	10	9	7	4	2	5
Petrol Euro 3 C	6	7	8	3	5	4	2	10	9	1
Petrol Euro 4 A	6	8	2	4	5	10	1	7	3	9
Petrol Euro 4 B	1	6	5	2	3	7	8	9	10	4

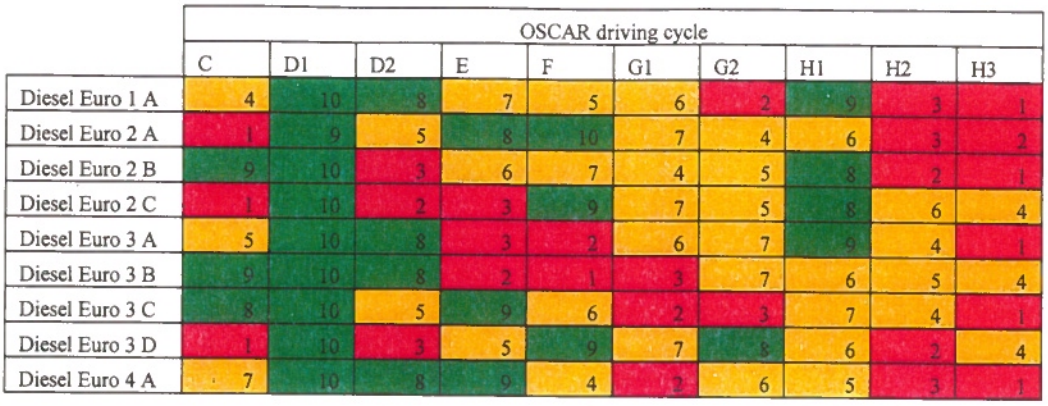
For the NO_x emission from petrol vehicles no clear trend becomes visible in this table. The cycles H1, D1 and G1 seem to have the best ranking overall. Especially cycles H1 and D1 have rather low driving dynamics, as expressed in Relative Positive Acceleration (RPA). Cycles E, G2 and C have the worst ranking. These cycles do have a rather high RPA, but do not stand out from the other cycles. As the absolute emission differences between the cycles per vehicle are relatively small and other cycle parameters play a role, it is difficult to draw general conclusions on the NO_x emission behaviour for petrol vehicles at cycles with high driving dynamics.

Table 24 Ranking of OSCAR cycles for NOx emissions of diesel vehicles

	OSCAR driving cycle									
	C	D1	D2	E	F	G1	G2	H1	H2	H3
Diesel Euro 1 A	10	9	8	7	6	4	5	2	1	3
Diesel Euro 2 A	10	9	8	7	6	5	3	4	2	1
Diesel Euro 2 B	10	9	8	7	6	5	4	1	2	3
Diesel Euro 2 C	9	10	5	6	8	7	4	3	2	1
Diesel Euro 3 A	10	9	8	7	6	5	4	3	2	1
Diesel Euro 3 B	8	7	6	10	9	5	4	1	3	2
Diesel Euro 3 C	9	10	2	8	7	6	5	4	3	1
Diesel Euro 3 D	9	10	8	7	5	6	2	4	3	1
Diesel Euro 4 A	8	10	9	7	2	5	1	6	4	3

The ranking of the cycles for the diesel vehicles gives a much more clearer picture. The cycles C, D1 and D2 (free flow) clearly have the best performance for NO_x diesel, whereas the cycles H1, H2 and H3 (strong congestion) perform the worst. Apparently, the driving dynamics play a rather small role here.

Table 25 Ranking of OSCAR cycles for PM emissions of diesel vehicles



	OSCAR driving cycle									
	C	D1	D2	E	F	G1	G2	H1	H2	H3
Diesel Euro 1 A	4	10	8	7	5	6	2	9	3	1
Diesel Euro 2 A	1	9	5	8	10	7	4	6	3	2
Diesel Euro 2 B	9	10	3	6	7	4	5	8	2	1
Diesel Euro 2 C	1	10	2	3	9	7	5	8	6	4
Diesel Euro 3 A	5	10	8	3	2	6	7	9	4	1
Diesel Euro 3 B	9	10	8	2	1	3	7	6	5	4
Diesel Euro 3 C	8	10	5	9	6	2	3	7	4	1
Diesel Euro 3 D	1	10	3	5	9	7	8	6	2	4
Diesel Euro 4 A	7	10	8	9	4	2	6	5	3	1

The ranking for the PM emissions from diesel vehicles gives a somewhat less clear picture. It is very clear though that cycle D1 is the cycle with the lowest PM emissions for each vehicle. On the other hand, cycles H2 and H3 have the lowest ranking.

Given the high absolute NO_x emissions from diesel vehicles, these vehicles will dominate the NO_x/NO_2 related air quality problems in urban areas. Therefore situations that resemble the C, D1 and D2 cycles are to be favoured as driving patterns in urban areas. For the PM emissions from diesel vehicles the most optimal situation is cycle D1. This leads to the rather obvious observation that situations in which traffic drives at moderate speeds with low dynamics and a low stop time is to be preferred in the light of urban air quality.

10.5 Emission modelling in the OSCAR system

The Emissions Module is planned as a separate entity in the OSCAR system, and would act as an input to all air quality prediction models. This is clearly advantageous, as it would provide:

I. The ability to produce emission estimates alone.
II. A consistent input to all models.
III. The most logical and consistent way of addressing different traffic scenarios.
IV. The ability to incorporate new emission functions at a later date without having to change each air quality prediction model.
V. Easier input of large traffic data files.
VI. An input which could be made country-specific, to a greater or lesser extent depending on the time available.
VII. Flexibility in terms of integration with other emission models.

A possible approach for estimating emissions (and the effects of scenarios) within the OSCAR system is depicted in figure 62. Both the traffic data pre-processor (TPP) and the emissions model form part of the emissions module. The scenario tool forms part of a separate scenario module.

It has been assumed that the emission modelling process within OSCAR will work roughly along the following lines. The user will define the baseline traffic characteristics on the road network, selecting each link at a time via the main user interface and entering the appropriate traffic data (possibly also for each lane and direction). Within the emission module, the TPP will convert the traffic data for each link into a format which can be used for modelling emissions. Once this process has been completed for all links, the baseline traffic data will be fed into the emissions model (a set of functions to determine emissions from the traffic), and the result of the emissions model will be fed into the different air quality models in the OSCAR system. For scenario analysis, a Scenario Tool will be used to apply changes to the baseline traffic data, according to the particular scenario being tested. The traffic data associated with the scenario will then be fed into the emission and air quality models as before.

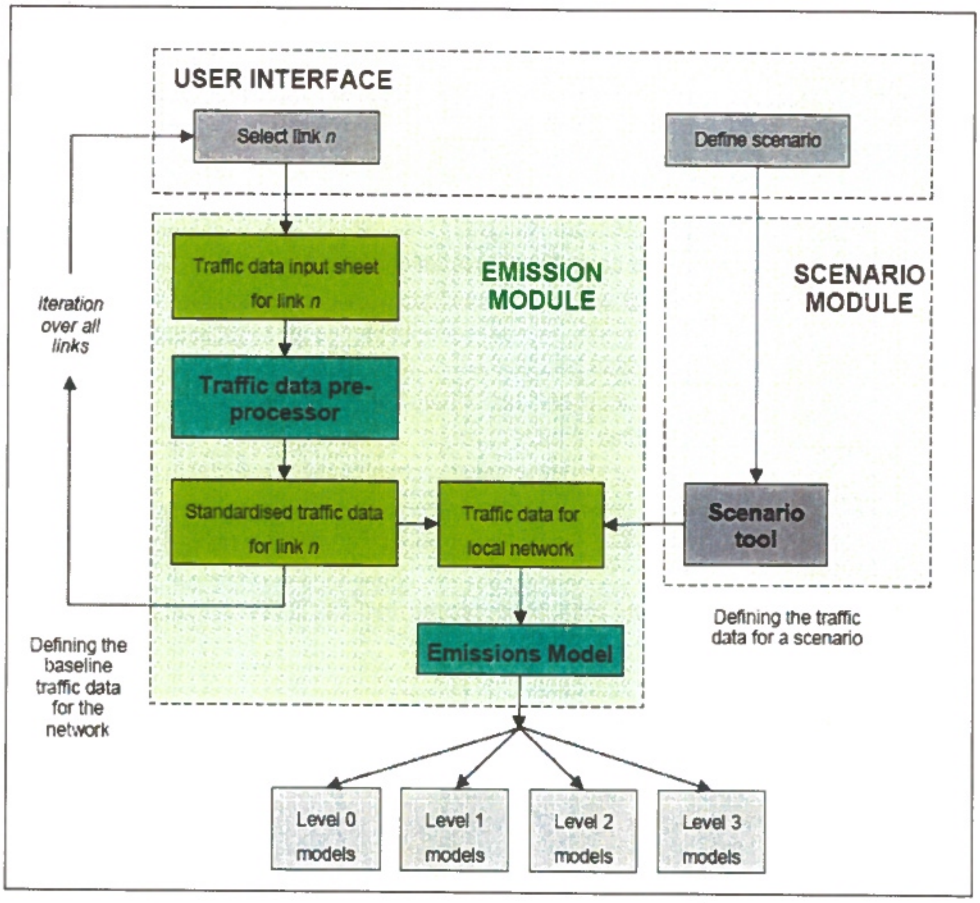


Figure 62 - Proposed structure of the OSCAR emissions module, and links to other system modules

The emissions model within the OSCAR emissions module will be based upon emission factors that will be generated with the TNO VERSIT+ model, see section 10.6. For this purpose a total of 900 sets of emission factors will be generated for 900 driving patterns that have been recorded in the four main cities.

The work on the OSCAR emissions module is expected to be finished in the first half of 2005.

10.6 The TNO VERSIT+ model

The TNO VERSIT+ emission model is one of the latest developments in the field of emission modelling. The new modelling approach developed for VERSIT+ is able to assess tailpipe emissions of passenger cars under specific driving conditions where there is no availability of measurement data. Driving conditions may refer to a traffic situation or a certain driving style, or a combination of both. Tailpipe emissions refer to CO, HC, NO_x, and CO_2 in [g/km] and PM for diesel vehicles. Basically the new modelling approach makes use of correlations between average emission results over complete test cycles and cycle parameters. Cycle parameters are characteristic parameters that are calculated from the speed-time pattern of the driving cycle. These can be very straightforward, for instance average speed or acceleration, but also more complex, for example Relative Positive Acceleration (RPA).

If the emission is required for a certain traffic situation, it can be calculated by substituting the cycle parameters for that situation in the equation. The new model will be provided with a graphical user interface, offering the user to choose between several traffic situations. Also a custom feature will be built in, enabling the user to enter any random test cycle. This way a great flexibility is ensured.

In VERSIT+ for each type of vehicle (e.g. petrol Euro 3) cycle parameters have been determined that correlate best with the emission component, using multivariable (log-linear) regression analysis. For each emission component this may be a different set of parameters. For each vehicle type and emission component an equation is obtained that calculates the emission as a function of two or more cycle parameters. The input for these analysis, on which VERSIT+ is based, is constituted by the In-Use Compliance Database which consists of more than 20000 data entries. It is important to note in this context that the measurements that have been executed for the OSCAR project have been added to this database. Therefore it is ensured that VERSIT+ has a higher statistical significance under situations where OSCAR-alike cycles are used.

A more detailed description of the TNO VERSIT+ model is given in [Smit, 2005].

11 Additional work

Apart from the work described in this report, several other topics were carried out in 2004 in the context of the In-Use Compliance Programme.

11.1 Taakgroep Verkeer en Vervoer

Just like previous years, in 2004 TNO Automotive participated in the "Taakgroep Verkeer & Vervoer", in which also the Dutch Institute for Public Health and Environment (RIVM) and the Dutch Statistics Institute (CBS) participate. The goal of this workgroup is gathering emission data on transport for the annual Dutch emission inventory. TNO Automotive delivers emission data for passenger cars, light duty vans and heavy duty vehicles. These data are derived from the emission results gathered in the In-Use Compliance programme.

Apart from its basic task, the workgroup also acts as a discussion forum for any topic on (transport) emissions.

11.2 DACH+NL

Germany, Austria and Switzerland also run In-Use Compliance programmes. In order to be able to exchange ideas and results between those countries and to increase the international harmonisation of emission factors, a discussion forum was set up in 1998. In 1999 the Netherlands also became a member of the group, that meets two or three times annually. In 2004 Sweden participated in one meeting as well.

11.3 Artemis

In 2004 the participating institutes have resumed their work under the 5th framework project Artemis. The results from Artemis, being harmonised and integrated emission models for all transport modes are expected now for early 2005. The work of TNO Automotive in Work Package 300 (on passenger cars) and Work Package 500 (on motorcycles) is co-financed by the Dutch Ministry of Housing, Spatial Planning and the Environment as part of the contract for the In-Use Compliance programme. The progress made in each work package in 2004 is discussed in the next sections.

11.3.1 WP 300 – Passenger Cars

The progress in WP 300 for passenger cars has been slow in 2004. Only a few items need to be finished for this work package, one of them being Round Robin tests.

In order to do a first check on the emission reproducibility a Round Robin test was executed. One Renault Mégane 1.6 petrol Euro 3 was sent to the 8 laboratories participating in WP300. The emission tests that were done were the Eurotest with a cold and a hot start, and the CADC urban and road cycles. One set of calibration gases have been analyzed by all laboratories as well. The results from these tests will be collected and analyzed in 2005.

For the laboratory correlation of the results of the diesel car, WP300 relies on the results of the particulate project in which also Round Robin testing programme was executed, although this programme typically focused on the measurement of particulate the other exhaust gas components were sampled as well, but not yet analysed.

Next to the Round Robin tests, the checks and the adaptations on the data-records of the WP 300 emissions database have been finalized. It is expected that the work under WP 300 will be finished early 2005.

11.3.2 WP 500 – Motorcycles

In 2004, activities in WP 500 were started-up again at the end of the year by a re-kick-off meeting that was scheduled in Budapest, Hungary. However, only a few items still remained to be finished for this work package. The actual emission measurements on 90 motorcycles have already been conducted in 2002. Also the results of the measurements carried out at the TÜV-Nord (Germany) laboratory can be included since TÜV-Nord is now an official partner.

In 2004, most progress has been made on the emission model. WP 500 decided to apply three approaches - in analogy with WP 300 - of emission modelling. These are:

1. Average speed based (MEET / COPERT)
2. Urban, Rural, Motorway emission factors
3. Traffic Situation scheme emission factors

A fourth option - multi-variable regression approach - will be left open for future activities.

For the Traffic Situation scheme approach, two activities have to be carried out:

- development of driving cycles representative for the identified situations
- development of emission factors for the identified situations.

Both activities will be carried out by RW-TÜV (Germany). The driving cycles will be developed from real-world data that is available from different measurements on road with motorcycles; these driving cycles need to fit in the Traffic Situations matrix that will be developed by INRETS (France). The approach to develop PTW emission factors will most probably be borrowed from the DACH 'Handbuch' emission model. The Traffic Situation emission factors will be the basis to derive emission factors for the U/R/M- and average speed-approach. LAT/AUTh (Greece) will be contacted since they have extensive experience with the average speed approach.

Since the measurements were all carried out in 2002, no beyond Euro 1 certified motorcycles were measured. Therefore, WP500 agreed to contact other sources that could probably provide emission factors for current and future motorcycles. These sources have been contacted and some data has already been received. All emission data will be collected in a customised emission factor database which origins from the work RW-TÜV did for the DACH 'Handbuch' model.

The key results of WP 500 in 2004 are:

- TÜV-Nord and RW-TÜV are finally acknowledged as official Artemis WP500 partner. TÜV-Nord has delivered bag and continuous emission data of 45

motorcycles which means that emission factors for 115 motorcycles instead of the original 90 are available. RW-TÜV will derive PTW emission factors;
- Collection of additional emission factors for motorcycles that meet current and future legislation requirements;
- Definition of three modelling approaches (average speed, Urban/Rural/Motorway and Traffic Situations like in WP300) including development of a detailed work plan for modelling and task division over the partners

Remaining issues to be conducted in order to finish WP 500:
- Additional research with regard to the effect on the emissions of:
  - cold start;
  - fuel properties;
  - inspection and maintenance;
- Development of driving cycles representative for the to be identified Traffic Situations;
- Derive emission factors for the identified Traffic Situations; these emission factors will serve as the basis for the average speed and Urban/Rural/Motorway approach;
- Delivery of the emission factor data to INFRAS;
- Delivery of the final report.

All WP 500 partners committed themselves to finish the needed work within the time-frame of the current contract. All relevant other work packages that need input from WP 500 are aware of this.

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