CITA

INTERNATIONAL MOTOR VEHICLE INSPECTION COMMITTEE

CITA PROJECT

SET – Sustainable Emissions Test

Final Report

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CONTENTS

Contents

1 INTRODUCTION

In the interest of environmental and health protection as well as fair competition it is important to ensure that vehicles on European roads are maintained to a high degree of technical roadworthiness, taking into account the standards the vehicle was designed to meet, the latest developments in vehicle and measurement technology, and the need for economically viable solutions. For modern-technology vehicles and engines with on-board diagnostic (OBD), and after-treatment systems such as exhaust gas recirculation (EGR), diesel particulate filters (DPFs), selective catalytic reduction (SCR), *etc*., there is a need to review the regulations which apply to the Periodic Technical Inspection (PTI).

The specific aim of this study was to investigate the possibility of defining an improved test procedure for the measurement of particulate matter (PM), with a view to this being included in PTI tests for modern diesel cars with different types of exhaust after-treatment system as well as an improved test procedure to measure carbon monoxide (CO) emissions from petrol cars. The use of OBD checks during the PTI inspection will also be investigated. The proposed new procedures will help to ensure that low emission levels of these pollutants are maintained over the lifetime of vehicles.

The projects include emission tests on vehicles operated by diesel engines as well as on modern petrol engine operated vehicles (using GDI as well as different exhaust after treatment systems). The tests have been performed in different Member States (MS) in Europe on two different vehicle categories:

- Passenger cars (M_1 category)
- Light-duty vehicles (N_1 category)

This investigation was developed on the work undertaken within the TEDDIE project (which was carried out on a limited number of vehicles) by performing field trials on a largest amount. These field trials were performed with a new advanced test procedure in different MS by using a similar approach at each test site with the inclusion of OBD scanning. The tests were performed on vehicles submitted normally for PTI inspections.

The project also investigated issues preventing the test from being performed as intended. The main issues here are engine control system on diesel engines that restrict the maximum engine speed at idle (i.e. lower than the rpm limit while driving) or limit the engine acceleration rate.

A test procedure for PTI and the specification of the necessary test equipment was drafted for the field trials. Also a cost-benefit analysis for the new test method has been carried out using an approved methodology.

2 BACKGROUND

2.1 Air pollution emissions in Europe

Under the National Emissions Ceiling Directive (NECD), European Member states have individual emissions limits, known as ceilings for four different pollutants: sulphur dioxide, (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and non-methane volatile organic compounds (NMVOC).

According to the European Environment Agency (EEA), eleven Member States exceeded at least one ceiling in 2011. The most commonly breached ceiling was NO_x – exceeded by nine Member States. Road transport contributes around 40 % of the total EU NO_x emissions and is one of the main factors behind the large number of NO_x exceedances – reductions from this sector over the last two decades have not been as large as originally anticipated. Some Member States have persistent problems in meeting their ceilings – for example, Austria, Belgium, France, Germany, Ireland, Luxembourg and Spain breached NO_x ceilings in 2010, 2011 and 2012.

The National Emission Ceilings Directive 2001/81/EC is currently being reviewed and will establish emissions reduction commitments for the regulated pollutants with the inclusion of fine particulate matter ($PM_{2.5}$).

2.2 Emission tests during periodic technical inspection (PTI) in Europe

2.2.1 Emission tests via a tailpipe test

In the early 1980s some Member States of the EU introduced emission testing of road vehicles as part of PTI. A European vehicle emission inspection program exists since 1992 (Directive 92/55/EEC and Directive 96/96/EC).

Motor vehicles equipped with positive-ignition (petrol) engines have been checked since 1994. The carbon monoxide (CO) content of the exhaust gases are measured when the engine is idling. These emission tests have been extended since 1997 when the exhaust emissions of these engines became controlled by an advanced emission control system. A three-way catalytic converter which is lambda probe controlled was the most commonly used control system to achieve the Euro II emission level. The efficiency of the vehicle's emission control system is checked by measuring the lambda value at high idle and the CO content of the exhaust gases at idle and high idle. The concentration of CO in the exhaust is measured by determining the absorption of an infrared light source by the sample. Furthermore oxygen is measured by an oxygen cell and lambda is calculated via the Brettschneider equation[1].

From 1996 on, the exhaust gas opacity of diesel vehicles is measured during a free acceleration (no load from idling up to cut-off speed) test program. The technical requirements of apparatus for measuring the opacity of exhaust gas are defined in the international standard ISO 11614:1999. Requirements for opacity meters are also given in UNECE Regulation 24 and in EU Directive 72/306/ECE.

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[1] Dr. Johannes Brettschneider, paper published in "Bosch technische Berichte", Volume 6 (1979) Number 4, pages 177-186.

Tailpipe testing was and is still today the de facto method of exhaust emission assessment.

Each Member State has an emission testing scheme which takes the EU legislation as the minimum requirement, but introduced adaptations to suit the local situation.

A general overview of emission testing in Europe as well as outside Europe, in particular for diesel engines, can be found in the predecessor of this study, the TEDDIE study (CITA, 2011)

Actually the differences between the test procedures are increasing in Europe. Some MS do follow exactly the existing regulation, some others have introduced OBD scanning, but in different manners and use. There is also a motivation to have a general comparison on today's appropriate solution for emission testing within the PTI in Europe.

2.2.2 Emissions tests via on-board diagnostic systems (EOBD)

The introduction of the EOBD system in vehicles was done by the homologation Directive 98/69/EC. It specifies that petrol and diesel vehicles must be fitted with EOBD from 2000 and 2003 respectively. EOBD systems are required to monitor critical functions of the engine and emission control system, store information of an emission-related component fault if this fault results in a deviated exhaust emission that exceed certain levels. In this event a diagnostic trouble code (DTC) is stored in the memory of the control module responsible for that component, and the system will report this fact to the driver via the malfunction indicator lamp (MIL) on the dashboard. Given their function, it is obvious that the potential of EOBD systems to enhance the effectiveness of periodic inspection would be investigated. An important investigation was done by the 2nd CITA Programme on Emission Testing (CITA, 2002). It was clear that, at that time, the EOBD system was not ready to be used during PTI since the conclusions of the study specified e.g.

- Not all current EOBD equipped and certified vehicles can ensure that important malfunction, which can cause the specified emission thresholds to be exceeded, can be detected
- Generally EOBD systems could detect electrical failures, but they were not always able to detect simulated aged components
- 50% of the vehicles with induced failures showed increased emissions beyond the threshold for the MIL without the MIL being activated

Furthermore some of the first generation vehicles with EOBD did not meet the EOBD regulations; in particular, the RCs were not set up as required.

Studies and experiences over the following years provided valuable information to introduce the use of EOBD within periodical inspection.

In November 2006 **Belgium** implemented an enhanced 'second-hand car inspection', which is applicable prior to a vehicle being sold and registered to a new owner. One of the newly introduced inspection items was an OBD scan on DTCs. Around 10% of the tested vehicles had data trouble codes (DTCs) related to engine management, and indirectly related to emissions.

During the last few years several EU Member States have considered updating their PTI emission testing schemes. Of course they have run some research programs on the comparison of tailpipe testing and EOBD measurement.

Since the1st of April 2002 a test procedure exists for petrol fuelled vehicles by using OBD-data in **Germany**. The aim was to improve the efficiency of the PTI by using information of the OBD system. Since 2009, EOBD has been used for emission testing. All vehicles after 2006 (petrol and diesel) are covered. Following the connection of the scan tool there is a visual check of the MIL and an examination of the readiness codes (RCs) and data trouble codes. If all RCs are not set, then an exhaust gas evaluation is conducted. If the RCs are set, then the emission evaluation is based on the EOBD scan. For diesel engines where an OBD test is conducted, no opacity test is required. Other countries in Europe, such as The Netherlands, France and Sweden also perform OBD tests.

The German project 'Emission 2010' for diesel vehicles has investigated new test equipment for opacity measurement, the thresholds for PTI, and the response of EOBD to fault simulation (VdTÜV and DEKRA, 2010). The study also included a field test with 800 vehicles. During this study it is clearly shown that EOBD does not measure the functionality of the overall emission control system. Its ability to detect faults is limited to the functionality of discrete emission control systems required to meet these standards. However, it has been shown that even where NO_x is higher than the EOBD threshold value for a defective EGR system, the EOBD cannot always detect the problem.

Furthermore it was clear that for recent vehicles the PTI limits must be reduced.

The follow-up to this project, the project 'Emission check 2020' compared in the period 09/2012-10/2013 the tailpipe tests with EOBD measurements (VdTÜV and DEKRA, 2013). Within this field trial 1,750 vehicles have been examined between September 2012 and October 2013 under real daily conditions at test stations in Germany. Only vehicles from 2006 and newer have been object of tests. OBD and tailpipe comparison was the key element and motivation of this project. TÜV and DEKRA have contributed to this study with measurements.

Failure Rate

- Using only OBD leads to a failure rate of **1.9%**
- The official two stage procedure actually in force for Germany (OBD-Scan, Tailpipe measurement only if RC are not set) leads to failure rate of **2.4%**
- The combination of tailpipe measurement and OBD as a standard measure leads to **7.1%** failure rate
- In consequence in Germany actually **1.02 million passenger cars** with bad exhaust emissions are in use without repair
- Only OBD scanning would permit **1.13 million passenger** cars to be operated on the road each year, with high exhaust emissions

OBD versus tailpipe measurement

- Of all the vehicles tested, only one vehicle out of 84, failed both measures
- The results underline that a combination of OBD and tailpipe measurement is not doubling the test, it is appropriate for detecting all the faults on modern vehicles

Thresholds

- The results are based on the official thresholds defined in Germany and also in line with the EU Regulation
- To deal with modern vehicles, the work proposed a slight adjustment to the thresholds (without the need of new measurement devices):
  - Diesel (from Euro 5): Plate value, in any case not higher than **0.2 m^{-1}**
  - Gasoline (from Euro 4): **0.1 Vol.-% CO** for high idle

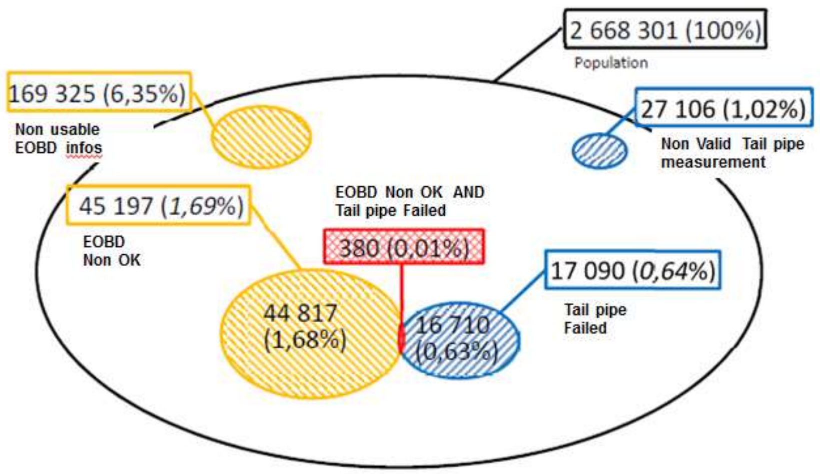
In April 2012 **The Netherlands** started with an EOBD emission test.

Dutch petrol and diesel vehicles registered after 2006 are tested with EOBD (RDW, 2013). Only at the end of the EOBD interrogation are the readiness codes verified. This gives that, even if the readiness codes are not all set, a vehicle could be rejected based on the EOBD information of the MIL and data trouble codes. Only data trouble codes of the P0-series gives a rejection. Vehicles with data trouble codes other than those of the P0-series or with an incomplete set of the readiness codes are measured with a tailpipe test.

The decision for this adapted test schema followed research conducted by RDW in cooperation with the University of Arnhem Nijmegen (HAN) in 2009 (RDW, 2014). The comparison of EOBD results with tailpipe results was evaluated over 711 tested vehicles. 15 Different scan tools were evaluated. The conclusions of the study could be summarised by the following:

- EOBD reading and tailpipe tests are 2 different measurement methods
- Using EOBD readings as an emission test more vehicles are rejected taking into account the current thresholds
- By a positive evaluation using the EOBD, mostly the tailpipe test gives a good result

In **France** petrol passenger cars with a first registration date after 1/1/2002 and diesel vehicles after 1/1/2004 or 1/1/2007 (depending max authorised mass and number of seats) are also tested since 2008 via both, the tailpipe test as well as an EOBD test (UTAC OTC, 2013a). They also have a program for measuring the emissions of heavy duty vehicles since 2011. The EOBD test is limited to the evaluation of the MIL and the data trouble codes. UTAC OTC (UTAC OTC, 2013b) published the results of the comparison between the tailpipe tests and the EOBD interrogation during the PTI of light vehicles in France in the period January – June 2013. They had a quite important sample of 2.668.301 diesel vehicles and 1.277.990 petrol vehicles.



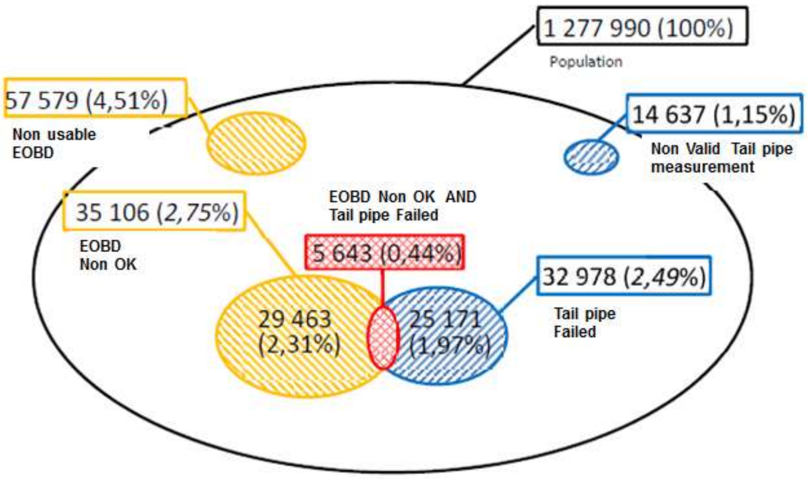
Note:

Overlapping between non usable EOBD info and no tail pipe measurement result is not part of the study

Dimensions of population are not related to dimension of drawings

Figure 1 – Comparison of the opacity tailpipe tests with EOBD (Taken from UTAC OTC, 2013b)

For the diesel vehicles 0.64% were rejected based on the opacity test, and 1.69% based on the EOBD test. Only 0.01% were rejected for both tests. Furthermore 6.35% could not be evaluated by the EOBD system and 1.02% by the opacity test. Similar results were noted for petrol vehicles, where only a small amount of the sample was rejected for both tailpipe as well as for EOBD (0.44%). Also 2.49% did not achieve the exhaust gas measurement and 2.75% the EOBD test. From the sample petrol vehicles 1.15% could not be evaluated by the tailpipe test and 4.51% by the EOBD. Note that the status of the RCs is not taken in account in France.



Note:

Overlapping between non usable EOBD info and no tail pipe measurement result is not part of the study

Dimensions of population are not related to dimension of drawings

Figure 2 – Comparison of the 4-gas analyse tests with EOBD (Taken from UTAC OTC, 2013b)

These studies and the different Member State solutions show a wide range of different approaches. One reason for different results might be due to the different ways these tests were conducted: with or without a combination of scan tools and emission test systems, or with different software which interrogated the OBD system, and also the overall inspection scheme might have an impact on the results.

The SET Study is the first time a project has been established using the same test procedure and equipment in different Member States for testing emissions behaviour. The SET Project can offer a good view of the fleet condition in different Member States and provide a statistically sound result by evaluating a large number of tests.

2.3 The aim of the SET study

The aim of the SET study was to follow up the TEDDIE study with a large scale measurement (field tests) including petrol vehicles in different Member States:

- Comparison of OBD read out (fault codes, RC Status, status information) versus the tailpipe emission test (CO, k values for PM)
- Definition of suitable thresholds for PM-measurement devices (m^{-1}; mg/m^3) for diesel vehicles, taking into account, accuracy of measurement devices as well as the level of gross pollutants today

- Definition of new thresholds for CO measurement, taking into account, accuracy of measurement devices as well as level of gross pollutants today
- Compiling a precise recommendation including a cost-benefit analysis for the European Commission to adjust the PTI directive

Testing was aimed at M_1 and N_1 vehicles. As these will be vehicles submitted for their normal PTI, they mainly include vehicles up to Euro 5 emission standard. A limited number of tests were also carried out on M_1/N_1 vehicles with Euro 6 emission standards.

The objective of the study was to develop an improved emission test, which is relevant to the emissions levels correctly functioning modern vehicles are designed to meet. This improvement may be from the introduction of new thresholds, which are appropriate to today's vehicle technology as well as from the introduction of a refined or extended test procedure; from the inclusion of OBD measurements; or from a combination of these.

The study has also investigated problematic vehicles – for example, vehicles which restrict the rpm at idle, hybrids etc.

2.3.1 TEDDIE study (CITA, 2011)

As already mentioned, this study is the following up of the TEDDIE study (A new roadworthiness emission **te**st for **die**sel vehicles involving NO, NO_2 and PM measurements) (CITA, 2011). TEDDIE was established to address a development of a harmonised procedure which is applicable to the needs of all European Member States and to investigate ways in which the diesel emission test could be improved. This included the possibility of measuring NO, NO_2 and/or NO_x, as well as improving the method for PM and revising the thresholds.

The measurement of NO_x emissions (or the NO_2/NO_x ratio) during PTI emission tests, and the identification of EGR and SCR faults, required further investigation. The NO_2/NO_x ratio is very sensitive to the actual after-treatment technologies and coatings used in different vehicles, and cannot be said to provide a reliable indication of the failure of any given component. Furthermore the instruments for measuring NO, NO_2 and NO_x could only be considered as prototypes in relation to their use in emission tests. Their performance must improve if they are to be certified for use in PTI, especially in the area of long-term stability and optimisations of delay time of the sensors for dynamic test procedures. Therefore these instruments are not taken in account for this study.

This SET study will give a following-up to TEDDIE recommendations 1, 2, 6, 7, 8, 10 and 11 for the EU PTI legislation as listed here below and will also take in account the various issues with EOBD and its use in PTI tests identified by the TEDDIE study.

Recommendations for EU PTI legislation from the TEDDIE study

NB: Considering the limited numbers of vehicles and engines tested in this study, it would be premature to modify the legislation without further evidence. Nevertheless, the following preliminary recommendations should be considered:

1. The evidence from TEDDIE suggests that the free acceleration test, as currently defined in the legislation, remains a suitable procedure for modern diesel cars.
2. Consideration should be given to how engine speed limiters are addressed in the legislation, so that the free acceleration test can be conducted for all vehicles. For example, it must be clear how engine speed limiters are deactivated for PTI tests, and it must be possible to accelerate the engine in an appropriate manner (*i.e.* in less than 2 seconds).

6. Limit values for PM during PTI tests can be defined in accordance with the existing legislation, using the plate values for opacity from type approval in conjunction with a correlation function such as the one developed by EGEA.
7. General limit values for PM (or any adjustments to plate values) should be based on the findings of field trials.
8. Pending the results of further studies, the extension of the use of OBD in the legislation should be considered for the evaluation of emissions and other parameters which are relevant to PTI tests (*e.g.* engine speed).
10. The implementation of the revised procedures and instruments in terms of application by date or emission standard will need to be agreed.
11. The implications of any of the above changes to the type approval legislation will need to be considered.

Since the second generation of opacity meters are much more sensitive and have a higher accuracy (VdTÜV and DEKRA, 2010) and (Zikoridse, 2011), there is at this moment no need to changeover to the measurement of the mass concentration of PM (in mg/m^3). Issues like investment in total new equipment and correlation between PM and k-value are no longer a topic. The SET study used second generation opacity meters which complied with the EU standards.

2.4 Directive 2014/45/EU

Directive 2014/45/EU of 3 April 2014 deals with the "*periodic roadworthiness tests for motor vehicles and their trailers*". This includes safety checks and also emission checks (Annex 1, section 8.2). This Directive is the latest revision, and includes amendments to the emissions tests which might not yet be implemented by the Member States, but should be done by May 2018. A discussion of the requirements for emissions testing is presented below. The original numbers used for notes and footnotes are used to avoid confusion with the original text of the Directive.

For vehicles up to emission classes Euro 5 and Euro V is the tailpipe test the default method of exhaust emission assessment. On the basis of an assessment of equivalence may Member States authorise the use of EOBD. Since the content of the assessment of equivalence is not clear, this SET study will have a focus on the comparison between both test methods.

For vehicles as of emission classes Euro 6 and Euro VI a tailpipe test or an EOBD test can be used as a valuable test.

Despite the progress of engine technology, emission limit values are only modified for Euro 6 and Euro VI engines, which introduce a new limit of 0.7 m^{-1}.

Outcomes of The German project 'Emission 2010' (VdTÜV and DEKRA, 2010) and the TEDDIE study (CITA, 2011) suggested adapting the mandatory emission limit values for vehicles to current vehicle technology conditions, as from EURO II. The project 'Emission check 2020' suggested more severe limits for Euro class engines as today introduced in the directive (VdTÜV and DEKRA, 2013). The use of the so called emission tag values on each vehicle identification plate, of diesel powered vehicles will probably not be introduced by each Member State because of point (b). During this SET study these emission limit values of paragraph (b) will for each emission class be evaluated.

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2.5 Tampering

Tampering of modern vehicles could be undertaken for a number of reasons:

- To improve the performance and/or fuel economy of a vehicle
- To avoid necessary maintenance or repair

The former generally involves reshipping or reprogramming the ECU, to use a different engine map.

The later can include the removal of the diesel particulate filter (DPF), which might be a lower cost option (€300-500) to the vehicle owner than fitting a new DPF (€1500-2000). This seems to be a regular occurrence on European vehicles since the introduction of Euro 4 vehicles in 2005. This is especially so for diesel vehicles which are used for short, slow journeys. In addition of the removal of the device, the OBD system also needs to be modified to trick it into believing that the DPF is still there.

In the USA, OBD tampering has also seen to circumvent the in-service OBD emissions test. This tampering is not detected during a routine test. The following sections discuss tampering – firstly the removal and emission control devices and secondly tampering with the OBD system.

2.5.1 Emission control device removal

2.5.1.1 Petrol - Catalytic converter

The catalyst is sometimes removed from vehicle and replaced with a decat pipe. This is sometimes done on performance cars in order to increase the power output of the engine. The number of vehicles affected is likely to be low.

The removal of the catalyst should be detected by the emissions tests (CO levels at lambda=1 would be around 1.0-1.5%, and if the mixture is weakened to meet the CO limit, the vehicle should then fail on the lambda check). The removal of the catalyst should also be detected by the OBD system for Euro 3 onwards vehicles (unless the post-catalyst lambda sensor has been modified – see OBD tampering section below).

Because of the overall high effort for such manipulation including OBD tampering, a reinstallation before the next emission check is not really likely. If only OBD scanning is in place, this kind of manipulation is not noticed.

2.5.1.2 Diesel - Particulate Filter (DPF)

The diesel particulate filter traps the particles from the exhaust, preventing them from being released into the atmosphere. To avoid the filter from getting blocked, a regeneration phase will be used to burn off the collected carbon. This can either be performed continuously (CRT) or, more commonly, periodically when the OBD system detects a certain pressure increase before the filter. To promote the burning off of the carbon, a number of strategies can be employed, which include raising the exhaust temperature by changing the engine fuelling and/or adding a liquid catalyst to the fuel which reduces the temperature needed to burn off the carbon. However, it is generally necessary to maintain a higher (e.g. over 80 km/h) vehicle speed for about 20 minutes, to allow the complete regeneration of the filter.

If a diesel vehicle fitted with a DPF is only used for short, slow speed journeys, then it may not be possible to regenerate the trap once it gets partially blocked. A light should appear on the vehicles dash showing that regeneration is required (i.e. drive at higher speed for 20 minutes). However, if this is ignored, the filter will get more and more blocked up until it is impossible to regenerate it on the vehicle. The OBD system will then put the vehicle into limp home mode.

The DPF will either need cleaning off the vehicle (if possible) or a new DPF will need to be fitted.

The cost of a new DPF is high for the owner (around €2000 for passenger cars, trucks DPF – systems are much more costly). A cheaper option is to remove the DPF completely. Companies are offering to do this for about €500, which permanently removes the problem for the owner. However, it is detrimental to the environment and health as well as illegal.

Removal methods include:

- Replace the DPF with a piece of normal exhaust pipe
- Cut open the DPF, remove the filter from inside, then weld the can back together
- Drill out the DPF, with a drill into the DPF's inlet and outlet pipes

In addition to removing the DPF, the sensor measuring the pressure difference across the DPF or the ECU will have to be modified.

A missing or faulty DPF would not be detected in the current smoke test using the existing high thresholds of 1.5 k. Even a value of 0.5 k is very high compared with the Euro 5 standard.

Apart from setting very low limits appropriate for a DPF equipped vehicle, the only other options of detecting DPF tampering include

- Looking for the presence of the DPF on the vehicle (the vehicle inspector would need to know if the vehicle should be fitted with a DPF or not)
- Looking for signs of tampering on the DPF – e.g. welding that is not original. However, it is likely that any tampering would have been hidden away. Also, drilling out the filter through the inlet/outlet would not show any external signs

Anyhow the visual measures might be limited and must be supported by appropriate thresholds for emission measurement.

2.5.1.3 Diesel/petrol – EGR

The exhaust gas circulation (EGR) feeds a proportion of the exhaust back into the engine, which dilutes the air/fuel mix. This lowers the combustion temperature which decreases the amount of NO_x produced. With time, external EGR can cause problems (e.g. sticking valve due to carbon build up). The valve might be disabled or the EGR system removed completely – either to overcome a fault or to improve the performance of the vehicle. EGR is a common fitment on diesel vehicles but can also be fitted to petrol vehicles.

The presence of EGR is not currently detected during the petrol emissions test or the diesel smoke test. If it is disconnected or missing, this may or may not be detected by the OBD system depending on the sensors fitted to the vehicle and those still remaining after tampering.

2.5.1.4 SCR

SCR is relatively new, and has been mainly used on heavy-duty vehicles. However, it is now also starting to be used on cars. This requires a diesel exhaust fluid (e.g. AdBlue) to be used which costs about €15 for 5 litres. The amount needed will vary depending on the manufacturer's emission control strategy (according to VW: *A passenger car will consume approximately 1.5 litres of diesel exhaust fluid every 620 miles [1000 km])*.

As these systems are quite new, tampering has not been noticed yet, though there are already websites offering to bypass these systems. As the vehicles get older, it is more likely that these systems could be tampered with. This could be aimed at avoiding the additional cost of filling up the additive tank with diesel exhaust fluid.

Removing the SCR system would result in a vehicle with higher NO_x emissions than a non-SCR vehicle (because the engine for the SCR vehicle will be setup to produce high NO_x emissions, which are then dealt with by the emission control system).

The current test does not detect NO_x emissions, so it would not notice tampering with an SCR system. It is likely that the OBD system will flag up a fault and also de-rate the engine. However, intentional tampering is also likely to include OBD tampering, to allow the vehicle to continue to be used with full power. If this is the case, then the tampering will not be detected.

2.5.2 OBD tampering

There are a number of ways that the OBD system can be tampered with, including:

- Inline “OBD simulator”
- Modified sensors
- ECU reflash

These are covered in the following section which is partially based on information for Drew Technologies (2013); Clean Air London (2013) and Schäfer (2014).

2.5.2.1 OBD simulator

The OBD simulator uses a standard J1962 port in the normal location on the vehicle for the technician to plug the OBD scanner in as normal. This looks like the original port as fitted by the manufacturer. However, there will be additional circuitry between this port and the vehicle’s OBD system. There may be two independent OBD protocols – one to talk to the vehicle and one to talk to the test equipment. There may also be a simple system to enable or disable it (e.g. a few short beeps on the horn).

The user is then able to control what is reported via the OBD port – which DTCs to report, which PIDs to report etc. Reported values could also be modified, while still maintain plausible relationships between items like rpm and vehicle speed. The system can also be used to continually tune off the MIL - by rapidly turning off the MIL, even though the vehicle OBD system turns it back on, it would appear to be not illuminated.

The simulator could also be used to make a non-OBD engine act as an OBD system which might be used when a vehicle’s engine is replaced with a non-standard engine.

There are a number of ways to detect these simulators:

- Look under the dash and look for additional wiring/circuitry – though this may involve removing panels which may not be practical or not allowed during the test.
- Perform a series of OBD message timings – measure the time between the request for information and the response. If this is repeated with various requests, then there will be a variation in the message timing for those messages that are modified and those that are not. The timing could also be compared with a vehicle database to identify any suspicious responses (i.e. messages that take longer than normal).
- Used manufacturer specific enhanced scan tool modes that are unlikely to have been modified.

2.5.2.2 Modified sensors

There are a number of known modifications that could be used to improve the performance of the vehicle. These include:

- Inlet air temperature – by adding a resistor to the circuit, the OBD system will think the temperature is lower than it actually is and increase the timing. This can be checked by comparing the OBD air temperature value with the workshop temperature.
- Disconnect EGR – the EGR system can be disabled by either removing it completely or by simply removing the control to it (vacuum pipe or electrical connection)
- Replace rear lambda sensor – the sensor can be replaced with non-working ones but which output a good signal to the ECU, giving the impression that the catalyst is functioning correctly. The only way to detect this would be to compare the sensor output to a correctly functioning one

2.5.2.3 ECU reflashing

There are numerous flash programmers available for the specialist workshop or even for the home enthusiast. Most of the performance gains are small and will not have a large effect on emissions. However, there will be a greater impact on emissions when reflashing turbo, supercharged or diesel vehicles due to the potential to increase boost and disable emission control equipment.

By modifying the ECU software, the following could be done:

- Disable emission control equipment – e.g. turn off EGR. The hardware would still be intact and properly connected, so it would not be noticed during a visual check
- Disable the MIL and all trouble codes – the MIL would not illuminate during the test or any DTCs be detected even though there are faults on the vehicle

There are ways to detect reprogramming but these would involve working with the manufacturer to provide the appropriate information. Additional functions may also need to be included within the ECUs to accommodate this (which may need legislation though the type approval process). Methods include:

- Binary image compare – this would involve downloading the binary image from the ECU and comparing it with the OEM stock image. Any differences would indicate tampering. However, there may be a number of variants of the binary image so it is important to ensure all relevant information is provided by the OEM. Also, although all OEMs support ECU upload with SAE J2534, none support ECU download. There may also be IPR issues – allowing downloads would allow other manufacturers to copy the binary image to use on their own vehicles
- Flash counter validation – Most ECUs have a counter that register the number of times the ECU has been flashed. If present, the test could include reading this value. This could then be compared with the OEM’s expected value for that vehicle

A visual inspection might reveal missing emissions control devices (if the inspector knows what should be fitted to the vehicle) but will not reveal OBD tampering. OBD scanning is unlikely to reveal evidence of OBD tampering.

3 FIELD TRIALS

The field trials were performed at a number of test stations located in various EU Member States. The following sections cover the test procedure, the test equipment and the test centres involved in the field trials.

3.1 Test procedure

A test procedure was developed which includes:

- Entering vehicle details (in some cases, to gain time, the trial database was enriched with the vehicle details after the trial tests)
- Establishing connection to OBD
- Checking for any OBD errors codes, together with the supported readiness codes
- Tailpipe test

For diesel vehicles, 3 free acceleration tests are performed, using the OBD system (where possible) to determine the engine speed. The opacity (and, where available, the PM) are measured during each free acceleration test. Only 3 tests were performed as the SET test was typically performed immediately after the regulatory test so the engine & exhaust had already been purged.

For petrol vehicles, the CO emissions were measured at natural idle, followed by a check of the CO emissions and lambda value at a fast idle (initially set to 2,500-3,000 rpm).

Flow charts showing the full procedures for diesel and petrol vehicles are contained in Appendix A, together with the file format used.

3.2 Test equipment

Test equipment has been provided to the test centres by the following companies:

- MAHA
  - MAHA MET 6.3 (combined mobile wireless tester for petrol and diesel)
  - The MAHA smoke meter measures Opacity in m^{-1} and PM in mg/m^3
  - MAHA Wireless OBD Tool
- Capelec
  - CAP3600 wireless emissions tester
  - CAP3040 smoke meter or CAP3050 smoke meter with NO_x
- AVL
  - Spain & Belgium: AVL DiTEST CDS 450
  - Germany: AVL DiTEST MDS 418 (mobile version)
  - For Gas measurement: AVL DiTEST Gas1000
  - For smoke measurement: AVL DiSmoke 480
  - For OBD diagnosis: AVL DiTEST OBD 1000

Each analyser was programmed using the SET test procedure as described above, so that a common procedure was used by all the vehicle inspectors.

3.3 Participating test centres

Following the project kick off meeting held in Brussels on 1 April 2014, a number of test centres volunteered to participate in the SET project field trials. Sixteen test centres were selected for the field trials. The list of these centres is shown in *Table* 1.

3.4 Training

A centralised training session was held in Brussels, hosted by GOCA & CITA, on 11 June 2014. The aim of this training session was to ensure that all the tests at each test centre would be performed in the same way. All but one of the participating test centres were able to send representatives to this training session. MAHA, Capelec and AVL provided the test equipment programmed with the SET test procedures plus one or more personnel to carry out the training. GOCA also provided some vehicles to perform tests on.

The day included a brief introduction to the SET project, and a description of the test procedure. Most of the day was spent with hands on experience performing the test – both with the equipment they would be using for the field trials, but also an opportunity to try the other equipment.

The day finished with a roundup and a brief question and answers session.

In addition to the centralised training, the equipment manufacturers have also provided localised training, when setting up the test equipment in each test centre.

Table 1. Participating test centres and the equipment used

		Organisation	Test centre address	Equipment provided by MAHA	Equipment provided by Capelec	Equipment provided by AVL
1	Belgium	GOCA (1)	AIBV HALLE Zinkstraat 3 Dassenveld, Halle		✔	✔
2	Belgium	GOCA (2)	KM OOSTENDE zandvoordestraat 442A B-8400 OOSTENDE		✔	
3	Belgium	GOCA (3)	AS/CTA/BIA WANZE rue de Villers 50, 4520 Wanze,		✔	
4	France	Dekra (1)	DEKRA Chambourcy 38 route de Mantes 78240 Chambourcy		✔	
5	France	Dekra (2)	Norisko Olivet 1160 rue de la Bergeresse 45160 Olivet	✔		
6	Germany	TÜV SÜD	TÜV SÜD Auto Service GmbH Ridlerstraße 57 80339 München			✔
7	Germany	TÜV Nord	TÜV NORD Mobilität GmbH & Co.KG Adlerstrasse 7 45307 Essen			✔
8	The Netherlands	RDW	RDW APK Centrum Nederland Dr. Van Deenweg 78 8025 BH Zwolle	✔		
9	Spain	Applus	Center B17 (Vilanova i la Geltrú, Polígon Industrial nº 2 de Roquetes, Ronda Europa s/n)	✔		
10	Spain	Certio	Center B-23 (C/ Caracas 10B, 08030 Barcelona)			✔
11	Spain	Itvasa	Center 3301 (Pruvia de Abajo, 89 CP 33192 - Llanera – Asturias)			✔
12	Spain	Veiasa	Center ITV-Sevilla (Polígono Industrial El Pino. C/ Pino Central, parcela 16-18, 41016 Sevilla)			✔
13	Spain	SyC	Center 1511 (Polígono Ind. Sabón, Parcela nº69, Arteixo, 15142 A Coruña)	✔		
14	Spain	Itevelesa	Center Santander (Parc 10, Poligono Raos, Maliaño, Santander)	✔		
15	Sweden	Bilprovningen	Jönköping	✔		
16	Sweden	Opus Bilprovning	Opus Bilprovning "Vallentuna" Okvistavägen 30 186 40 Vallentuna SWEDEN		✔	

3.5 Field Test Results

3.5.1 Number of test results submitted

The field trials started in August 2014 and continued until the end of November 2014.

A list of the test results that have been submitted are listed in *Table 2* DEKRA set up a project website to hold all the test data and other information. As the data is submitted to the Project Manager, it is uploaded to the website where DEKRA performed initial checks on the data.

Table 2. Test results submitted

	Diesel	**Petrol**	**Total**	
Test centre	With all necessary information	With all necessary information	Delivered data set	With all necessary measure values
GOCA	412	350	763	**762**
DEKRA France	26	22	57	**48**
TÜV SÜD	100	96	202	**196**
TÜV Nord	69	172	247	**241**
RDW	29	151	205	**180**
Applus	36	10	74	**46**
Certio	27	17	48	**44**
Itvasa	244	104	358	**348**
SyC	517	125	644	**642**
Itevelesa	109	99	210	**208**
Bilprovningen	0	0	65	**0**
Opus Bilprovning	85	228	316	**313**
Total	**1654**	**1374**	**3189**	**3028**

The “with all necessary information” refers to additional information about the vehicle (make, model, Euro class etc.) being supplied with the SET data file. If not all data was achieved the measurement file could not taken into evaluation scheme.

Note there are more diesel test results than petrol. In most countries, more diesel vehicles were encountered than petrol vehicles due to the dieselification of the car fleet that has occurred across Europe. The only exceptions were the Netherlands and Sweden, where petrol vehicles were more common.

This SET Project is the first project in Europe or worldwide concerning emissions testing, where different member states use an identical test procedure and test equipment. For future challenging tasks concerning standardisation in Europe in the framework of PTI, this seems to be the best approach to do such studies for better evaluation and better acceptance in different member states in general.

3.5.2 Number of test results submitted by emissions class

A breakdown of the submitted test results by emissions class are shown in *Table 3*. The majority of the vehicles were Euro 4 or Euro 5. A few Euro 6 vehicles were also tested. Some of the data had no emission class included in the data – either this had not been submitted or was unknown to the tester.

Table 3. Test results by emission class

	Diesel	Petrol
Euro 3	48	35
Euro 4	1052	818
Euro 5	464	435
Euro 6	5	7
no declaration	85	79
	1654	1374

3.5.3 Analysis of the tailpipe measurements

3.5.3.1 Petrol vehicles

The results of the petrol emission tests (%CO) are shown plotted as frequency distributions in the following figures. *Figure 3* shows the results of the fast idle test for all of the petrol vehicles tested. *Figure 4* shows the results for the Euro 4 vehicles. *Figure 5* shows the results for the Euro 5 vehicles. Similar graphs showing the results from the natural idle test are in Appendix D

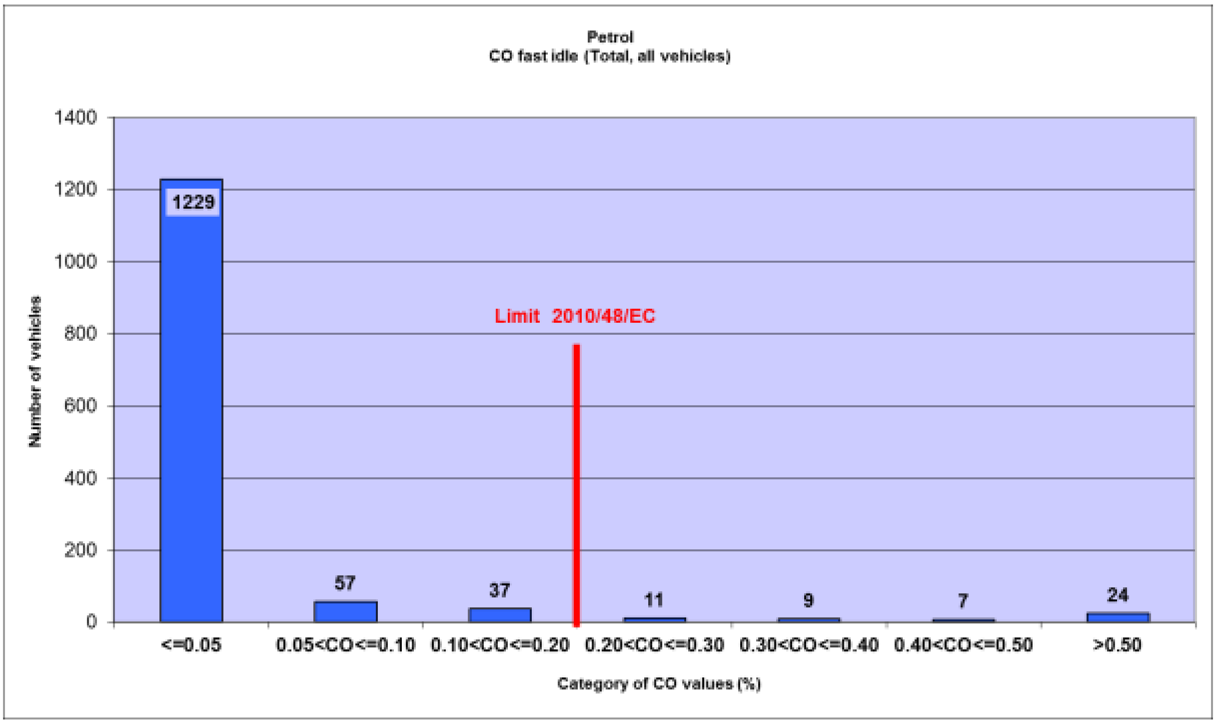

Figure 3. Distribution of CO fast idle emission tests – all petrol vehicles

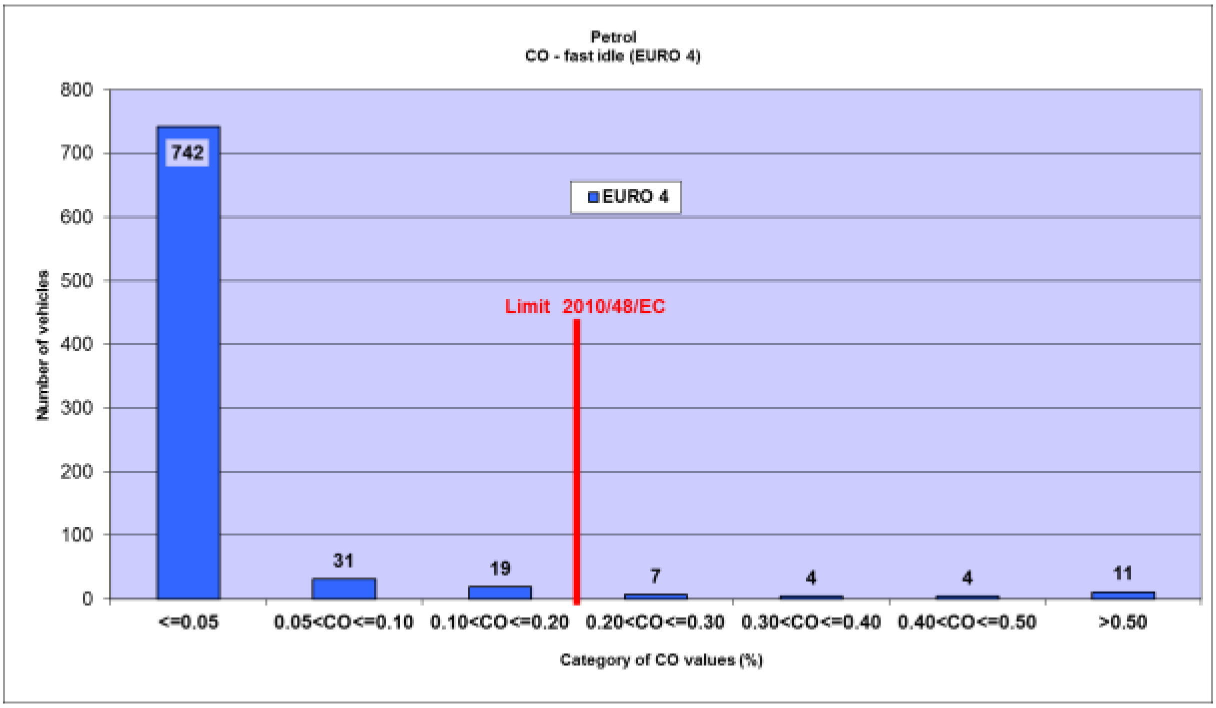

Figure 4. Distribution of CO fast idle emission tests – Euro 4 petrol vehicles

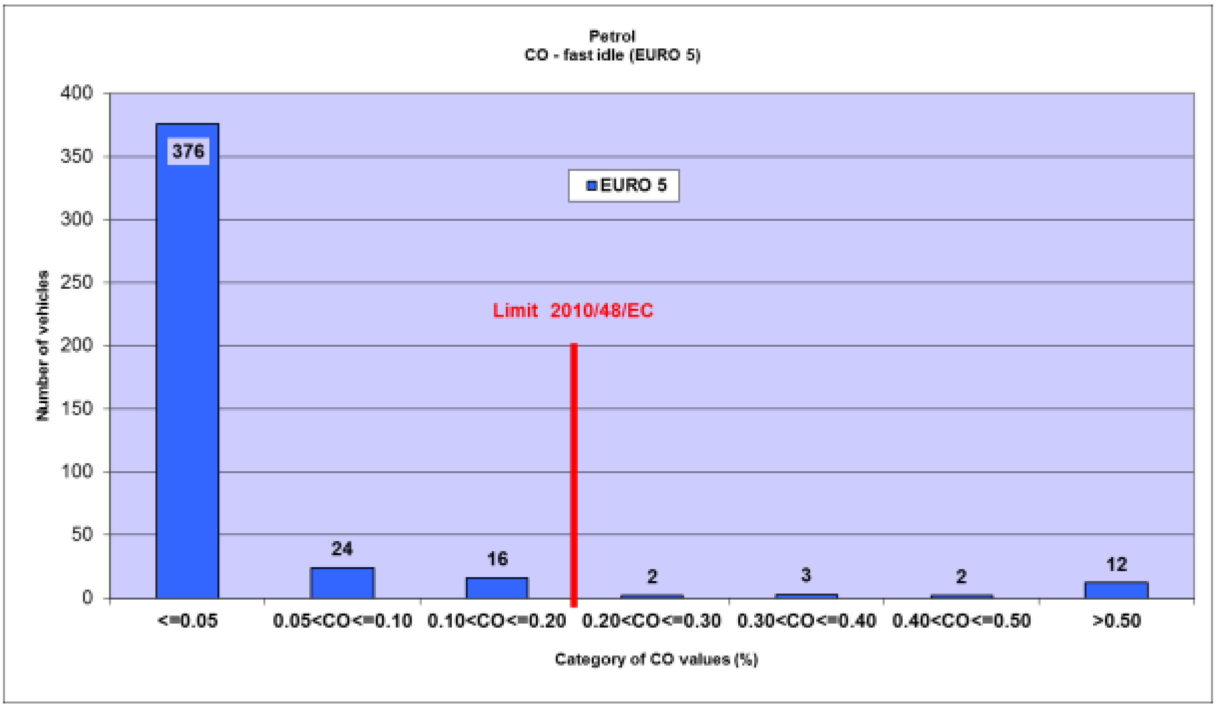

Figure 5. Distribution of CO fast idle emission tests – Euro 5 petrol vehicles

Findings:

- For petrol vehicles there is a good consistency of the CO-values, independent of the Euro class of the vehicle. This indicates that lower thresholds could be applied from Euro 3 vehicles* (introduced January 2000 for new types, January 2001 for new registrations and January 2002 for N_1 class 2 and 3 vehicles).
- For petrol vehicles the limits according to 2010/48/EC are not sufficient to detect gross polluter. As 2014/45/EU does not change the limits for high idle measurement on petrol vehicles, this is an area that needs further consideration.
- There were a number of vehicles with **Lambda** outside the range 0.97 to 1.03.

*regarding the PTI test procedure Euro 3 emission standards are comparable to Euro 4

3.5.3.2 Diesel vehicles

The results of the free acceleration smoke (FAS) test are shown plotted as frequency distributions in the following figures. *Figure 6* shows the results for all diesel vehicles. *Figure 7* and *Figure 8* show the results for Euro 4 and Euro 5 vehicles respectively.

Only a few Euro 3 vehicles were tested. Therefore the main analysis has been aimed at Euro 4 and Euro 5 vehicles. Unlike the petrol vehicles, there is a distinct difference between the Euro 4 and Euro 5 results. These have therefore been dealt with separately in the following analysis.

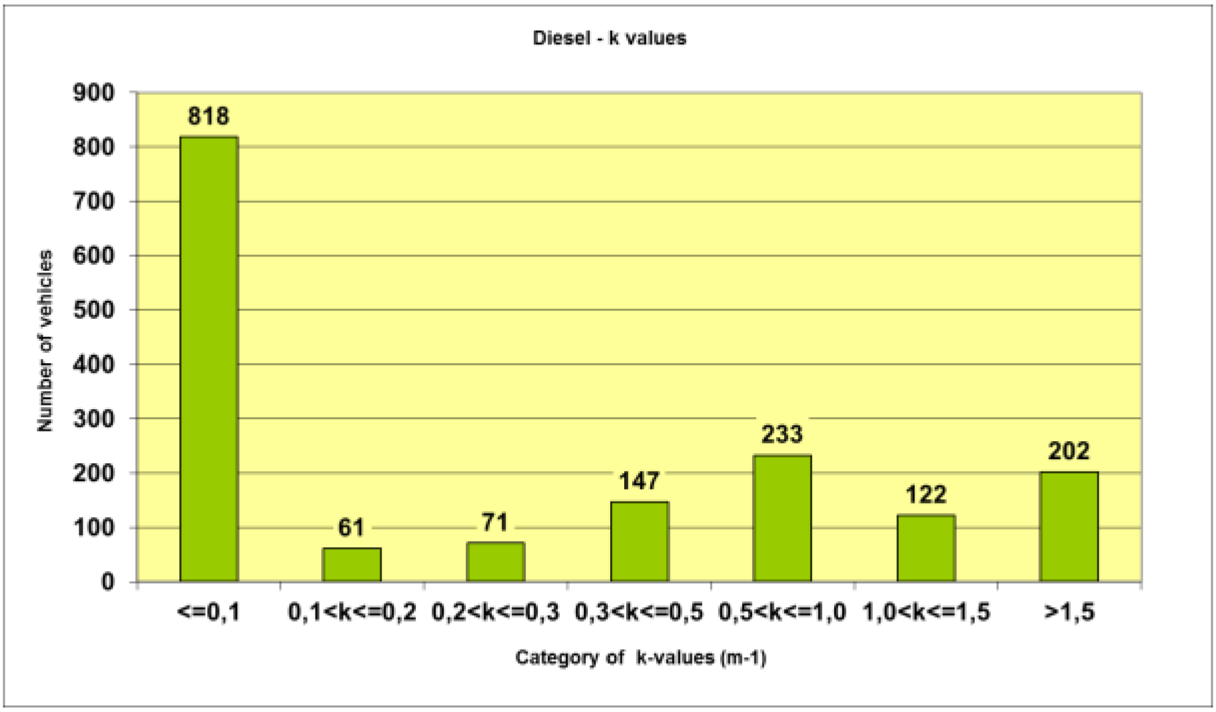

Figure 6. Distribution of the FAS test results – all diesel vehicles

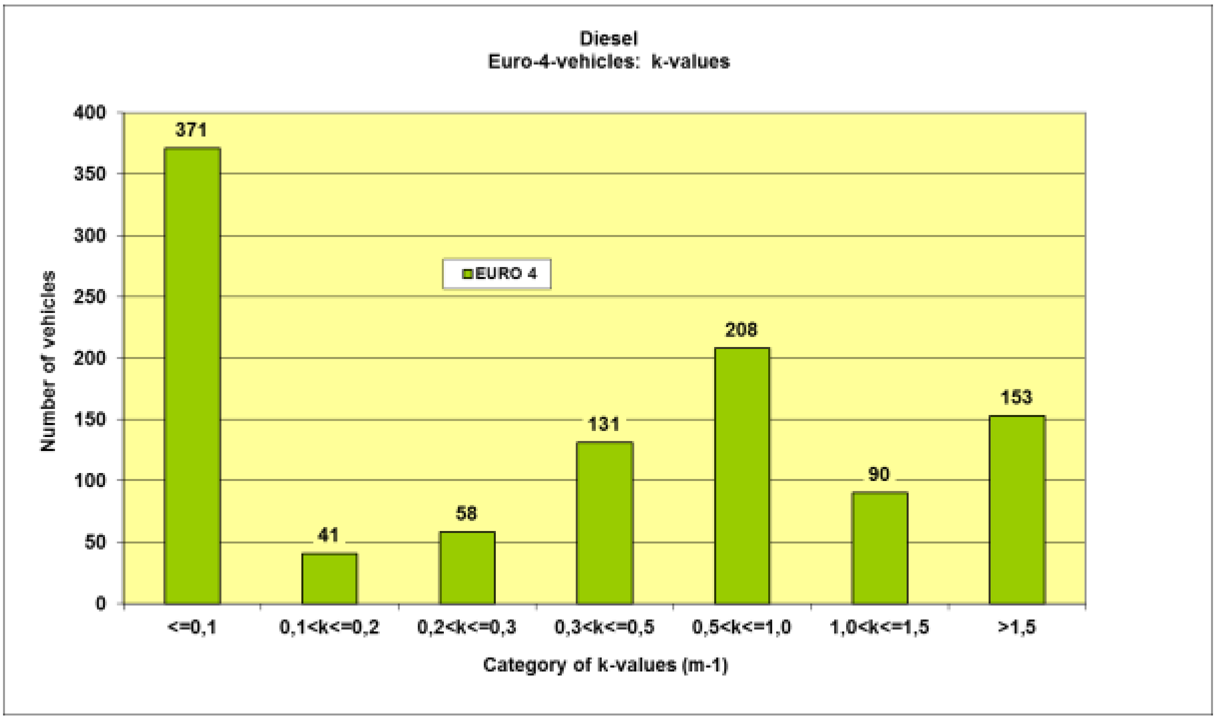

Figure 7. Distribution of the FAS test results – Euro 4 diesel vehicles

Findings (Euro 4):

- Depending on vehicle manufacturer, engine displacement, vehicle weight, regional requirements (e.g. low-emission zones) or customer requirements (e.g. tax benefits), Euro-4-vehicles are sometimes equipped with particulate filter (DPF), sometimes not.
- If equipped with DPF, there are original-systems (closed systems) and retrofit-systems (open systems) on the market.
- The Euro 4 vehicles have the greatest variance of k-values.
- For Euro 4 the limits would have to be "specific" (depending on emission control devices fitted to the vehicle) or a general limit should be relatively wide.

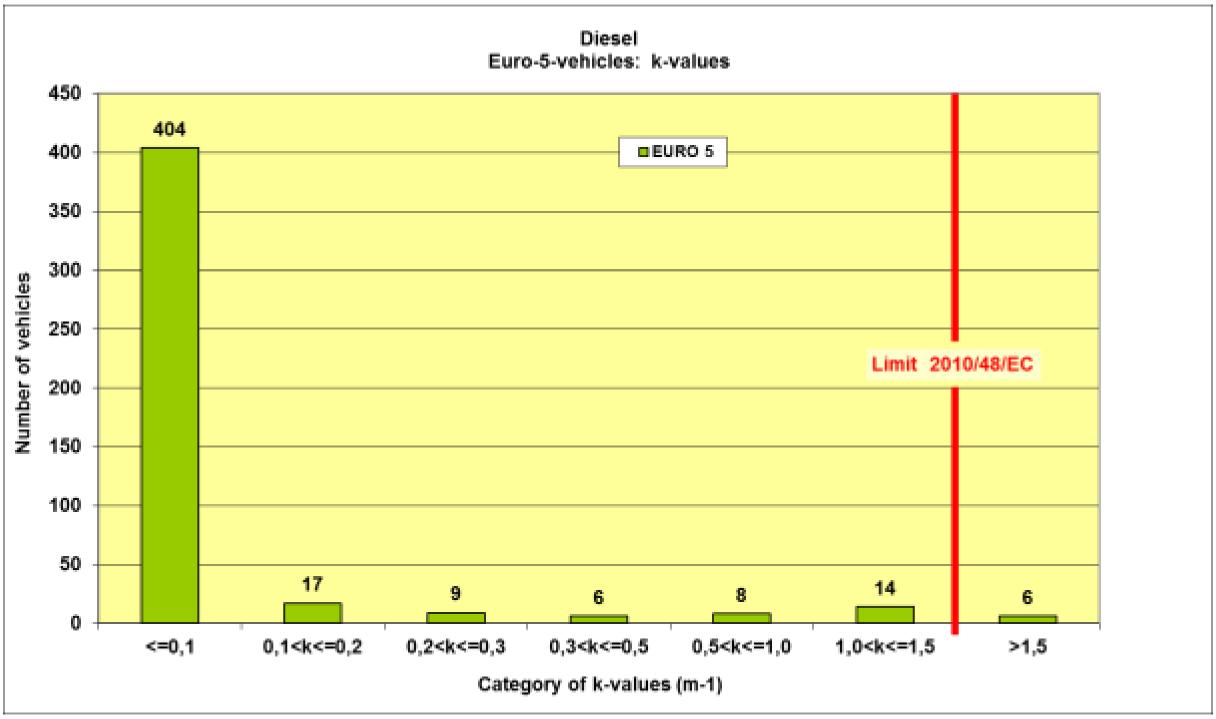

Figure 8. Distribution of the FAS test results – Euro 5 diesel vehicles

Findings (Euro 5):

- Euro 5 vehicles are normally equipped with a diesel particulate filter (DPF).
- For Euro 5 there is a good consistence of k-values.
- For Euro 5 and Euro 6 the limits contained in 2010/48/EU are not useful.

3.5.4 Pass and fail rates by EU limits and by member state limits

The following sections compare the test results with the limits set by the European Directive and also the local limits set by individual Member States participating in the field trials.

Table 4. Failure rates for petrol vehicles

	Test results			Test Criteria			
	Number tested	Number failed	Failure rate	Fast idle CO	Idle CO	Lambda	Notes
Europe	1374	113	8.22%	0.20%	0.30%	0.97-1.03	
Spain	355	16	4.51%	0.20%	0.30%	0.97-1.03	> 1/07/2002
Belgium	350	42	12.00%	0.20%	0.30%	0.97-1.03	
Netherlands	151	19	12.58%	0.20%	0.30%	0.97-1.03	> 1/07/2002
Germany	268	22	8.21%	0.20%	0.30%	0.97-1.03*	> 1/07/2002
Sweden	228	7	3.07%	0.20%	0.30%	0.97-1.03	> 1/01/2002
France	22	4	18.18%	0.20%	0.30%	0.97-1.03	> 1/07/2002

***** or manufacturer specific

Table 5. Failure rates for diesel vehicles

	Test results			Test Criteria			
	Number tested	Number failed	Failure rate	Criteria 1		Criteria 2	
Europe	**1654**	**109**	6.59%	< 1/7/2008	3.0	> 1/7/2008	1.5
Spain	**933**	**65**	6.97%	< 1/7/2008	3.0	> 1/7/2008	1.5
Belgium	**412**	**68**	16.50%	Euro 3	3.0	Euro 4-6	1.5
Netherlands	**29**	**0**	0.00%	< 1/7/2008	3.0	> 1/7/2008	1.5
Germany**	**169**	**10**	5.92%	Euro 3	1.5	Euro 4-6	0.6
“	**169**	**12**	7.10%	Euro 3	1,5	Euro 4-6	0.4
Sweden	**85**	**3**	3.53%	Euro 3	3.0	Euro 4-6	1.5
France	**26**	**0**	0.00%	< 1/7/2008	3.0	> 1/7/2008	1.5

** Germany uses a range of different plate values

Table 6. Failure rates - overall

	Spain	Belgium	Netherland	Germany	Sweden	France	EU
Petrol failed (%)	**4.51**	**12.00**	**12.58**	**8.21**	**3.07**	**18.18**	**8.22**
Diesel failed (%)	**6.97**	**16.50**	**0.00**	**5.92**	**3.53**	**0.00**	**6.59**

3.5.5 Effect of kilometres covered

3.5.5.1 Petrol vehicles

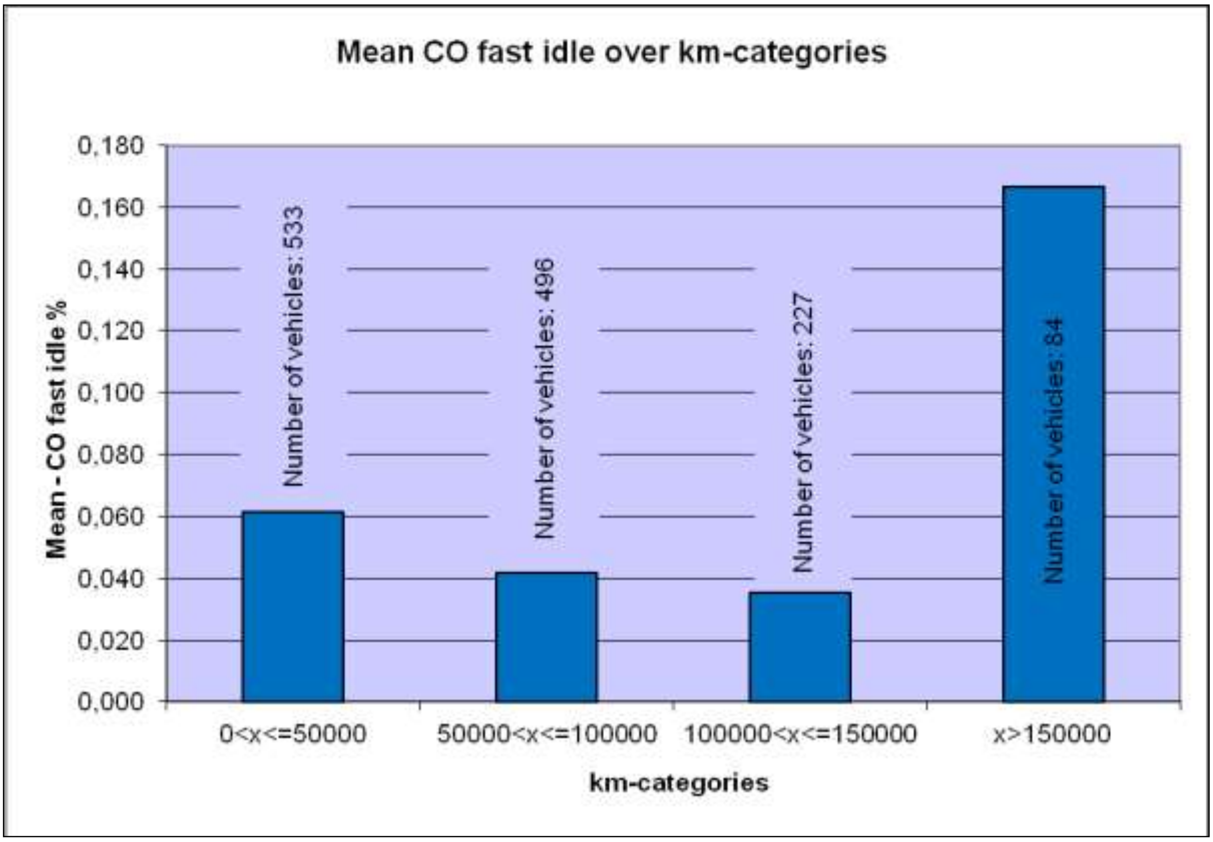

Figure 9. Fast idle CO emissions by odometer reading range (34 vehicles without odometer readings)

Figure 9 shows that there is no direct and clear correlation of kilometres driven and CO concentration. Repair and other impacts over the time in service seem to have a higher influence of CO emissions.

3.5.5.2 Diesel vehicles

Figure 10 shows a direct and constant correlation between kilometres driven and k value measurement. This might be forced by worn out components as well as by defective particulate traps.

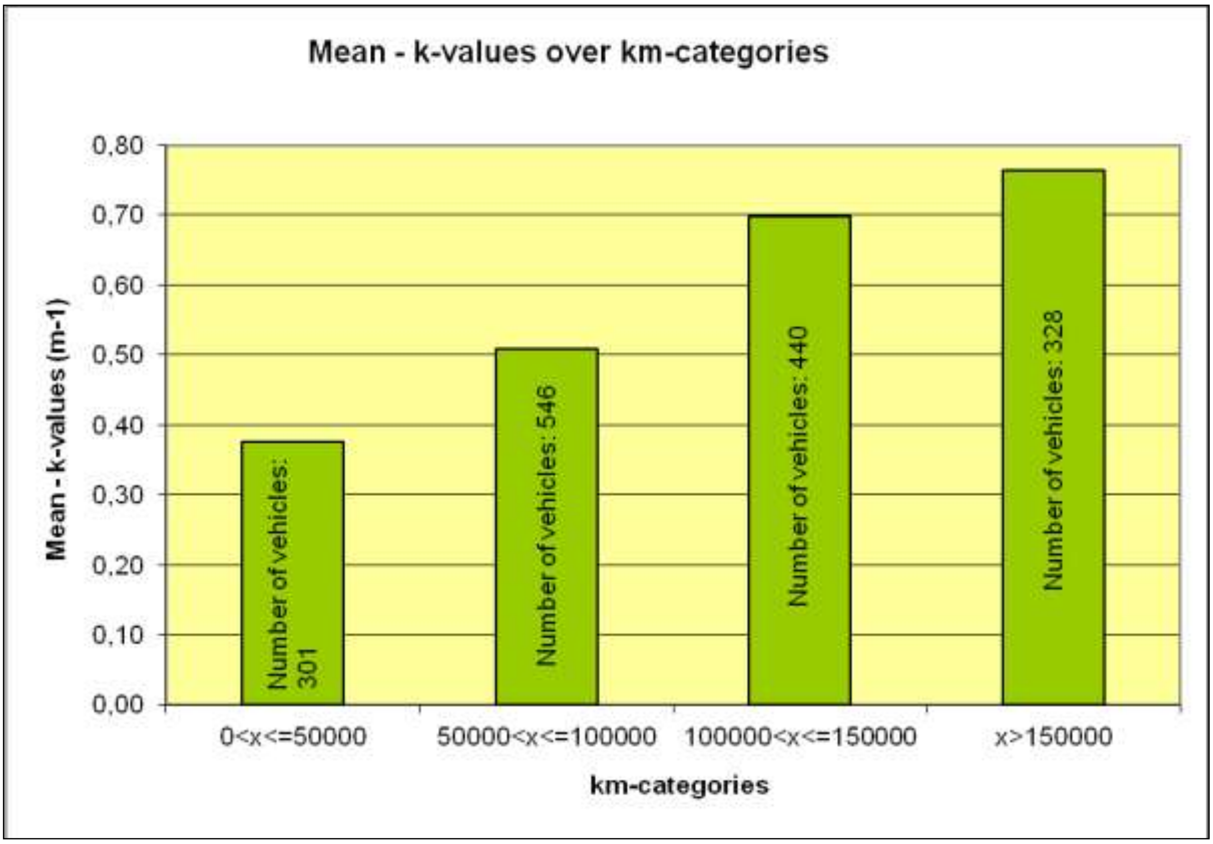

Figure 10. FAS test results by odometer reading range (39 vehicles without odometer readings)

3.5.6 Effect of vehicle age

3.5.6.1 Petrol vehicles

Figure 11 shows that here is obviously no clear effect of the vehicle age on CO emissions. Vehicle up to 3 years old had the highest CO emissions. There is a gradual deterioration of vehicles over 3 years old.

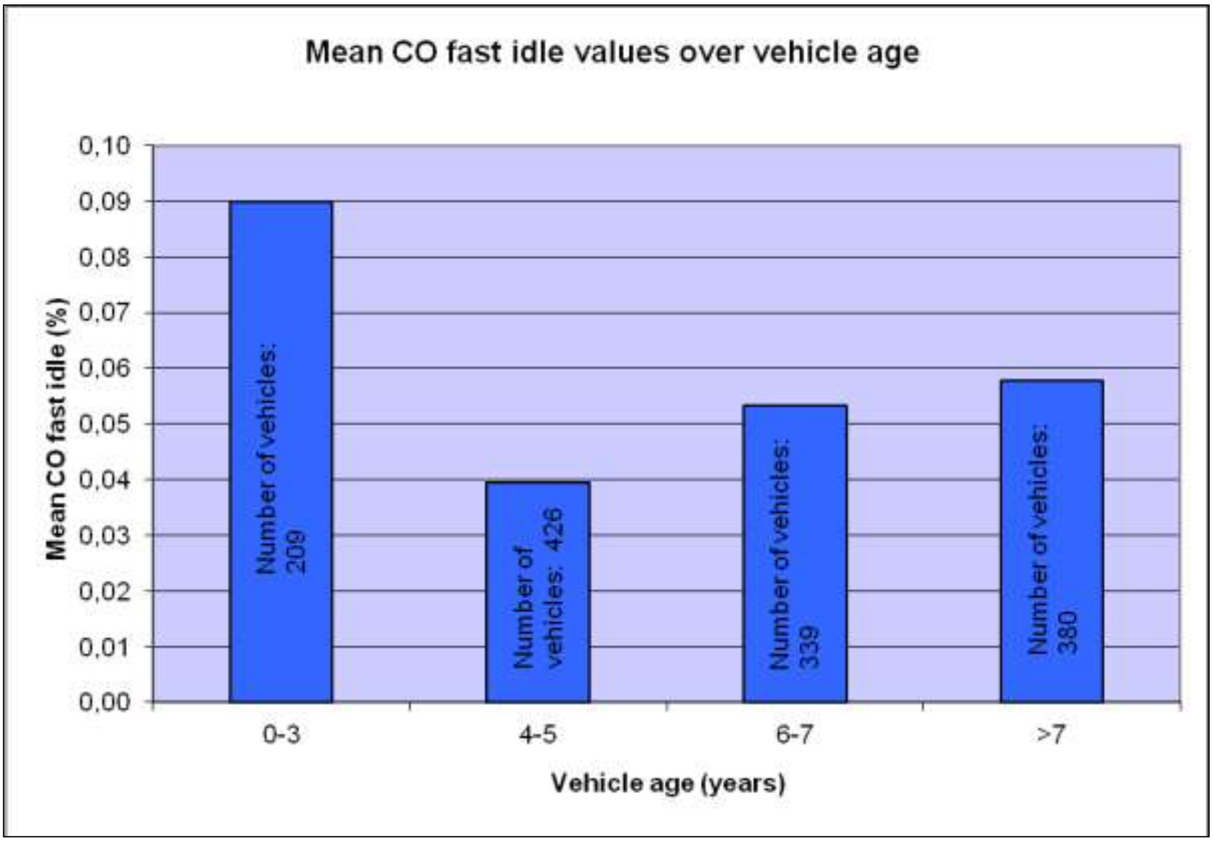

Figure 11. Fast idle CO emissions plotted against vehicle age band

3.5.6.2 Diesel vehicles

Compared with the petrol vehicles, diesel vehicles seem to have a clear correlation of age and k value measurement as can be seen in *Figure 12*. This might also be due to the very different emission behaviour between the old Euro 4 vehicles and the new Euro 5 vehicles; e.g. new vehicles will, in most of the cases, be fitted with a diesel particulate trap, whereas the older Euro 4 and 3 vehicles will not.

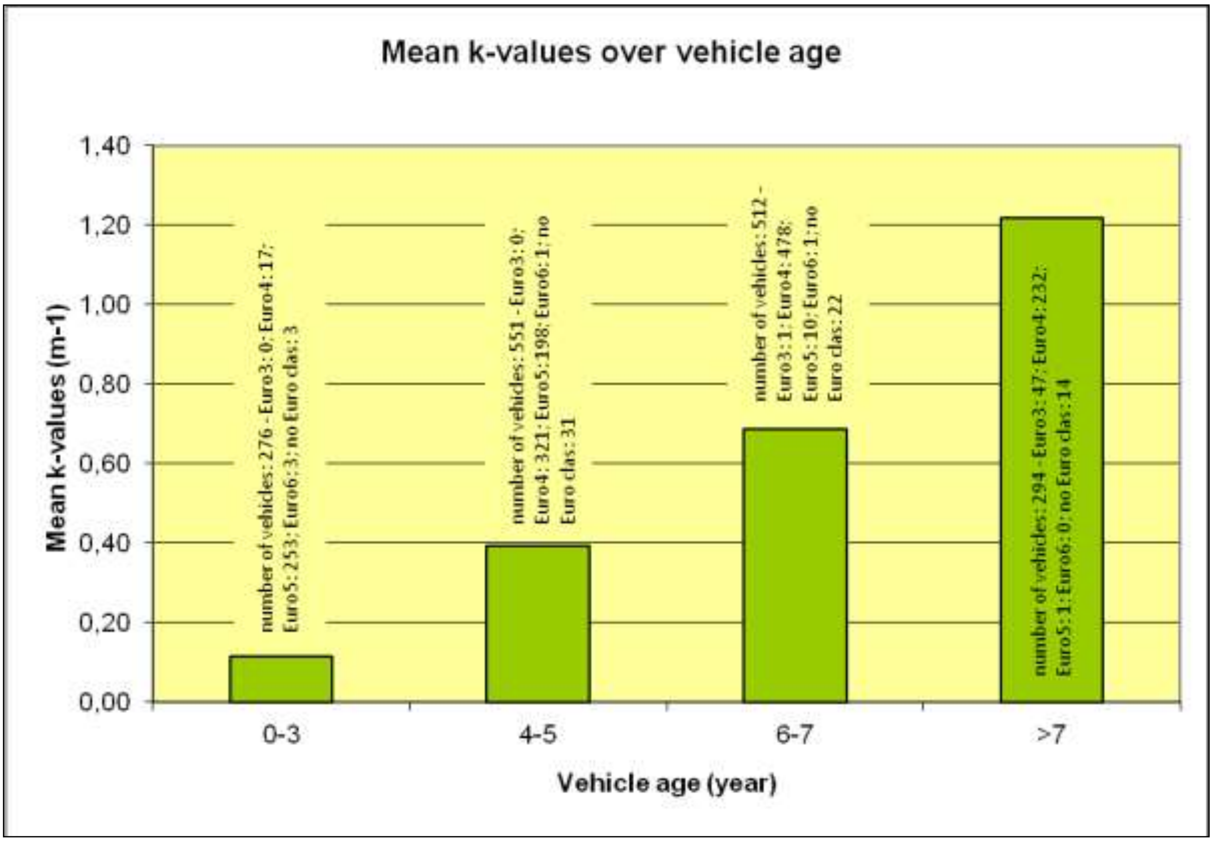

Figure 12. FAS test results against vehicle age band ("no Euro class" means no Euro class noted)

3.5.7 Effect of kilometres and the effect of vehicle age with high emitters removed

In the previous sections, the emissions of petrol cars did not show any clear correlation with the kilometres recorded on the odometer or the age of the vehicle. A deeper investigation regarding the 209 vehicles with an age of 0 – 3 years shows that there are some vehicles in this group with extremely high CO-values (*Table 7*).

Table 7. Vehicles with extremely high CO emissions

Description	Manufacturer	Odometer	1st registration	Fast idle engine	CO Fast idle	Lambda fast idle	CO idle	CO2 idle	HC idle
Organisation		km	date	tr/min	%	-	%	%	ppm
TÜV-Nord	Volkswagen	113762	20.09.2011	2870	1.16	0.963	0.57	14.31	231
TÜV-Süd	Seat	31360	08.08.2011	2810	1.33	0.956	0.58	13.90	252
TÜV-Nord	Volkswagen	34007	23.09.2011	2680	157	0.968	1.05	13.66	581
RDW	Volkswagen	12447	01.08.2011	2761	3.80	0.882	2.10	13.36	466
TÜV-Nord	Volkswagen	26560	15.09.2011	2580	6.01	0.823	4.02	12.05	447

Due to a few but very high emitting vehicles, the average value for this vehicles category increases dramatically. Because of the low mileage and age of these vehicles it seems to be a defect of components than deterioration over time. If we look to the lambda readings we see also extreme rich values for these vehicles having high CO emissions. It has also to be noticed, that on this high emitting vehicles no DTC`s were stored; e.g. by using the only OBD – method, these vehicles would pass the emission test.

Figure 13 and *Figure 14* show the results without the mentioned vehicles, plotted against kilometre range and by age bands respectively. After rejection of these vehicles the average of the category is more likely in line with the expected level of CO emissions.

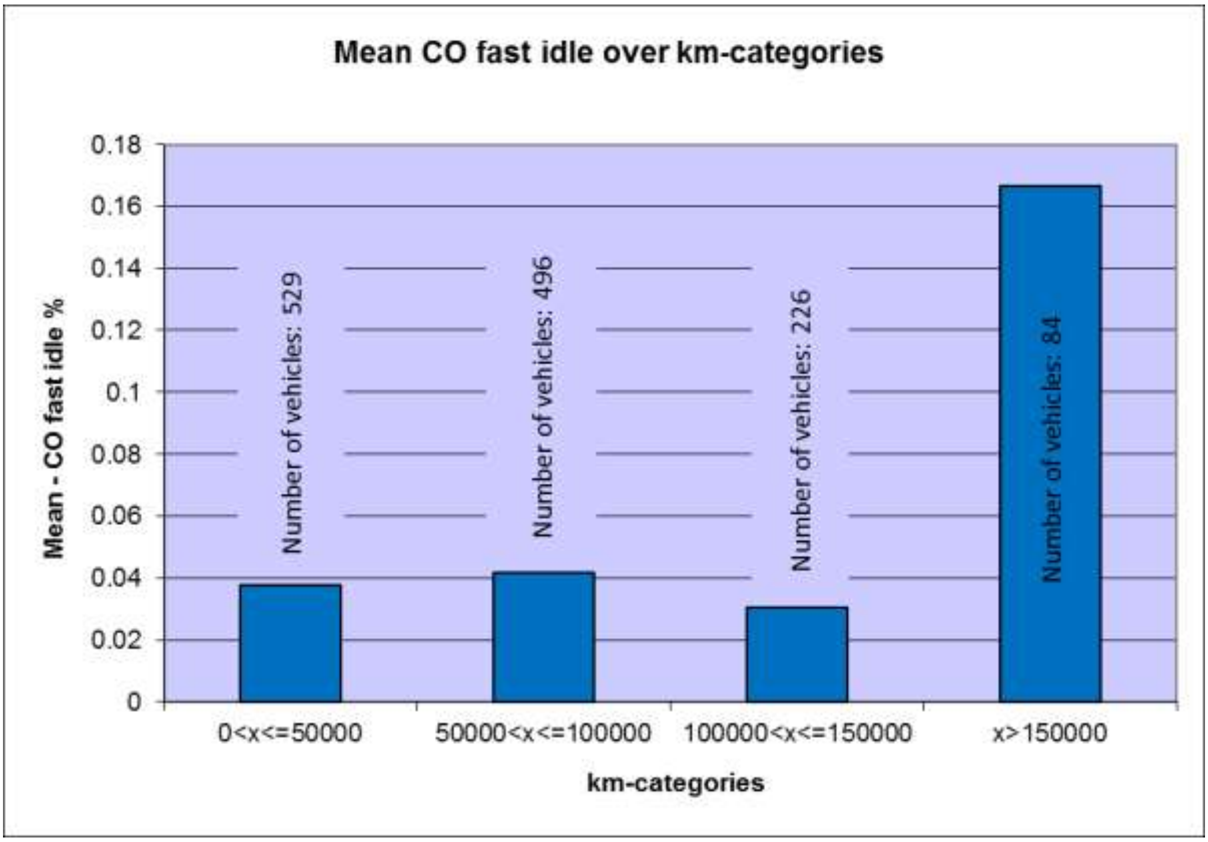

Figure 13. Fast idle CO emissions by odometer reading range without the statistic spike vehicles

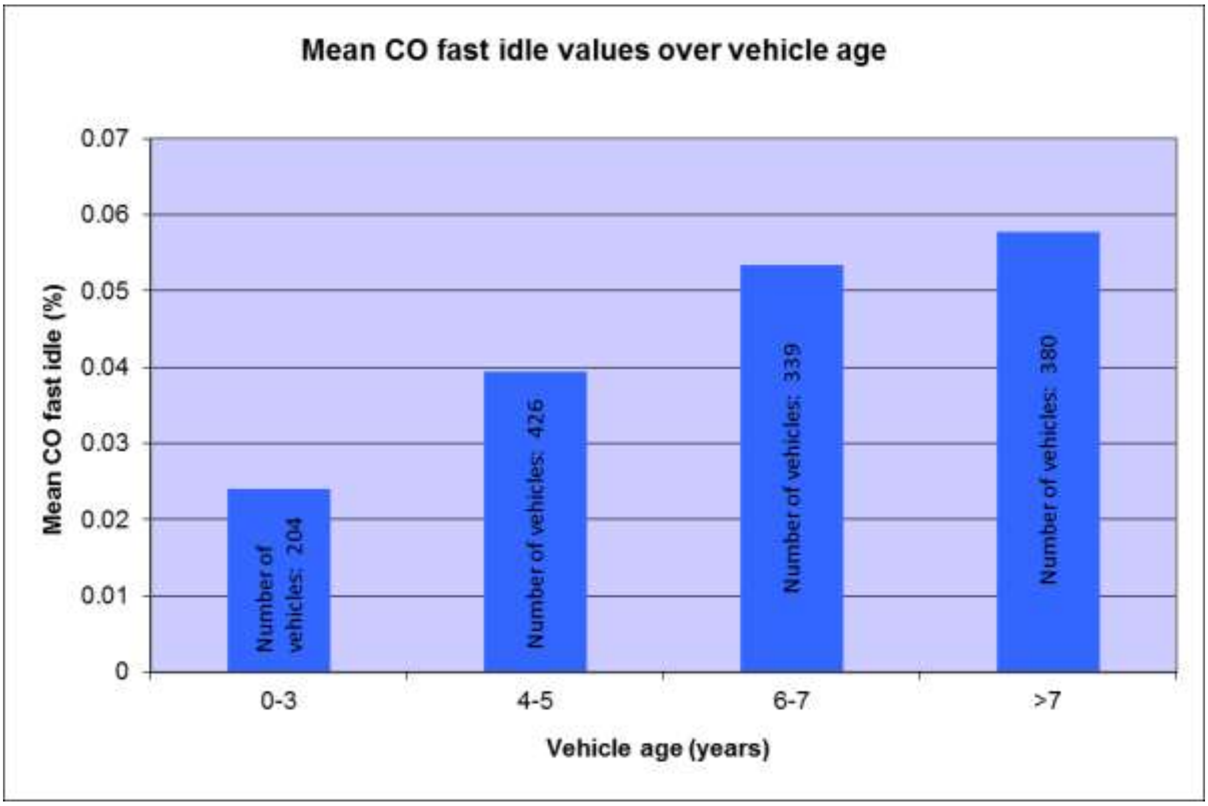

Figure 14. Fast idle CO emissions plotted against vehicle age band without the statistic spike vehicles

3.5.8 Effect of engine acceleration times on k values

The following graphs show the effect on the "rising time" – the time taken to accelerate the engine from idle to its maximum speed – on the resulting smoke emissions. *Figure 15 – Figure 18* in general show clear indications, that acceleration time above 2 seconds lead to lower k values. Increasing time is equal to decreasing load on the engine, resulting in lower emissions. These values are based on all measurements from the field trials. This is examined in more detail on one vehicle in the laboratory test section. The reasons for the very long acceleration times is not known – it will be partly due to the time taken for the engine to react and also due to the operator pressing the accelerator pedal very slowly.

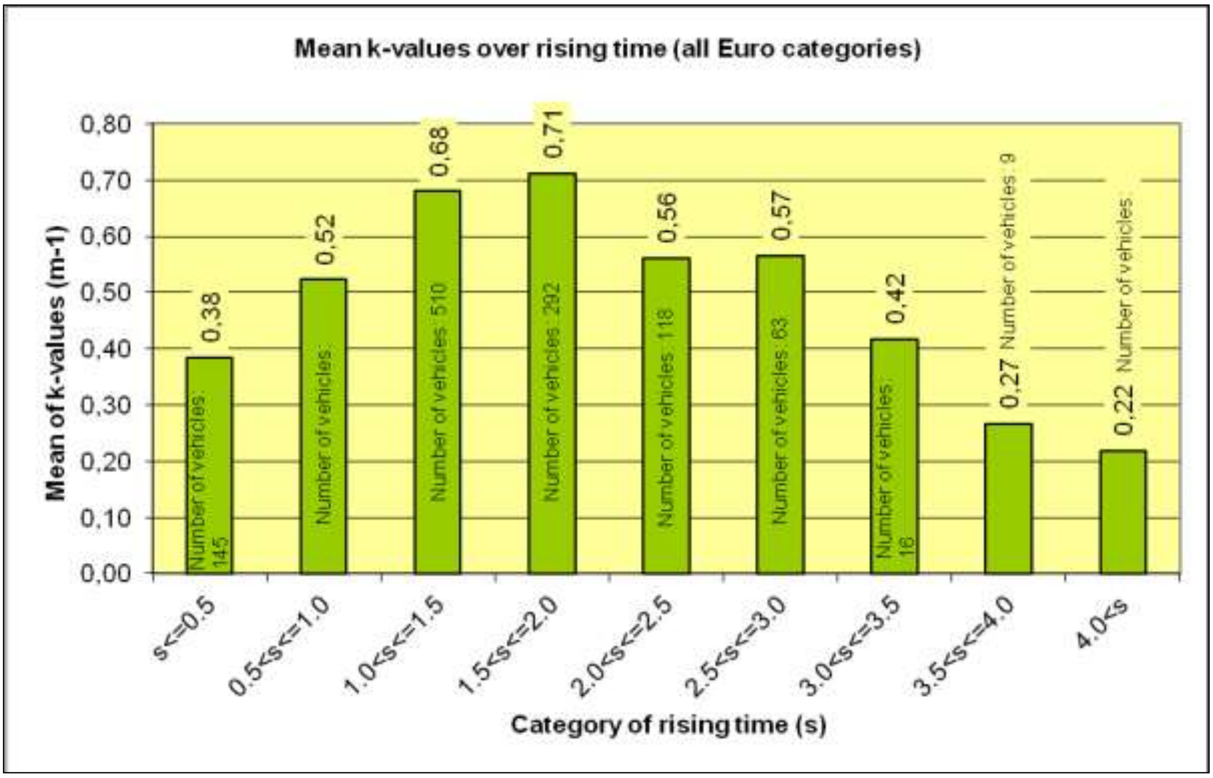

Figure 15. FAS test results plotted against engine acceleration time – all diesel vehicles

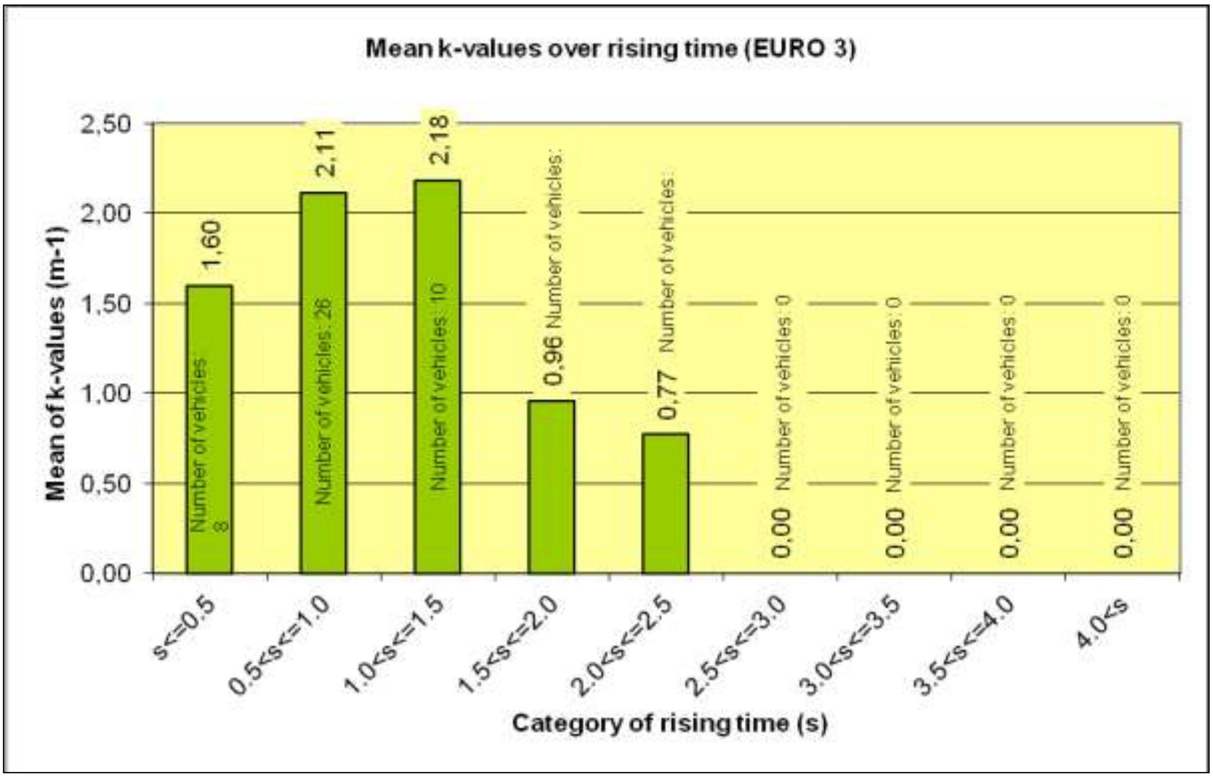

Figure 16. FAS test results plotted against engine acceleration time – Euro 3 diesel vehicles

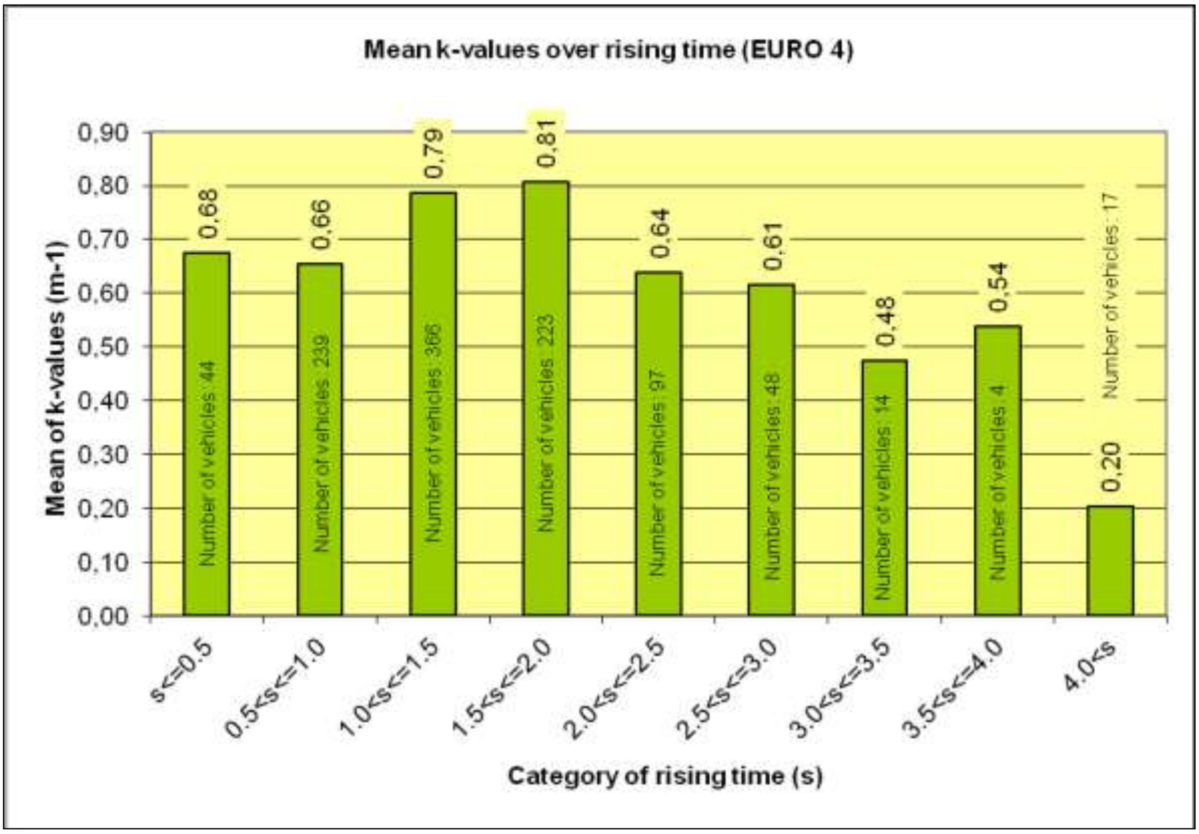

Figure 17. FAS test results plotted against engine acceleration time – Euro 4 diesel vehicles

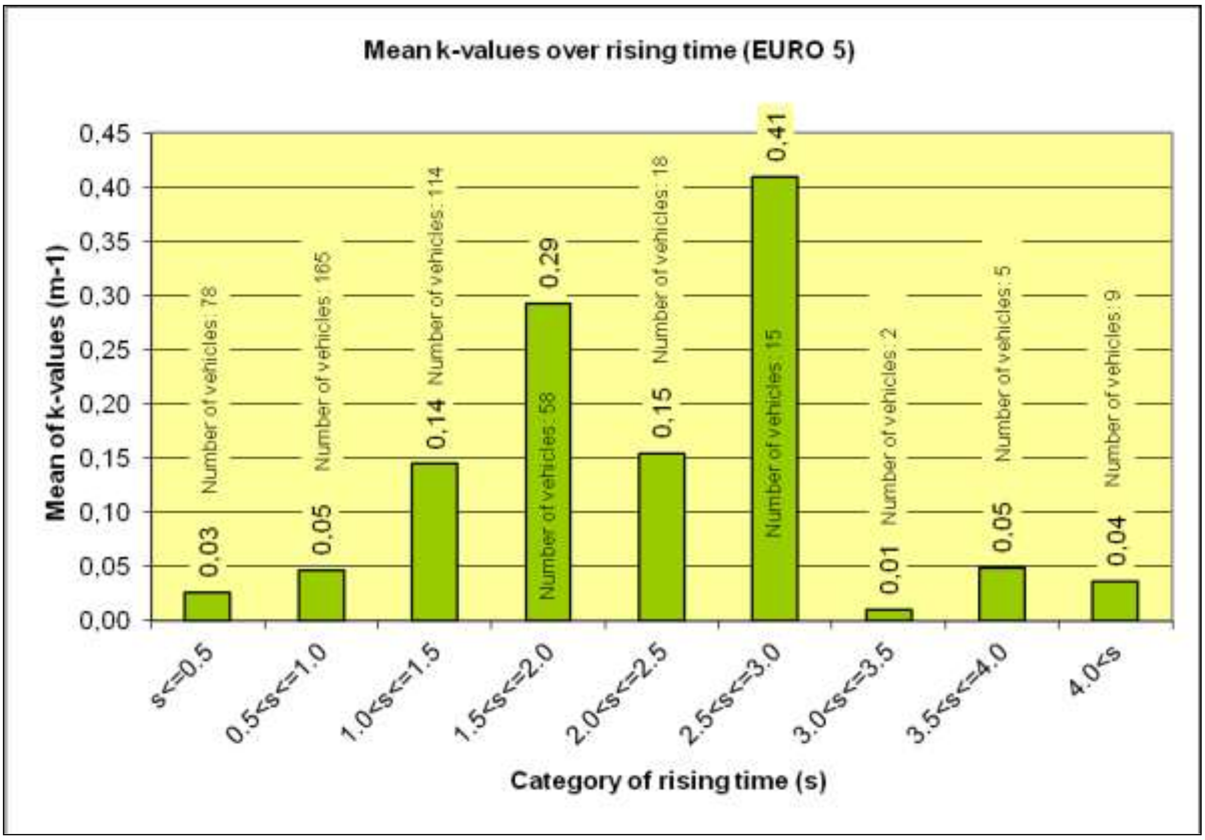

Figure 18. FAS test results plotted against engine acceleration time – Euro 5 diesel vehicles

3.5.9 Diesel vehicles with limited engine speeds

The maximum engine speed of a diesel engine is limited to prevent engine damage occurring. On some vehicles, this maximum speed (or cut off speed) may be much lower when the vehicle is stationary than under normal driving conditions. The cut off speeds of the diesel vehicles observed during the field trials are shown in the *Figure 19*. This shows that a lot of the vehicles tested had low maximum engine speeds during free acceleration, with some less than 2,500 rpm. For vehicles with an engine speed cut-off speed of 3,750 rpm or lower, the age distributions of these vehicles are shown in *Figure 20*.

Similar graphs for shown in:

- *Figure 21* and *Figure 22* for Euro 4 vehicles only
- *Figure 23* and *Figure 24* for Euro 5 vehicles only

It can be seen that the limited engine speed is more of a problem with recent vehicles than with older vehicles, especially for Euro 5 vehicles. The effect is similar to the high acceleration time: the engine is subjected to lower loads or a shorter loading time period during the smoke test.

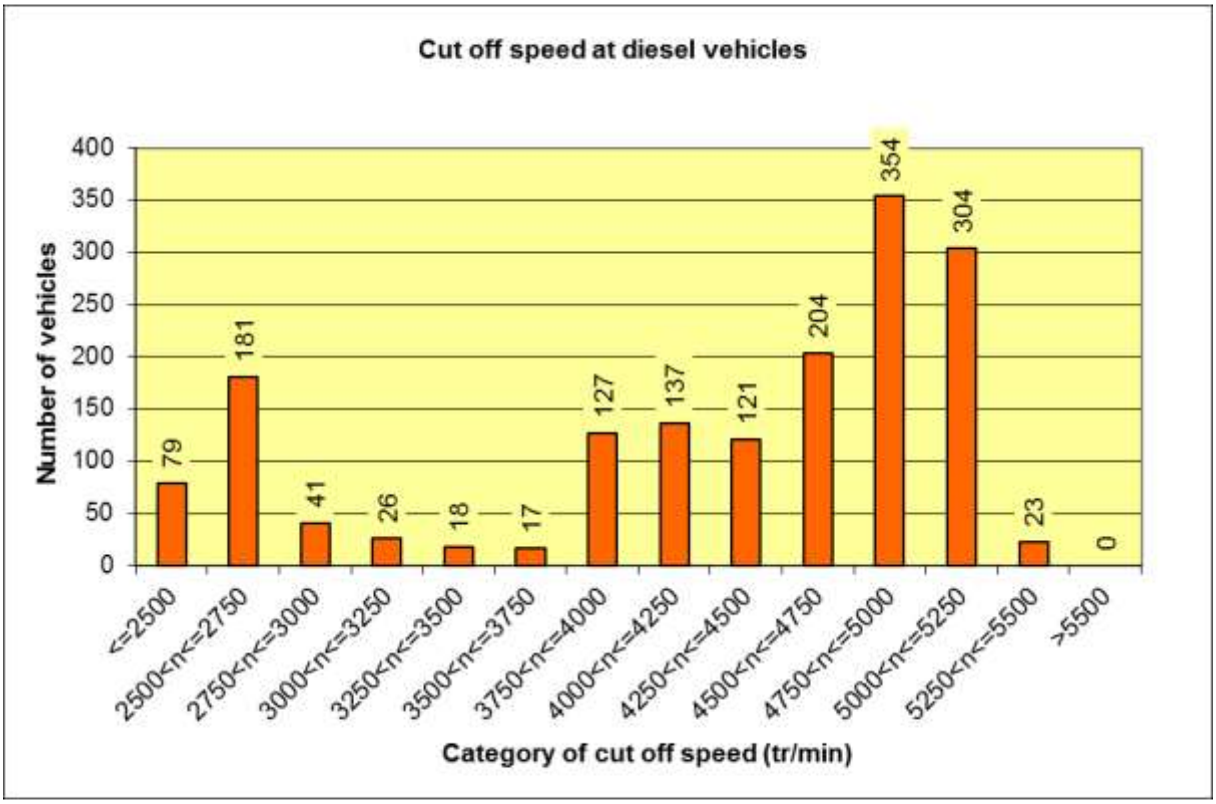

Figure 19. The distribution of engine cut-off speeds observed during the smoke test - all diesel vehicles

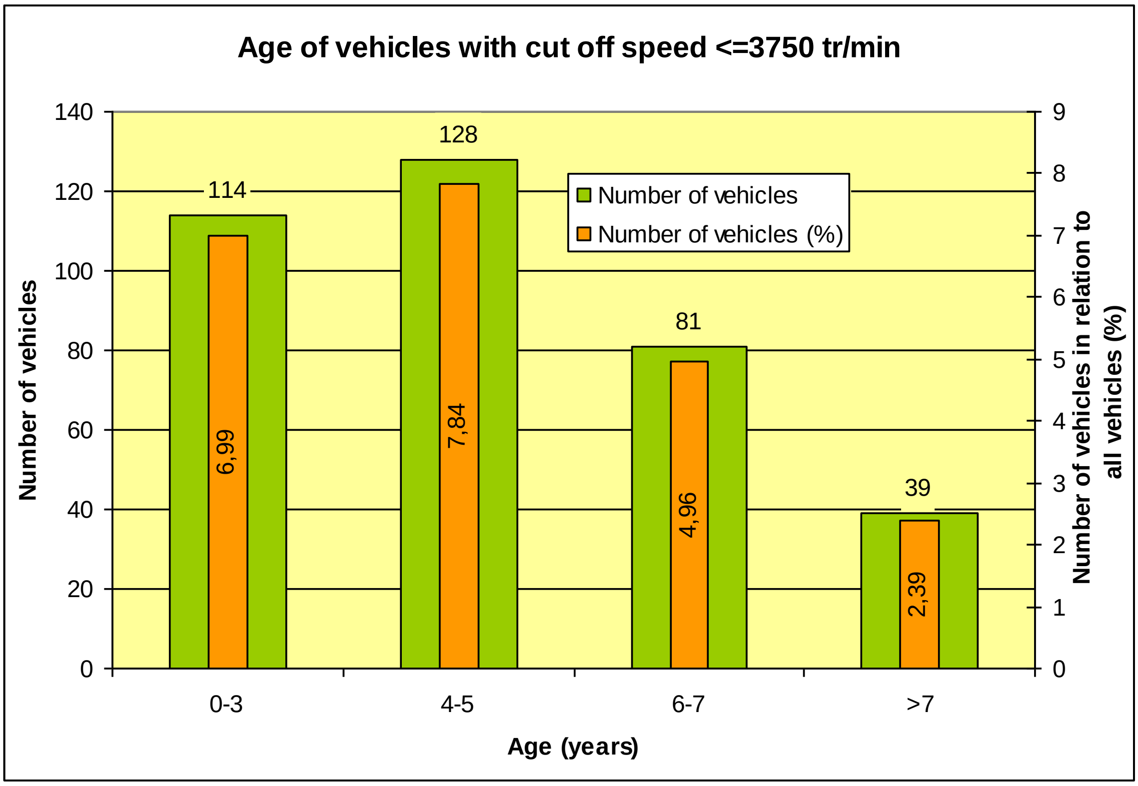

Figure 20. Ages of vehicles with a maximum engine speed less than 3750 rpm - all vehicles

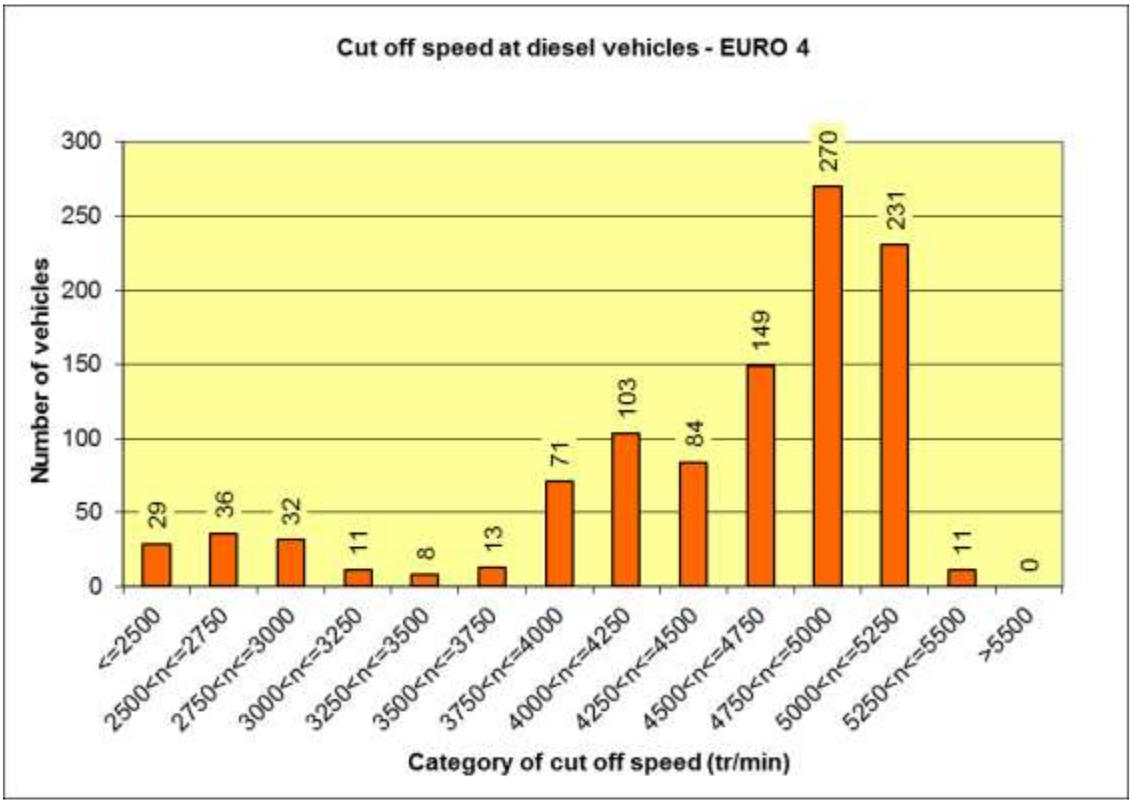

Figure 21. The distribution of engine cut-off speeds observed during the smoke test – Euro 4 diesel vehicles

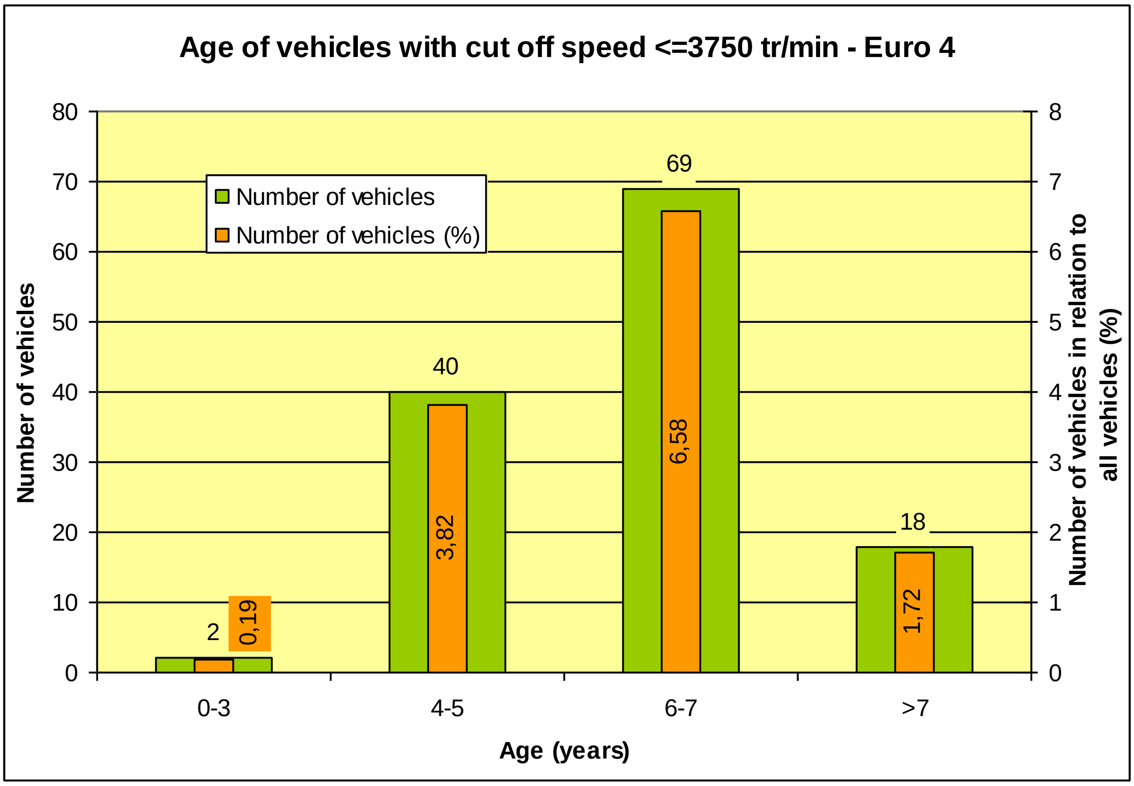

Figure 22. Ages of vehicles with a maximum engine speed less than 3750 rpm – Euro 4 vehicles

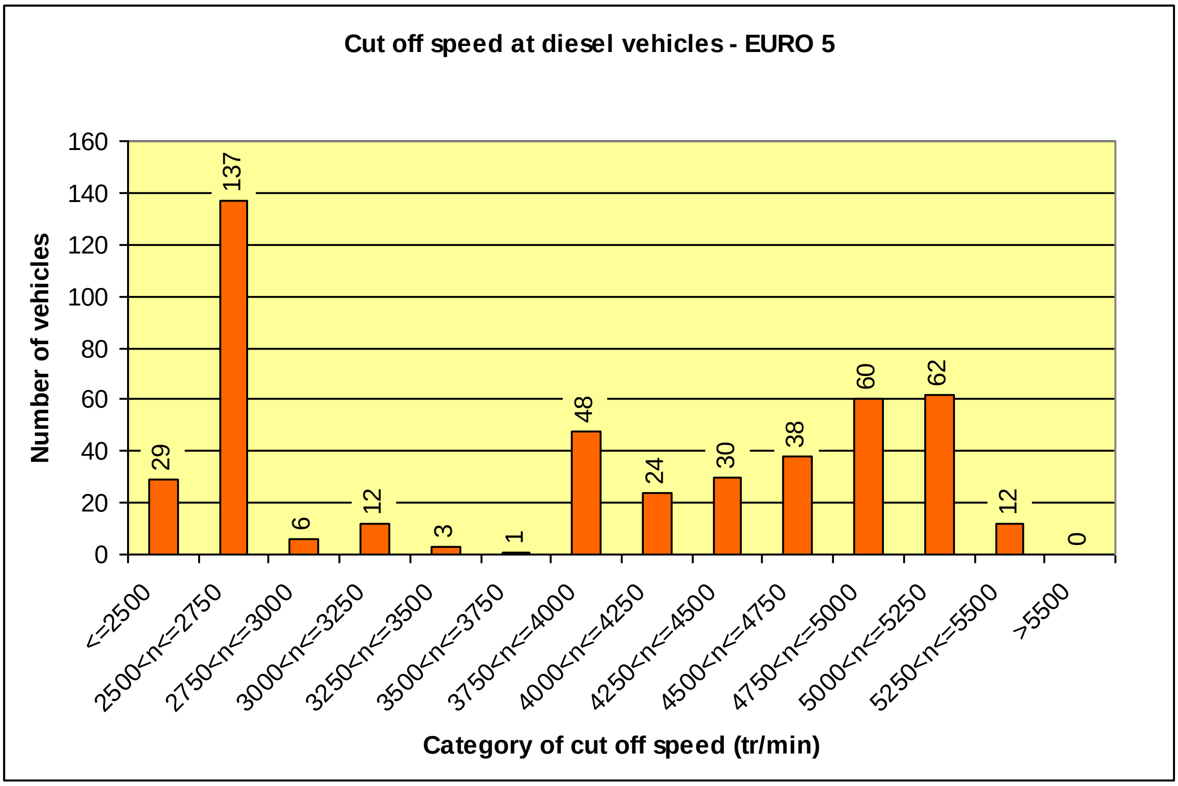

Figure 23. The distribution of engine cut-off speeds observed during the smoke test – Euro 5 diesel vehicles

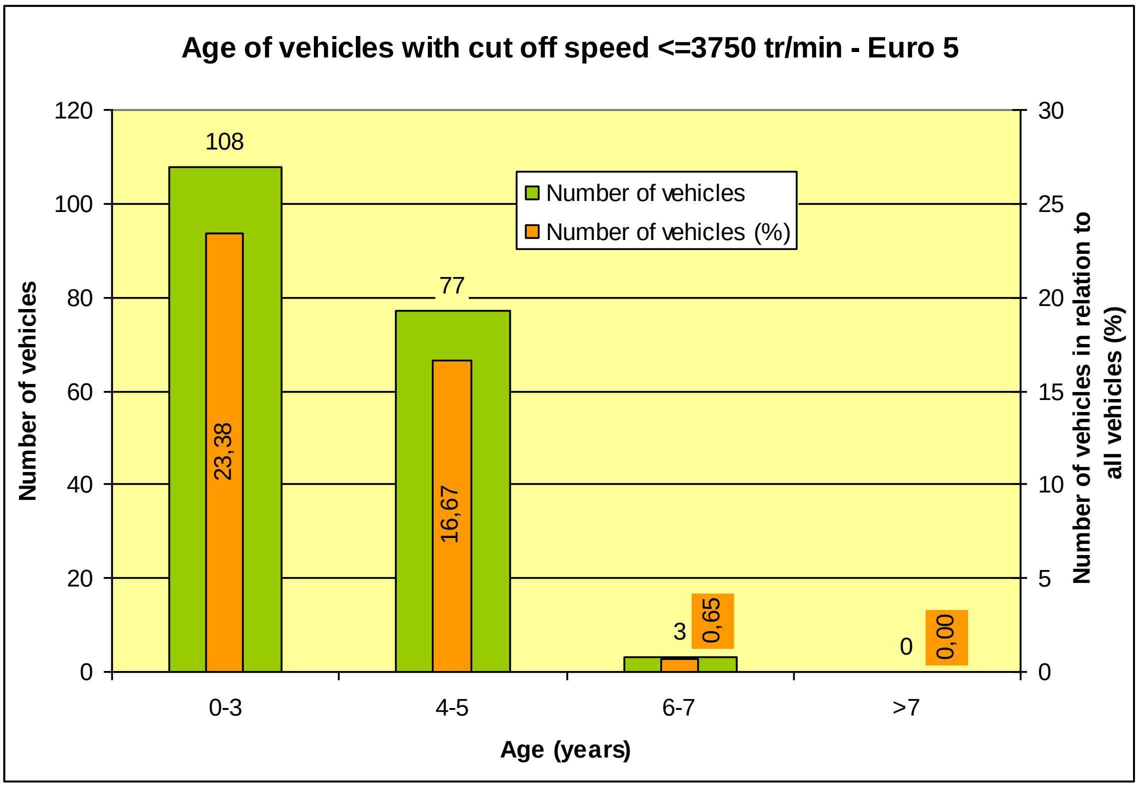

Figure 24. Ages of vehicles with a maximum engine speed less than 3750 rpm – Euro 5 vehicles

3.5.10 Variation of the thresholds

Lowering the threshold (limit) would help to detect more gross polluting vehicles and increases the number of vehicles that would fail the test. This is illustrated in *Table 8* for petrol vehicles. Over 94% of all petrol vehicles have a measured CO value below 0.1% Vol. and represent a well-functioning emission system. In the case of petrol vehicles, a general limit is possible and useful in detecting faulty vehicles:

- A limit of 0.1% CO at fast idle would result in 83 vehicles (6.4%) failing the test
- A lower limit of 0.05% CO at fast idle would be possible, resulting in 138 (10.7%) of vehicles failing the test

Table 8. Cumulative number of failures by threshold for petrol vehicles

Petrol vehicles

	number of failed vehicles				
Threshold - CO high idle (%)	Euro 3	Euro 4	Euro 5	Euro 6	**Total**
>0.01	10	210	141	2	**363**
>0.02	6	143	88	1	**238**
>0.03	6	113	72	1	**192**
>0.04	5	93	65	1	**164**
>0.05	3	76	59	0	**138**
>0.1	3	45	35	0	**83**
>0.2	3	26	19	0	**48**
>0.3	1	19	17	0	**37**
>0.4	0	15	14	0	**29**
>0.5	0	11	12	0	**23**
Total tested petrol vehicles:					
	35	818	435	7	1295

In addition to the above, there were also 79 vehicles with no emissions class declaration

The table above can be used for a kind of sensitivity analysis; e.g. which thresholds lead, in European Member States, to which kind of failure rate. Thresholds below 0.05% CO concentration are not seen actually as useful because of the need of new equipment and new and more demanding calibration effort. 0.1% or 0.05% CO are realistic today and able to be introduced in a short time frame.

Findings:

- For Euro 4 petrol vehicles onwards, a limit of **0.1% CO** at fast idle could be used to detect gross polluter*.
- It would also be possible to set as future limit of **0.05% CO** at fast idle. However, this may require some Member States to upgrade their emission analysers.
- The natural idle CO limit can remain unchanged.

*gross polluter: vehicle which pollutes minimum twice as much pollutants as allowed

For diesel, the number of vehicle failing the test according to the threshold (limit) is shown in *Table 9*

Table 9. Cumulative number of failures by threshold for diesel vehicles

Diesel vehicles

	number of failed vehicles				
Threshold - k-value	Euro 3	Euro 4	Euro 5	Euro 6	**Total**
>0.1	46	681	60	2	**789**
>0.2	46	640	43	2	**731**
>0.3	44	582	34	2	**662**
>0.5	39	451	28	1	**519**
>1	31	243	20	1	**295**
>1.5	25	153	6	1	**185**
Total tested diesel vehicles:					
	48	1052	464	5	1569

For Euro 3 vehicles, not many tests were performed. With a limit of 1.5 m^{-1}, 25 vehicles out of 48 would have failed the test – a failure rate of 52.1% which is very high. This is not statistical relevant due to the very low number of tested vehicles. For some MS there are still higher thresholds than 1.5 m^{-1} k value in force; which might be reviewed by the commission in the light of today's experience and vehicle population.

The Euro 4 vehicles should really be tested according to their plate values – because some of the vehicles are fitted with a DPF (very low PM emissions) and some are not (moderate PM emissions). Using a limit of 1.0 m^{-1}, 23.1% of the vehicles would have failed the test.

For Euro 5 vehicles a general limit is practical and useful, as all the vehicles are equipped (when new) with a DPF. A limit of 0.2 m^{-1} would have resulted in a 9.3% failure rate. Increasing the limit to 0.3 m^{-1} would result in a 7.3% failure rate.

Laboratory tests have shown that if the emission system is working well the measured k-value is about 0,001 m^{-1} for Euro 5 vehicles with particulate trap.

If plate values are available, this threshold can be used if the plate value is not exceeding the general limit of 0.3 m^{-1} or 0.2 m^{-1}. Actually the experience is given by different empiric evaluations, that in some cases the calculation for the plate value is not correctly understood. The binding calculation in accordance to the EU regulation 72/306/EC followed by EU 715/2007 and ECE R24, offers two different calculations. The lowest result is to be used. For example the first calculation is based on simply adding 0.5 m^{-1} for deterioration over time in use. If within the type approval a measurement value of 0.05 m^{-1} is measured, simply 0.5 m^{-1} are added as plate value.

According to UN Regulation No 24 (Rev 2, Annex 5), the absorption coefficient is calculated according to

$$X_L = S_L / S_M * X_M \quad \text{or} \quad \text{if lower: } X_L = X_M + 0.5$$

Where:

X_M = value of the absorption coefficient under free acceleration measured as prescribed in paragraph 2.4 of annex 5 of R24;

X_L = corrected value of the absorption coefficient under free acceleration;

S_M = value of the absorption coefficient measured at steady speed (annex 4, paragraph 2.1 of R24) which is closest to the prescribed limit value corresponding to the same nominal flow;

S_L = value of the absorption coefficient prescribed in annex 4, paragraph 4.2 of R24, for the nominal flow corresponding to the point of measurement which gave the value S_M .

The second calculation is different. It might be questioned by the commission to the MS – how this definition is understood and handled, when a lot of the plate values on modern vehicles appear to be quite high. It appears wrong that some modern Euro 6 diesels vehicles have a plate value higher than 0.2 m^{-1}.

Findings:

- For Euro 4 diesel vehicles the limit should be the plate value, but maximum **1.0 m^{-1}.**
- For Euro 5 diesel vehicles onwards, a general limit of **0.2 m^{-1}** or lower would be possible and effective to detect gross polluter.
- Existing smoke meters could be used to test at this limit. For lower limits, new equipment or a new certification process would be required to meet the accuracy requirements.

3.6 PM measurement

To investigate alternative methods and definitions for diesel emissions, measurements of the mass PM measured in mg/m^3 were also done within the SET project in parallel to the conventional k- value measurement. Some of the analysers used for the field trials were able to measure and display PM mass values as well as k values for each measurement. The following figures show the fairly good correlation between the two measurements. *Figure 25* shows all the values whereas *Figure 26* focuses on the interesting low value area and shows a very good correlation between k values and PM mass measurements between 0 – 1m^{-1}. For future developments it can be recognised that appropriate measurement devices are available to measure very low particulate concentrations with a high accuracy, far below 0.1 m^{-1}.

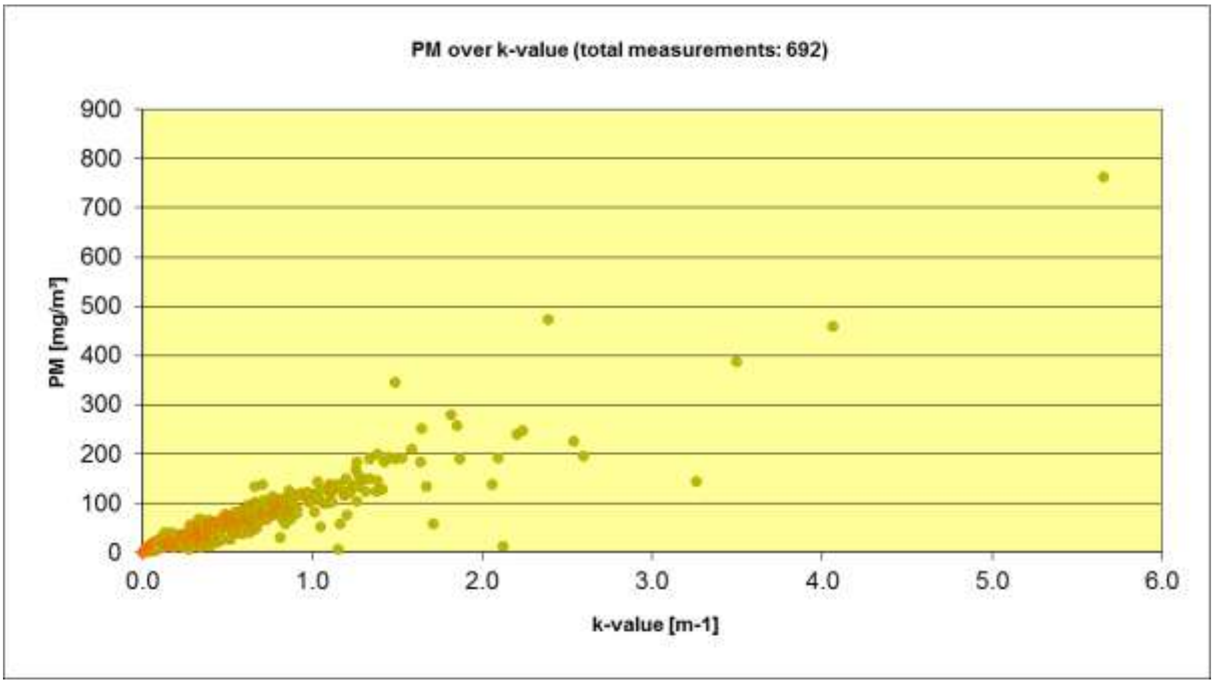

Figure 25. Correlation of k-value (m^{-1}) and PM mass (mg/m^3) – all measured vehicles

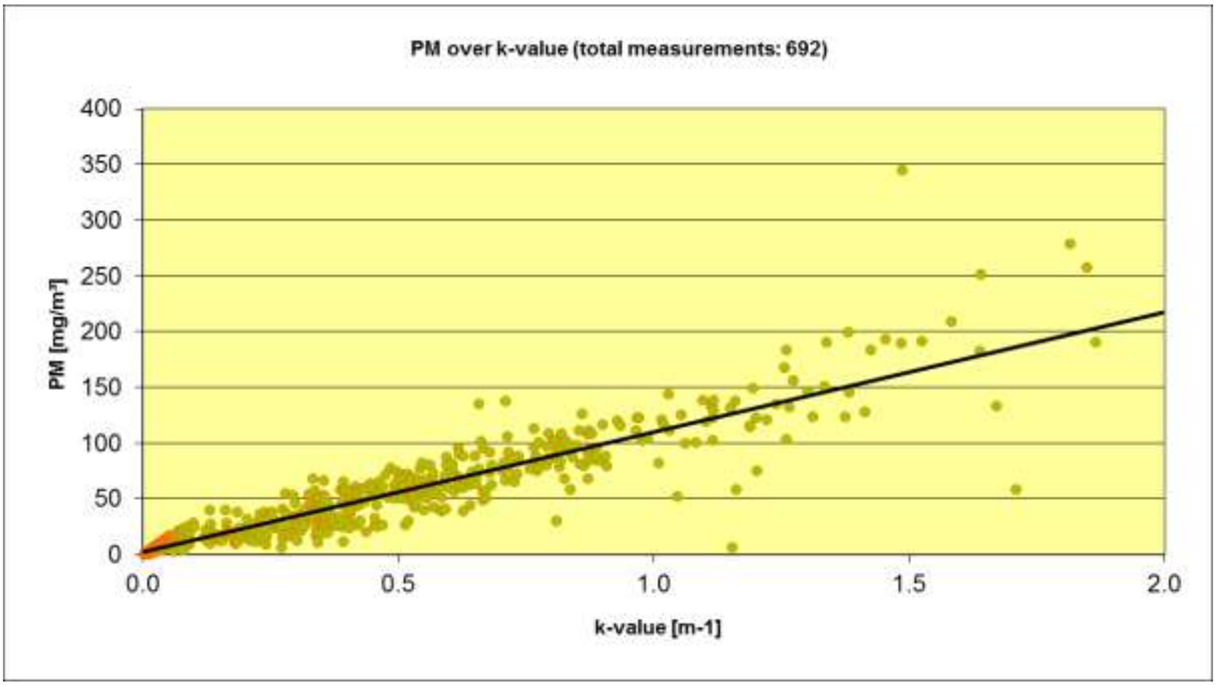

Figure 26. Correlation of k-value (m^{-1}) and PM mass (mg/m^3) – k-values up to 2.0 m^{-1}

3.7 Analysis of the OBD testing

One of the most important issues for the SET study was to have within one test procedure the full overview on all relevant data concerning tailpipe measurement together with OBD scanning. The following tables and figures are showing the results from more than 3,000 tests in Europe following the same test procedures as described earlier.

Table 10 shows the OBD status of all the vehicles tested. According to the table, only 0.46 % of the vehicles had their MIL set on (i.e. the **M**alfunction **I**ndicator **L**amp on the dashboard was illuminated). Interestingly, the number of vehicles with their MIL status set to "On" was higher than the number of vehicles with MIL on. Explanations for this could be that the MIL lamp had failed (fault); the bulb had been removed (tampering) or it was not correctly connected (tampering of fault).

Table 10. Number of vehicles with MIL set or with DTCs

	Number of vehicles	**Number of vehicles (%)**
MIL on	14	0.46
MIL Status on	41	1.35
Number of DTC ≥1	244	8.06

Overall, the number of vehicles with the MIL Status On is quite low at 41 (1.35%). The amount of vehicles with DTC stored is around 8% equal to earlier evaluations. The breakdown of vehicles with DTCs by Member State is shown in *Table 11.*

Table 11. Number of vehicles with DTCs by Member State

Country	Number of vehicles with DTC	Number of vehicles with DTC (%)
Belgium	67	8.79
Netherlands	14	7.78
Spain	130	10.09
Sweden	15	4.79
France	4	8.33
Germany	14	3.20

By comparing the results of different MS it is obvious, that in MS where OBD scanning is already performed and affecting the pass/fail decision, the percentage is lower than in MS were OBD is not used within the inspection.

The readiness state of the vehicles is shown in *Table 12*. Overall, the number of "not complete" RC is very similar to other experiences. Around 10% is also the average in Germany from their PTI programme. On these vehicles the RC are not set because of having repair just before the test and not all driving conditions being reached or some other manipulations has led to "not set" RC (readiness codes – indicates the OBD system is ready to detect failures or mismatch of functions).

Table 12. Readiness state of the vehicles by country performing the tests.

Country	0= complete	1= not complete	no content	**total**
Belgium	629	118	15	**762**
Netherlands	150	30	0	**180**
Spain	1219	69	0	**1288**
Sweden	285	27	1	**313**
France	28	16	4	**48**
Germany	421	16	0	**437**
Total	**2732**	**276**	**20**	**3028**

3.7.1 DTCs for petrol vehicles

Figure 27 shows one key finding concerning correlation or non-correlation of OBD testing and tailpipe measurement.

We can see a high amount of DTC`s on vehicles having very low tailpipe emissions as well as overall classes of emission concentrations. There is no correlation between both methods. The distribution of DTC seems more stochastic than related to emission concentrations.

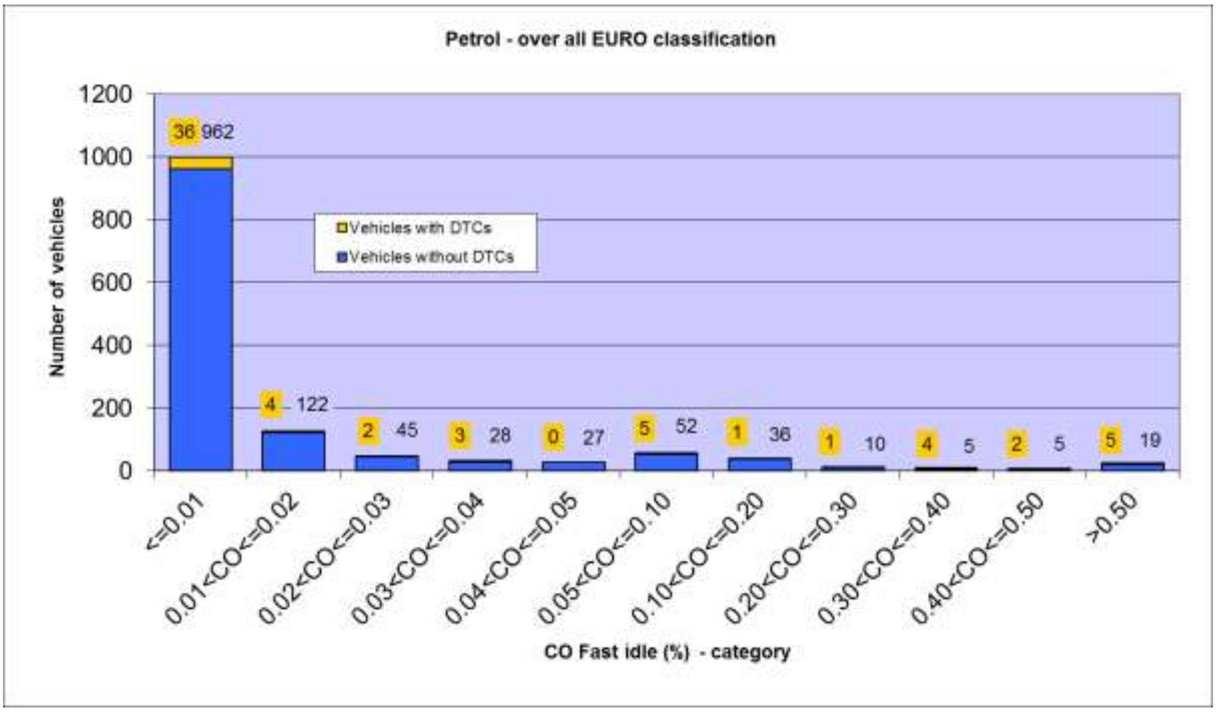

Figure 27. DTCs compared to fast idle CO emissions

For all the petrol vehicles, 4.6% of vehicles were found with at least one DTC stored.

63 vehicles with DTC of 1374 tested petrol-vehicles = 4.6 %

Using the limit of 0.2 % CO:

- There were 12 vehicles (0.9%) exceeding the limit with DTCs, but
- There were 39 vehicles (2.8%) with DTCs which are within the CO limit

The comparison of DTCs and fast idle emissions test is shown separately for Euro 4 and Euro 5 vehicles in *Figure 28* and *Figure 29* respectively.

For Euro 4, 48 of 818 vehicles tested (5.9%) had at least one DTC stored

For Euro 5, 12 of 435 vehicles tested (2.8%) had at least one DTC stored

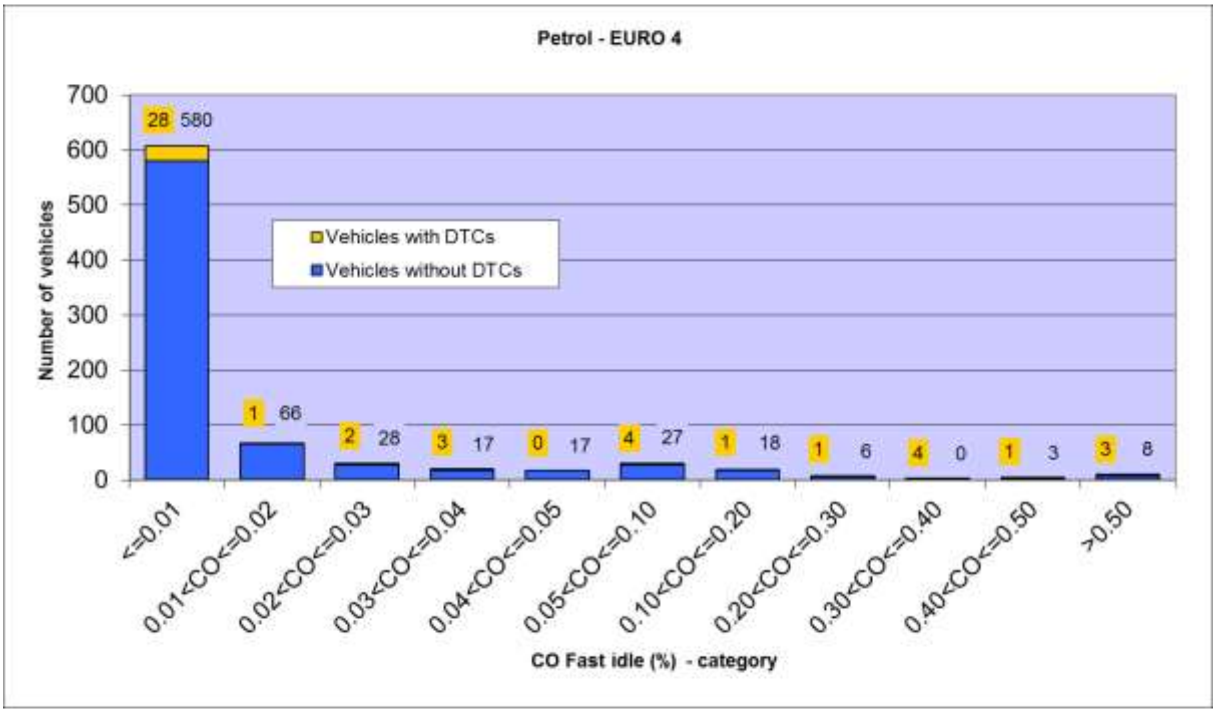

Figure 28. DTCs compared to fast idle CO emissions – Euro 4 vehicles

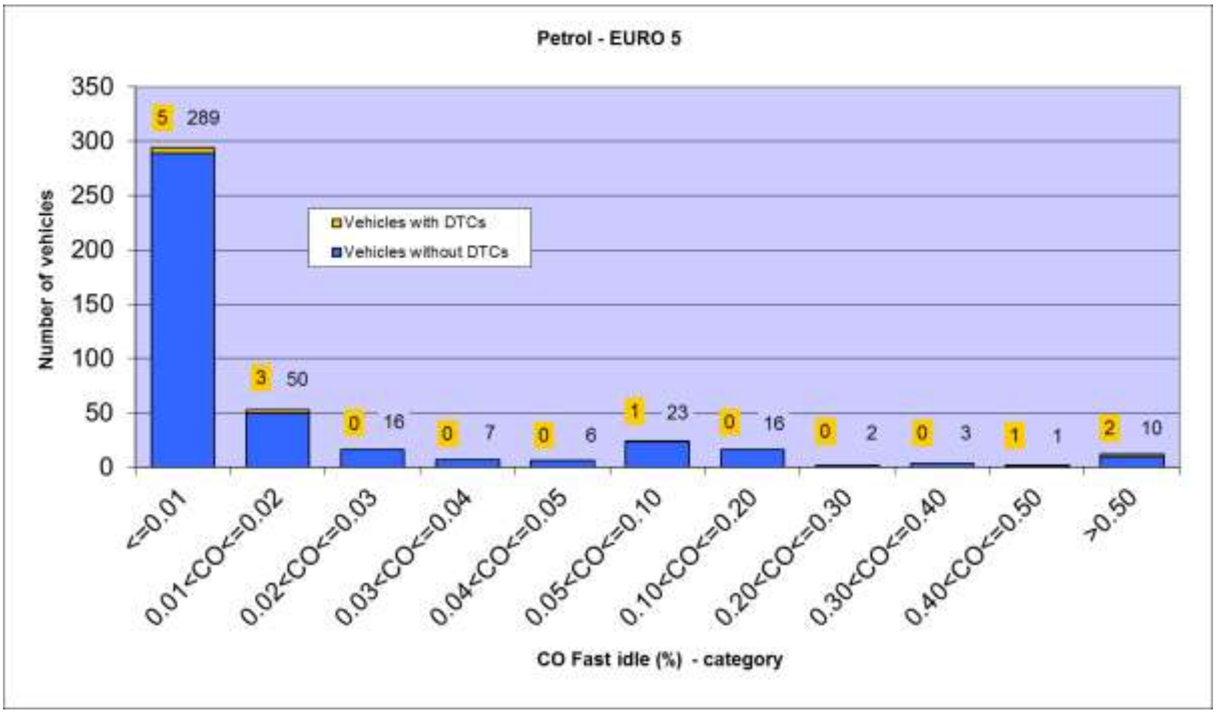

Figure 29. DTCs compared to fast idle CO emissions – Euro 5 vehicles

Even on the relative new EURO 5 vehicles the number of vehicles presented with DTC`s is not in correlation with the emission behaviour. There are vehicles with low measured tailpipe concentrations but stored DTCs, and there are vehicles with high measured concentrations but no stored DTCs.

There does not appear to be any correlation between tailpipe measurement and OBD scanning. One explanation is because of the different mechanism and ability to detect failures between OBD – scanning and tailpipe measurement.

3.7.2 DTCs for diesel vehicles

For diesel vehicles the findings are similar to the petrol vehicles. Overall diesel vehicles have DTC`s despite what k values are measured. Over 10% of diesel vehicles had at least one DTC stored as shown in *Table 13*. The number of vehicles with and without DTCs is shown plotted against the smoke test k value in *Figure 30*.

For Euro 4 vehicles, over 14% of the vehicles had one or more DTC, which is shown tabulated in *Table 14*. *Figure 31* shows there are vehicles with high k-values and DTCs (which indicates good correlation between tailpipe and OBD), as well as there are vehicles with low k-values and DTCs as well (which means bad correlation between tailpipe and OBD). Therefore, there is no clear correlation between tailpipe and OBD for Euro 4 - Diesel

Over 3% of Euro 5 vehicles, even though they are relatively new vehicles, had one or more DTC as shown in *Table 15*. For Euro 5-Diesel, as shown in *Figure 32*, there are vehicles with high k-values and no DTCs, as well as there are vehicles with low k-values and DTCs (both means bad correlation between tailpipe and OBD). Therefore, there is no clear correlation between tailpipe and OBD for Euro 5 – Diesel.

Table 13. DTC status of vehicles by FAS test smoke level - all diesel vehicles

Total			
k-value category	Vehicles without DTCs	Vehicles with DTCs	Percentage of category
≤≤0.1	775	43	5.3%
0.1<k≤0.2	54	7	11.5%
0.2<k≤0.3	61	10	14.1%
0.3<k≤0.5	129	18	12.2%
0.5<k≤1.0	192	41	17.6%
1.0<k≤1.5	106	16	13.1%
>1.5	156	46	22.8%
Total	**1473**	**181**	

181 vehicles with DTC of 1654 tested diesel-vehicles = 10.9 %

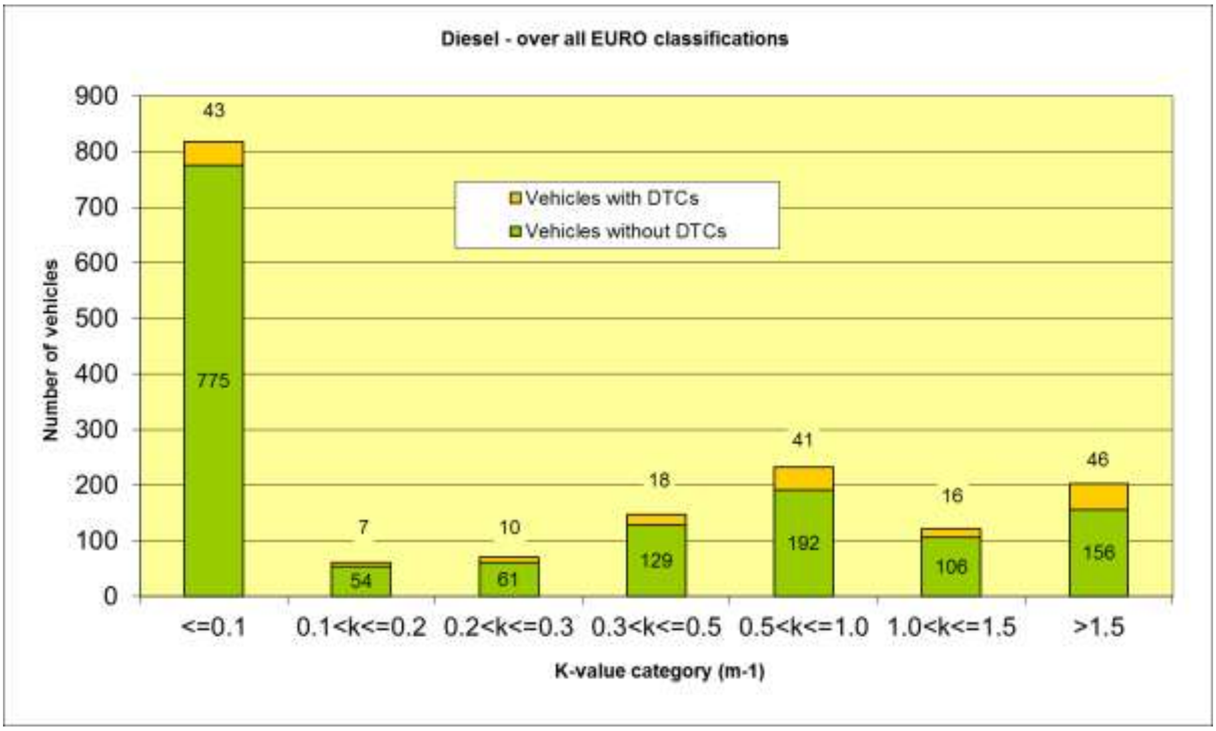

Figure 30. DTC status of vehicles by FAS test smoke level - all diesel vehicles

Table 14. DTC status of vehicles by FAS test smoke level – Euro 4 diesel vehicles EURO 4

k-value category	Vehicles without DTCs	Vehicles with DTCs	Percentage of category
≤0.1	339	32	8.6%
0.1<k≤0.2	37	4	9.8%
0.2<k≤0.3	49	9	15.5%
0.3<k≤0.5	115	16	12.2%
0.5<k≤1.0	169	39	18.8%
1.0<k≤1.5	76	14	15.6%
>1.5	113	40	26.1%
Total	**898**	**154**	

154 vehicles with DTC of 1052 tested euro-4-diesel-vehicles = 14.6 %

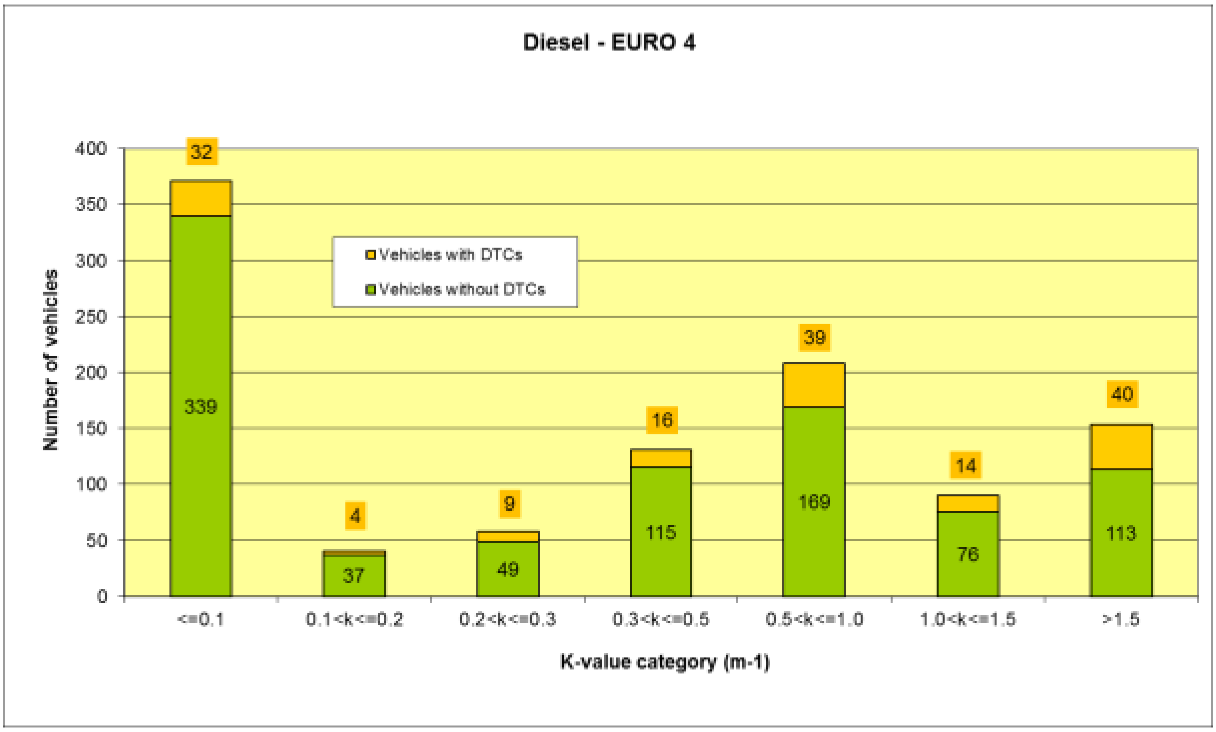

Figure 31. DTC status of vehicles by FAS test smoke level – Euro 4 diesel vehicles

Table 15. DTC status of vehicles by FAS test smoke level – Euro 5 diesel vehicles

EURO 5			
k-value category	**Vehicles without DTCs**	**Vehicles with DTCs**	**Percentage of category**
≤0.1	396	8	2.0%
0.1<k≤0.2	15	2	11.8%
0.2<k≤0.3	8	1	11.1%
0.3<k≤0.5	5	1	16.7%
0.5<k≤1.0	7	1	12.5%
1.0<k≤1.5	13	1	7.1%
>1.5	6	0	0.0%
Total	**450**	**14**	

14 vehicles with DTC of 464 tested euro 5 -diesel-vehicles = 3.0 %

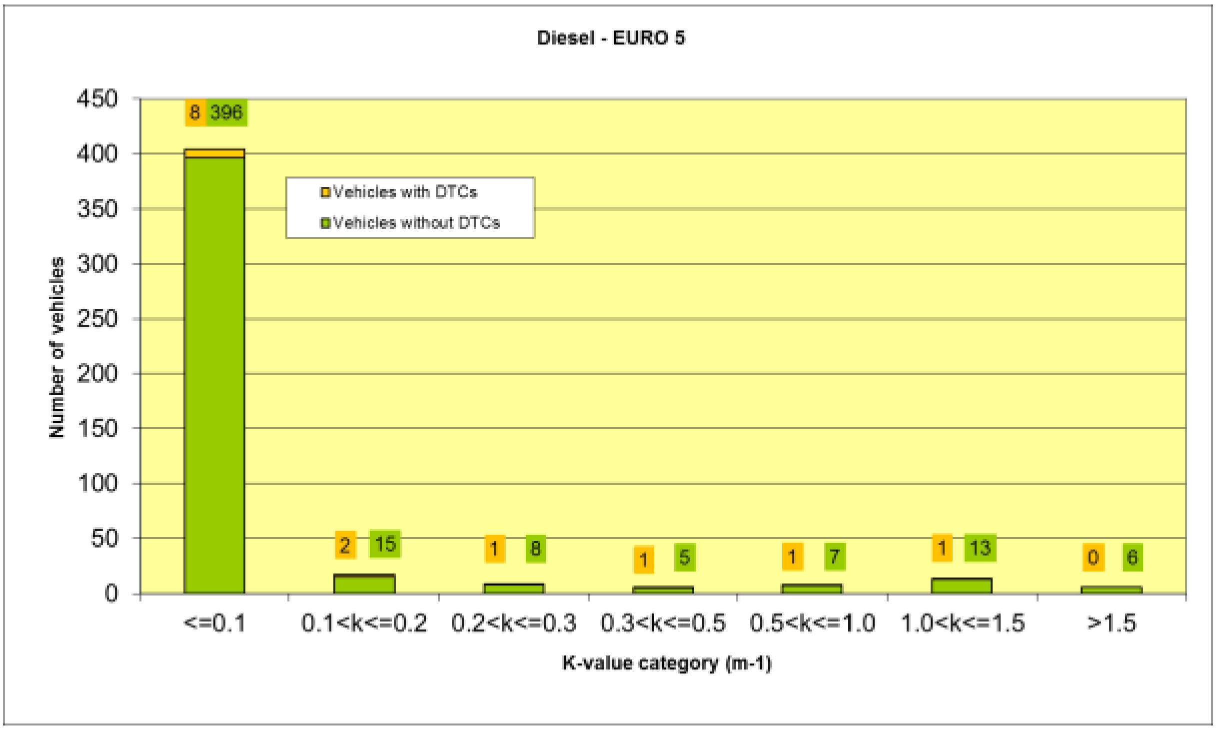

Figure 32. DTC status of vehicles by FAS test smoke level – Euro 5 diesel vehicles

Table 16 lists the most common DTCs detected during the field trials, sorted by the number of occurrences (a full list is contained in Appendix C). The most frequent DTC was the misfire codes (P1351). This was found on 58 petrol vehicles. For standardised OBD functionality, only P0 codes are required, but in practice most of the OEM`s also use P1 codes. For diesel vehicles P0670 Glow plug module control circuit was the most common fault (35 vehicles).

Both examples are faults that are unlikely to influence the tailpipe measurement because these failures are more relevant when the engines are under higher load (petrol: misfire) or when the engine is cold (diesel: glow plug). However, these faults may affect the emissions under real driving conditions (i.e. during the normal use of the vehicle).

At the same time we have failures, like defective particulate traps or failures of other components, which are not easily detected by OBD and only occur at PTI measurements.

Table 16. DTCs detected, sorted by number of occurrences

DTC	Number of occurrences	Description
P1351	58	Manufacturer Controlled Ignition System or Misfire
P0670	35	Glow Plug Module Control Circuit
P0401	13	Exhaust Gas Recirculation Flow Insufficient Detected
P1461	9	Manufacturer Controlled Auxiliary Emission Controls
P0381	6	Glow Plug/Heater Indicator Circuit
P0409	6	Exhaust Gas Recirculation Sensor "A" Circuit
P0400	5	Exhaust Gas Recirculation Flow
P0490	5	Exhaust Gas Recirculation Control Circuit High
P1462	5	Manufacturer Controlled Auxiliary Emission Controls
P0135	4	O2 Sensor Heater Circuit
P0300	4	Random/Multiple Cylinder Misfire Detected
P0403	4	Exhaust Gas Recirculation Control Circuit
P0420	4	Catalyst System Efficiency Below Threshold - Bank 1
P2002	4	Particulate Trap Efficiency Below Threshold - Bank 1
P0011	3	"A" Camshaft Position - Timing Over-Advanced or System Performance - Bank 1
P0335	3	Crankshaft Position Sensor "A" Circuit
P0340	3	Crankshaft Position Sensor "A" Circuit - Bank 1 or Single Sensor
P0471	3	Exhaust Pressure Sensor Range/Performance
P1162	3	Manufacturer Controlled Fuel and Air Metering
P14A3	3	Manufacturer Controlled Auxiliary Emission Controls
P0014	2	"B" Camshaft Position - Timing Over-Advanced or System Performance - Bank 1
P0016	2	Crankshaft Position - Camshaft Position Correlation - Bank 1 Sensor A
P0030	2	HO2S Heater Control Circuit - Bank 1 Sensor 1
P0101	2	Mass or Volume Air Flow Circuit Range/Performance
P0120	2	Throttle/Pedal Position Sensor/Switch "A" Circuit
P0122	2	Throttle/Pedal Position Sensor/Switch "A" Circuit Low
P0123	2	Throttle/Pedal Position Sensor/Switch "A" Circuit High
P0130	2	O2 Sensor Circuit
P0172	2	System Too Rich - Bank 1
P0183	2	Fuel Temperature Sensor a Circuit High
P0222	2	Throttle/Pedal Position Sensor/Switch "B" Circuit Low
P0303	2	Cylinder 3 Misfire Detected
P0380	2	Glow Plug/Heater Circuit "A"
P0487	2	Exhaust Gas Recirculation Throttle Position Control Circuit

P0 codes are standardised (they have the same definition) and are therefore important for PTI checks. P1 codes are manufacturer specific, so may differ between vehicles. However, they are still valid indicators of an emissions related fault. If the DTCs are stored at service mode 3 of the OBD system then they are relevant for emissions testing. Therefore both P0 and P1 DTCs should be considered. The OBD system offers various service modes as shown in *Table 17.*

Table 17. OBD service modes

Service	Definition
1	Show Current Diagnostic Data
2	Show Freeze Frame Data
3	Show stored Diagnostic Trouble Codes
4	Diagnostic Trouble Codes
5	Test results, oxygen sensor monitoring
6	Test results, other component/system monitoring
7	Show Pending Trouble Codes detected during current or last driving cycle
8	Control operation of on-board component/system
9	Request Vehicle Information

As mentioned earlier, tampering with the ECU could lead to false passes if only an OBD check is performed. Therefore, there is the need for both a physical inspection and tailpipe emissions test in addition to any OBD checks.

4 LABORATORY TESTS

4.1 Free-acceleration test

To investigate specific technical questions, the following measurements were done on 1 diesel and 1 petrol engine vehicle.

4.1.1 Limited maximum engine speed

First issue was the reduced maximum engine speed (cut-off speed) during the smoke test on modern cars. The tested car was fitted with a particulate trap deteriorated by several holes inside the trap. For the vehicle under test it was not possible to disable the engine speed limiter. The vehicle's maximum speed was limited to 2.500 rpm during the free acceleration test. If the vehicle was operated on a 4 wheel dynamometer (i.e. representing real driving conditions) the cut off speed was around 4.000 rpm.

While the measurement was done, engine load was also recorded. *Figure 33* and *Figure 34* show the observed differences which are also tabulated in *Table 18*. Despite the low cut off speed the engine load was not much lower than without the limited speed of the engine. The k value has increased from 0.22 m^{-1} to 0.29 m^{-1}.

Different thresholds (stricter) for vehicle with low maximum engine speeds could be developed to cover these issues.

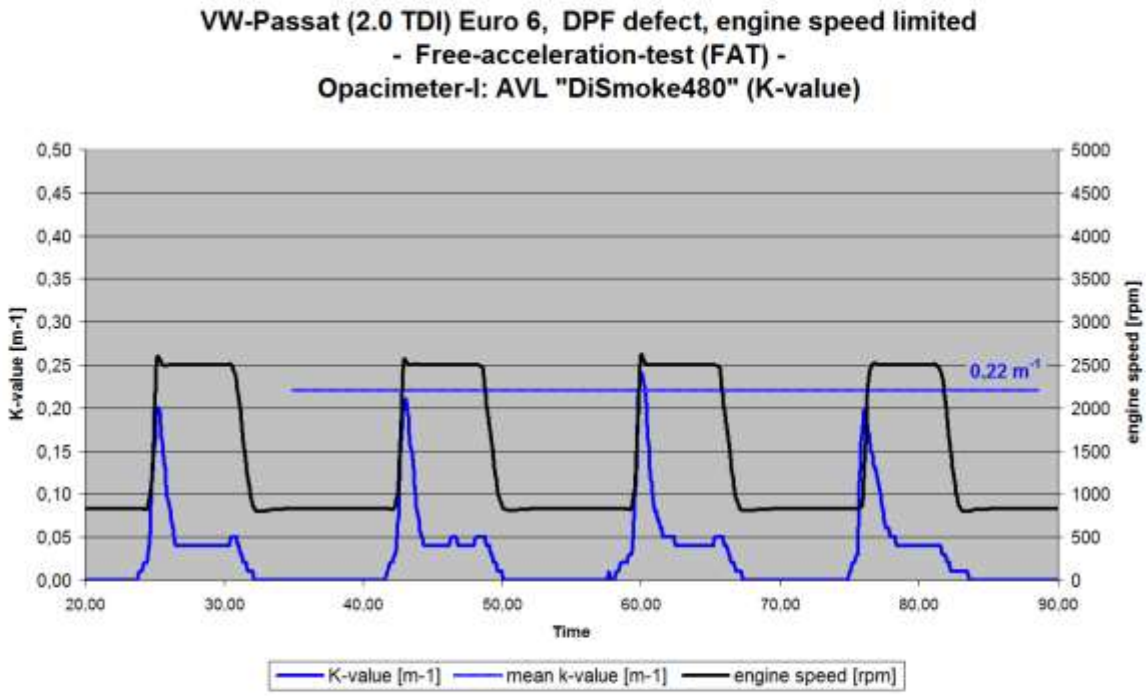

Figure 33. Opacimeter value – with limited engine speed

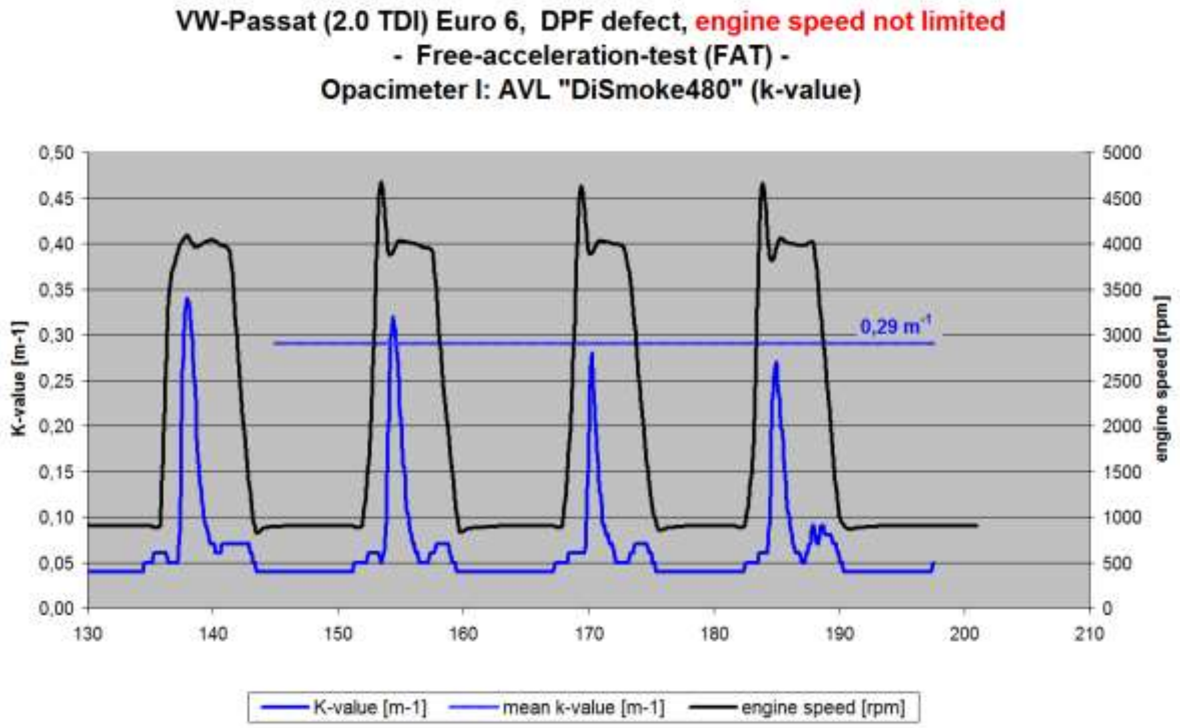

Figure 34. Opacimeter value - without limited engine speed

Table 18: Free-acceleration-Test with the engine speed limited and not limited

		limited (2.500 rpm)	not limited (4.000 rpm)
Engine load (%) by OBD		97%	98%
k-value	Opacimeter I	0.22 m^{-1}	0.29 m^{-1}
k-value	Opacimeter II*	0.23 m^{-1}	0.26 m^{-1}
PM		24.47 mg/m^3	28.17 mg/m^3

*Opacimeter II is a new Opacimeter with higher accuracy and measurement resolution

The tests described above were performed on a vehicle which had a defected DPF fitted to it. After repairing the vehicle these tests were repeated. The results are shown in *Table 19.*

Table 19. Free-acceleration-Test with the engine speed limited and not limited - after repair

		limited (2.500 rpm)	not limited (4.000 rpm)
Engine load (%) by OBD		97%	97%
k-value	Opacimeter I	0.02 m^{-1}	0.03 m^{-1}
k-value	Opacimeter II	0.01 m^{-1}	0.01 m^{-1}
PM		1.14 mg/m^3	1.17 mg/m^3

4.1.2 Effect given by extended acceleration time

Because of the key effect to the engine load, the acceleration time is significant for the overall accuracy of the smoke test. *Table 20* shows the difference changing from 0.4 second to 1.6 second acceleration time while the engine cut off speed is limited to 2.500 rpm.

When simulating vehicle movement (to overcome the engine speed limiter) and performing the same test with a cut off speed at 4.000 rpm, the results are very different as shown in *Table 21.*

The above tests were performed with a defective DPF. After repairs, the same results without the limited engine speed are shown on *Table 22*. The tendency is to lower measurement values if we have a slower acceleration time. But the overall emissions are so low, that we can only see some differences in the PM values using mg/m³ devices.

Table 20. Free-acceleration test (engine speed limited) with fast and slow acceleration – defect DPF

		Fast acceleration (≅ 0.4 Sec.)	Slow acceleration (≅ 1.6 Sec.)
Engine load (%) by OBD		**97%**	**54%**
k-value	**Opacimeter I**	**0.22 m^{-1}**	**0.06 m^{-1}**
k-value	**Opacimeter II**	**0.23 m^{-1}**	**0.03 m^{-1}**
PM		**24.47 mg/m³**	**3.37 mg/m³**

Table 21. Free-acceleration test (engine speed not limited) with fast and slow acceleration – defect DPF

		Fast acceleration (≅ 0.4 Sec.)	Slow acceleration (≅ 1.6 Sec.)
Engine load (%) by OBD		**98%**	**84%**
k-value	**Opacimeter I**	**0.29 m^{-1}**	**0.46 m^{-1}**
k-value	**Opacimeter II**	**0.26 m^{-1}**	**0.56 m^{-1}**
PM		**28.17 mg/m³**	**62.25 mg/m³**

Table 22. Free-acceleration test (engine speed not limited) with fast and slow acceleration – after repair

		Fast acceleration (≅ 0.4 Sec.)	Slow acceleration (≅ 1.6 Sec.)
Engine load (%) by OBD		**97%**	**84%**
k-value	**Opacimeter I**	**0.03 m^{-1}**	**0.00 m^{-1}**
k-value	**Opacimeter II**	**0.01 m^{-1}**	**0.00 m^{-1}**
PM		**1.17 mg/m³**	**0.37 mg/m³**

4.2 Constant speed and load – diesel vehicle

Driving on a light-duty roller performance test bench was done to provide a comparison of the different ways of putting load onto the engine for exhaust emissions measurements – see *Figure 35*. The ASM (Acceleration Simulation Method) was used, with constant loads of 250N and 500 N and vehicle speeds of 20 km/h, 30 km/h and 40 km/h (each for a minimum of 15 seconds).

The roller test bench is very similar to the AM240 and IM Program from US at the late 90`s. The test was done with the same vehicle like used for the other tests. The loads reported by the vehicle's OBD system are shown graphically in *Figure 36*.

Figure 35. Vehicle on the chassis dynamometer

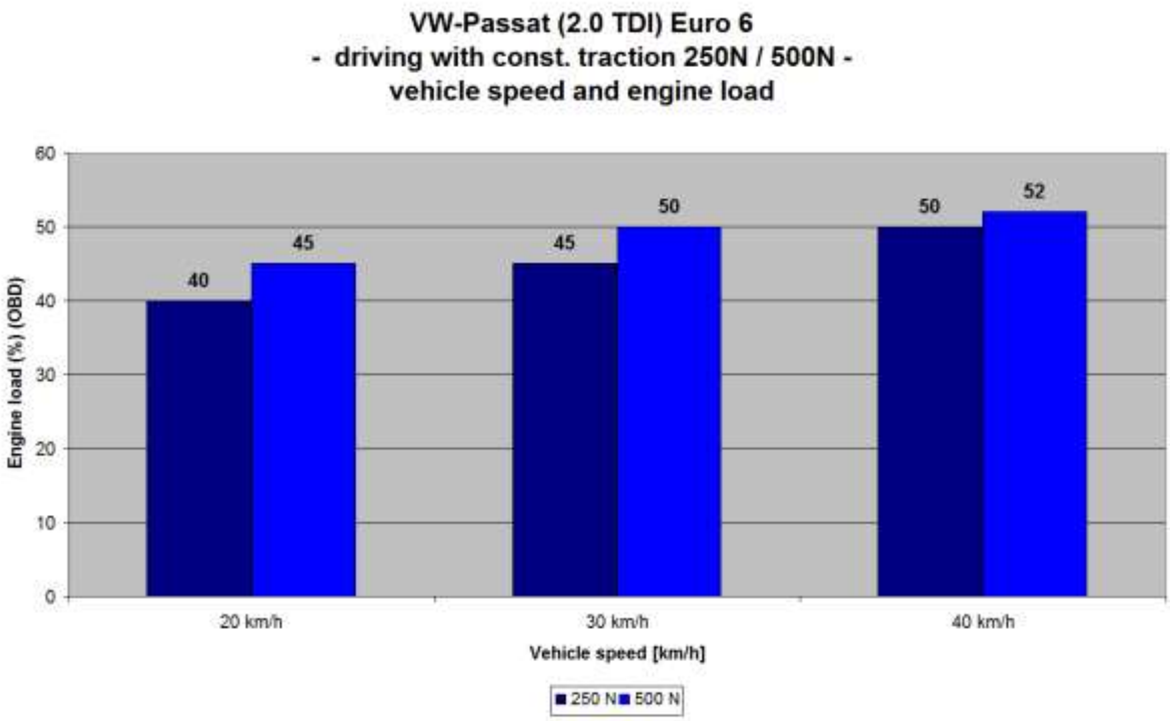

Figure 36. Engine loads reported by the OBD system under the various ASM conditions

The OBD reported engine load and measured emissions are sown in *Table 23*. The engine loads (45% to 52%) are lower than observed earlier for the FAS test (54% to 98%). However the advantage by using the chassis dynamometer is that the load is sustained for a much longer time and is kept stable. The smoke k values are similar for the FAS method.

Table 23. Engine load and emissions at the various vehicles speeds with a load of 500N- defect DPF

Traction 500 N		20 km/h	30 km/h	40 km/h
Engine load (%) by OBD		45%	50%	52%
k-value	Opacimeter I	0.15 m^{-1}	0.22 m^{-1}	0.38 m^{-1}
k-value	Opacimeter II	0.20 m^{-1}	0.29 m^{-1}	0.41 m^{-1}
PM		22.30 mg/m^3	31.79 mg/m^3	45.35 mg/m^3
NO	NDUV	47,9	-*	-*
NO_2		0,32	-*	-*
NO_x		48,3	-*	-*

* technical defect on the measurement device

The results for the vehicle after the defective DPF was repaired are shown in *Table 24*. The stable engine speeds and loads also allow NO_x measurements to be made reliably.

Table 24. Engine load and emissions at the various vehicles speeds with a load of 500N – after repair

Traction 500 N		20 km/h	30 km/h	40 km/h
Engine load (%) by OBD		30 %	38 %	48%
k-value	Opacimeter I	0.00 m^{-1}	0.00 m^{-1}	0.01 m^{-1}
k-value	Opacimeter II	0.00 m^{-1}	0.00 m^{-1}	0.01 m^{-1}
PM		0.11 mg/m^3	0.15 mg/m^3	1.15 mg/m^3
NO	NDUV	17.0 ppm	19.1 ppm	32.2 ppm
NO_2		13.7 ppm	15.2 ppm	19.9 ppm
NO_x		31.3 ppm	34.4 ppm	52.5 ppm

4.3 Constant speed and load – petrol vehicle

Measurements were done on a Euro 4 petrol vehicle, to find a relation between a defective catalytic converter and the CO concentration as well as the mass CO emissions in g/km. In addition, analysis was carried out to feed into the benefit cost analysis, to give an indication of the relationship between CO concentrations and mass emissions.

Measurements were done on a chassis dynamometer, adjusting the different load conditions similar to those used for the type approval test cycle. For the type approval test procedure, the applied force varies as a function of vehicle speed ($F = F0 + F1.v + F2.v^2$). However, for the constant speed tests a number of constant forces have been applied which are similar to the average forces over the type approval test. These measurements provide an approximation to a type approval measurement. The raw exhaust gas was measured as the exhaust gas concentration and also the exhaust mass was measured using a PEMs (Portable Emissions Measurement) device.

The observed relationship is shown in *Figure 37*.

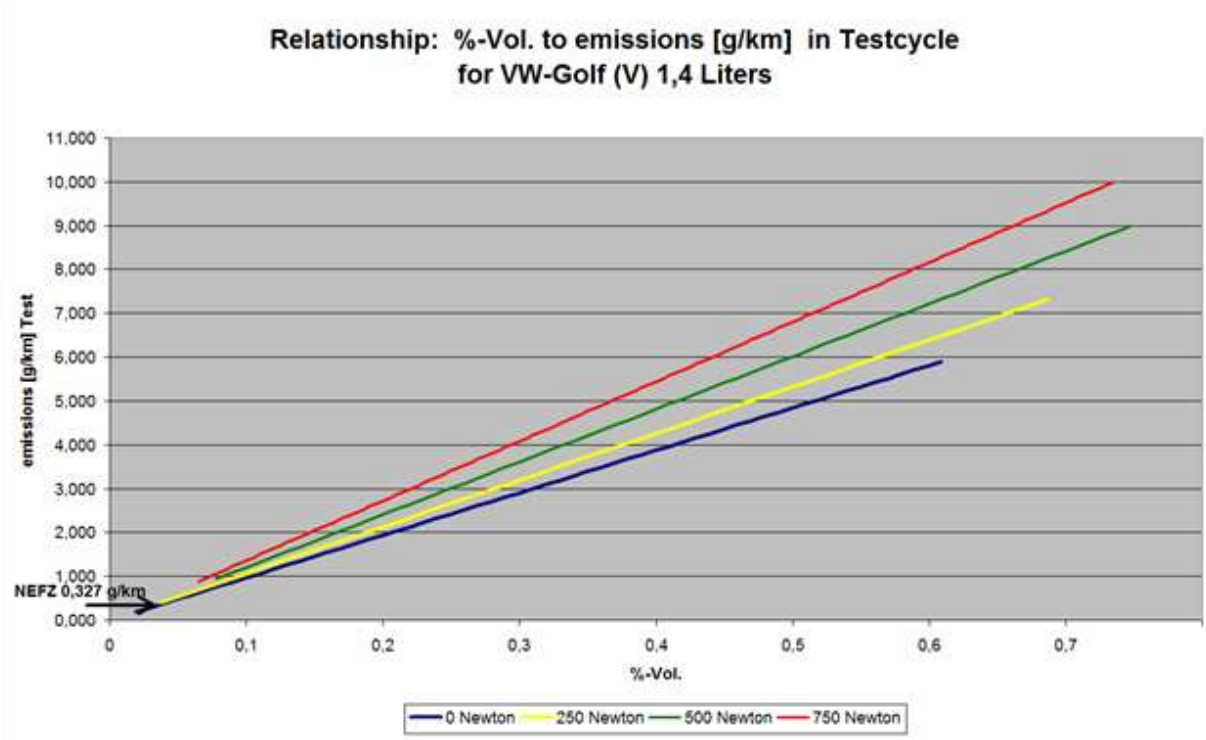

Figure 37. Mass CO emissions relative to CO concentrations

Measurements were carried out over the ASM test with different dynamometer loads applied. The CO emissions were measured with a PEMs device in addition to a standard AVL 4-gas analyser. The mass emissions were measured at the tailpipe. The CO concentration was measured at the tailpipe (to indicate a correctly functioning catalytic converter) and also before the catalyst (engine out emissions) to represent a 100% defective catalytic converter. The resulting emissions are shown in *Table 25*. In addition, the type approval emissions for the vehicle are also included – both over the NEDC and also over the new WLTC.

The results include the ratio between the mass emissions and the CO concentrations. The mass CO emissions at a load of 250 N are similar to the NEDC emissions levels. The vehicle used in the test could be considered an average vehicle. Larger, heavier vehicles would have higher mass emissions and concentrations. Therefore we can assume a mass emission factor of 10.65 g/km per 1% concentration with an accuracy of +/-10%.

Table 25. Comparison of CO mass emissions with CO concentrations over the ASM test

Dyno load N	CO PEMS (tailpipe) g/km	CO concentration (tailpipe) %	CO concentration (engine) %	PEMS - concentration ratio	NEDC (g/km) g/km	WLTC (g/km) g/km
0	0.184	0.019	0.604	9.68	0.327	0.581
250	0.394	0.037	0.675	10.65		
500	0.938	0.078	0.732	12.03		
750	0.884	0.065	0.702	13.60		

4.4 Summary for the laboratory measurements

Engine speed (limited/not limited):

- Modern vehicles with “electronic acceleration pedal” often have a limited maximum engine speed. However, this had only a small effect of the smoke test results.
- The reason for this might be the dependence of load and smoke (PM/k-value). In both cases the engine load is temporary (in “peak”) nearly 100%
- This statement is under the premise that acceleration-time is “fast”

Acceleration Time (fast/slow):

- There is a **big** influence of the acceleration time on the measured value
- The reason for this might be the dependence of load and smoke (PM/k-value). Slow acceleration means less load of the engine.
- It is necessary to have a technically reasonable acceleration-time
- For passenger-vehicles, an acceleration time **much less than 1 second** is optimal. There should be a specified limit

There are still further tests with different vehicles necessary to prove these first findings.

Repaired vehicle with defective DPFs:

Table 26 shows the strong impact of repairing a defective DPF on a diesel vehicle. The k values are between 10 times and 25 times higher on the defective vehicle than with a correctly functioning DPF. These results also show that it is possible to measure the existence of DPFs on vehicles in the fleet, from Euro 5 onwards.

Table 26. Effect on measured smoke and particulate emissions after repair of a defective DPF

	DPF defect limited (2.500 rpm)		DPF repaired limited (2.500 rpm)
Engine load (%) by OBD	97%		97%
k-value Opacimeter I	0.22 m^{-1}	⇐ ≈10x ⇒	0.02 m^{-1}
k-value Opacimeter II	0.23 m^{-1}	⇐ ≈20x ⇒	0.01 m^{-1}
PM	24.47 mg/m^3	⇐ ≈20x ⇒	1.14 mg/m^3

	DPF defect Not limited (4000 rpm)		DPF repaired Not limited (4.000 rpm)
Engine load (%) by OBD	98%		97%
k-value Opacimeter I	0.29 m^{-1}	⇐ ≈10x ⇒	0.03 m^{-1}
k-value Opacimeter II	0.26 m^{-1}	⇐ ≈25x ⇒	0.01 m^{-1}
PM	28.17 mg/m^3	⇐ ≈25x ⇒	1.17 mg/m^3

Comparison of FAS test with chassis dynamometer measurements:

- Dynamometer based tests do not offer much advantage over the free acceleration test for detecting failures when looking at the smoke k values. For NO_x measurement, it might be of advantage to evaluate this kind of loaded test for future solutions.
- When considering the time needed to perform the test, the FAS test is the better choice.

This is only valid when compared to a correctly performed FAS test, with regards the acceleration time and other conditions, like vehicle conditioning and appropriate thresholds for the k values. Roller test benches can support a lot of other benefits if this bench is used for other purposes at the same time, like functional testing of components.

Mass CO emission versus CO concentrations

- Tests were carried out to compare the mass CO emissions (needed for the cost benefit analysis) to CO concentrations (measured during the field trials and used as limits)
- Based on typical vehicle loading, the average value is 10.65 g/km per 1% CO concentration

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4.5 NO_x MEASUREMENT

The constant reduction of the NO_x emission limits imposed by the European type approval regulation have led to vehicle manufacturers offering solutions to reduce emissions at the source point (the engine) or by the use of dedicated systems such Exhaust gas Recycling valve (EGR) or post treatment device (SCR).

The vehicle regulations limit the emissions of NO_x (oxides of nitrogen) - the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrous oxide (N_2O) (greenhouse gas) is not included in the sum.

NO_x have a very strong impact on human health (NO: Hypoxemia, NO_2: irritating to the respiratory tract and on the environment - acid rains, ozone generation, etc.)

NO_x generation occurs during high temperature mechanisms when the nitrogen part of the air is combined with various radical species. Typically this occurs under high engine load conditions.

Solutions for reducing NO_x emissions at the source point consist in trying to block or reduce the formation mechanisms by modifying the chemical and thermodynamic conditions of the gaseous mixture. This goal is achievable by the modification of various engine parameters (injection, internal aerodynamic, etc.), but generally speaking NO_x reduction is achieved by the use of the exhaust gas recycling techniques (EGR: Exhaust Gas Recirculation, IGR: Internal Gas Recirculation).

The EGR’s principle consists to take a part of the exhaust gas flow after combustion and to feed this back into the engine’s intake. This recycling allows:

- the substitution of oxygen from the air by inert gas (CO_2, N_2, H_2O etc.) in order to dilute the combustion mixture within the engine. This will reduce the combustion temperatures and reduce the formation of NO_x
- the limitation of the combustion’s speed by the action of the CO_2 inhibitor

Ideally, the recycled exhaust is passed through a heat exchanger in order to drop their temperature before their injection to the air intake (cooled EGR).

EGR ratio is set in order to match with the maximum amount on each point in order to reach the requirements of the homologation cycle. This is a general trend, but the EGR ratio compromise’s sensitiveness which is variable from one point to another on the engine map.

As the EGR valves are subject to the hot & corrosive exhaust gases, faults can occur over time including:

- Partial or total tightening up of the valve leading to a modification of the optimal EGR ratio having for consequences an higher NO_x emission and associated particulates.
- Loss of thermal efficiency of the heat exchanger leading to a modification of the exhaust temperature before recycling, resulting in higher NO_x emission
- Clogging of the exchanger (frequent start and stop operation) higher NO_x emission

In most cases, these faults affect the NO_x control system before spreading to the diesel particulate filter (DPF) and affecting PM emissions. This means that the identification of a malfunctioning NO_x control system would allow deterioration of the DPF to be prevented.

Two strategies could be considered for vehicle testing:

1. Search for the maximum NO_x emission by loading the engine with the use of a power roller bench (chassis dynamometer) and comparison to an official threshold (which would have to be defined)
2. Check of the functional behaviour of the NO_x control system by comparison of values measured at particular engine conditions

The first strategy requires the use of a chassis dynamometer, which would require a high level of investment in term of equipment and space required.

The second approach is more pragmatic, upgrading the smoke meter equipment associated to an appropriately modified procedure and managing with lower levels of NO_x emission. The sensitivity and response time of NO_x sensor would have to measure a few tens of ppm with rapid variation below 1 second in order to be able to follow, in real time, the NO_x variation during the test.

Measurement under low load conditions is a problem, as little NO_x is produced. If we considered the depolluted area (red zone of *Figure 38*), those variations are extremely low.

EGR action is used only on function points considered by the approval cycle. For functional point with high engine speed and/or high engine load (outside the approval cycle conditions), EGR is not used. Each acceleration generates NO_x emissions of approximately 50 to 100ppm in the area where the EGR is used

There is a direct relationship between NO_x emission level and particulate emission level. Engine design has to balance those two values at the same time and keep them both as low as possible. A pull down strategy focusing only on one of them will automatically increase the other one.

The SET project had provided a good opportunity to test on a large car parc a low level emission test procedure based on specific point of the EGR valve operating area:

- Idle (EGR valve closed)
- Fast idle (EGR valve open).

Additional free acceleration cycles have been performed in order to collect data from this test campaign.

This procedure had been applied to 230 vehicles mixing Euro 4 and Euro 5 types. Test conclusions are available in most of cases, 96% of them, but in 4% data collected was not viable to allow a fair conclusion.

Data examination shows that NO_x values obtained at fast idle were really reliable but the data collected at idle was too dependent on the strategy of the engine management system and were not reliable in some tests conditions. On the other hand, the free acceleration test shows that if the high RPM values are maintained for a few seconds (in order to fully warm up the combustion chamber), then they were a good alternative as values for the Closed EGR status.

The test procedure evaluated during the SET project can be improved by using both values from the tail pipe, even with low emission levels:

- Fast idle (EGR valve open).
- High RPM value (EGR valve closed)

Additionally EOBD real time values, such RPM and air flow, can provide the way to cross check the value expected (by the engine controlling system) and the effective ones (at tail pipe).

The air filling ratio of the engine reflects the EGR valve action, due to the substitution of a part of fresh air from the air intake with the recirculated exhaust gas. This ratio is defined by the following formula:

$$\rho_{filling} = \frac{\dot{m}_{air}\,(kg/h)}{\frac{60 * N(rpm)}{2} \cdot \frac{Cyl(cm^3)}{1E6} \cdot \rho_{air}}$$

Real time

Theoretical

- EOBD physical engine values:
  - **Air Flow ➔ Air Mass Sensor**
  - **RPM**
  - **Engine size**

The procedure is to move on the EGR control map from a fast idle (FI) to a maintained high rpm (FA) as shown in *Figure 38*.

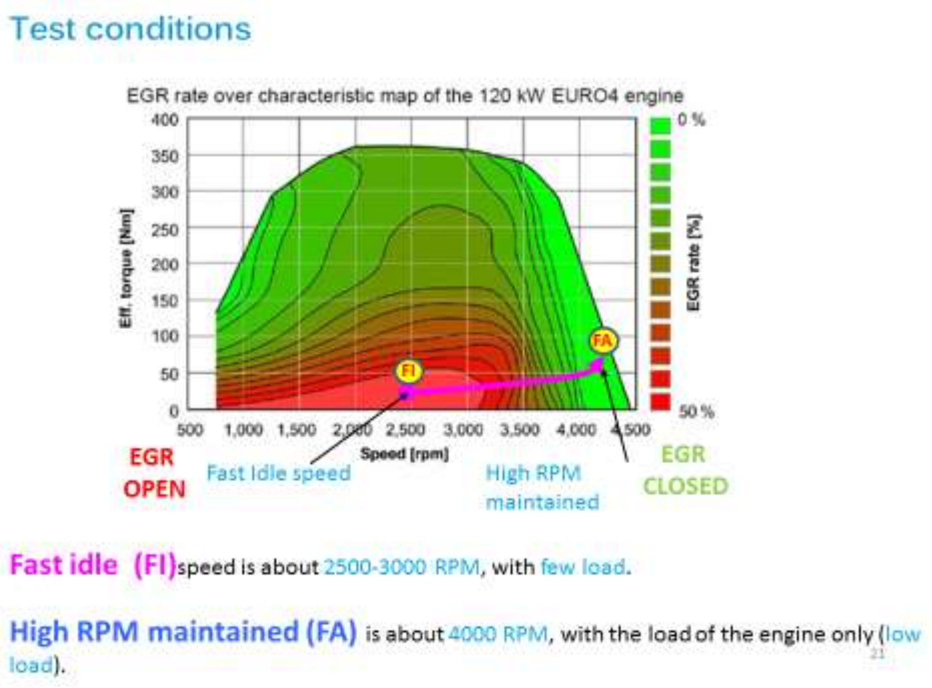

Figure 38. Test conditions
(Source : Institut Français du Pétrole – Energie Nouvelle (IFP-EN))

If the move is done from Fast Idle (FI) to the point High RPM maintained (FA), then, as illustrated in *Figure 39*, the test conditions would move from low left green area to the 2nd green up right. Otherwise the condition will move to a red area, leading a failure in terms of test conclusion.

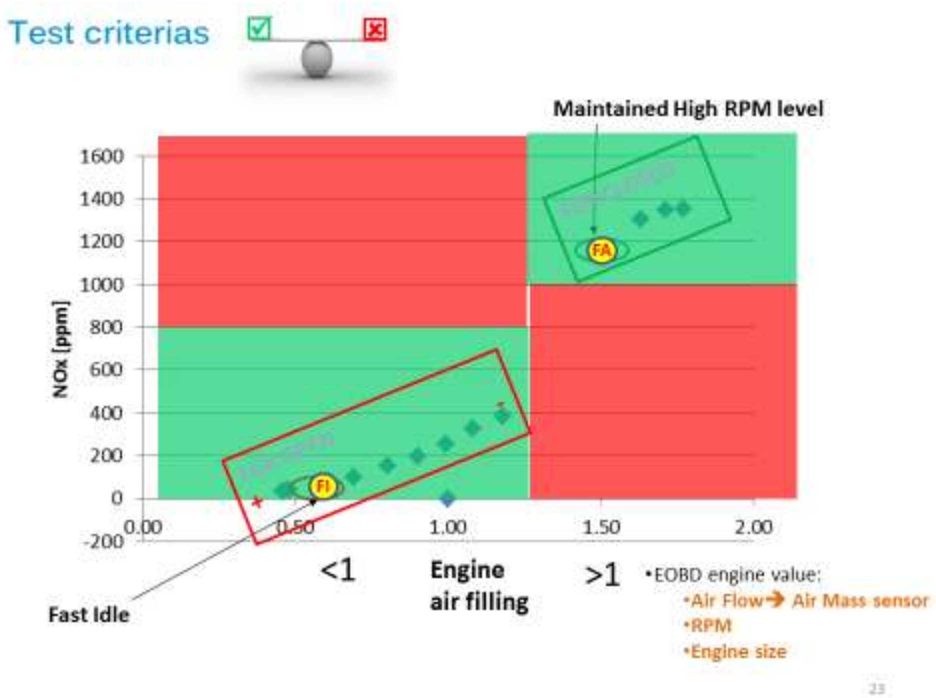

Figure 39. NO_x emission at various conditions

(Source : Institut Français du Pétrole – Energie Nouvelle (IFP-EN))

This test campaign is targeting at a correlation between the type approval test cycle and this PTI test method on various vehicle types:

- Euro 4 vehicles
- Euro 5 vehicles
- Euro 6 vehicle
- Euro 6 vehicle SCR equipped.

With different EGR health status:

- Zero default
- EGR valve blocked open
- EGR valve blocked at 60 % closed
- EGR valve blocked at 80 % closed
- EGR valve blocked at 100 % closed

5 COST BENEFIT ANALYSIS

5.1 Methodology

5.1.1 The Role of Cost-Benefit Analysis

Cost-benefit analysis (CBA) is an accepted and preferable approach for the socio-economic assessment of measures, novel technology or tests. It has already been successfully applied, for instance, for the assessment of new emissions tests for diesel. Its calculation is based on an objective methodology that does not include any subjective weighting schemes.

In consequence, this approach can be considered as suitable for assessing the implementation of new thresholds for emission testing of petrol and diesel vehicles. It assesses costs on the one hand (e.g. cost of implementation, technology costs, etc.).

On the other hand, benefits are calculated as reduction in costs, such as accident costs, time costs, vehicle-operating costs and/or emission costs (for this project, a reduction in emission costs, i.e. the impact of emission savings). By forming benefit-cost ration (BCR) an objective criterion based on the theory of economic welfare is calculated. The ratio follows certain logic:

0 < BCR < 1 poor ratio, socio-economic inefficiency

1 ≤ BCR < 3 acceptable ratio, positive net benefit

BCR ≥ 3 excellent ratio

Figure 40 shows the impact channels of roadworthiness strategies.

It clearly shows that a stepwise approach is chosen for calculating the final benefit-cost ratio. It can lead to a reduction of accident costs, time costs, vehicle-operating costs, emission costs (of relevance here), CO_2 costs, and vehicle-break-down costs. An improved emission testing for petrol and diesel engines can therefore lead to environmental savings. For this background, it is necessary to identify how the current emission situation can be changed by introducing a new emission testing method.

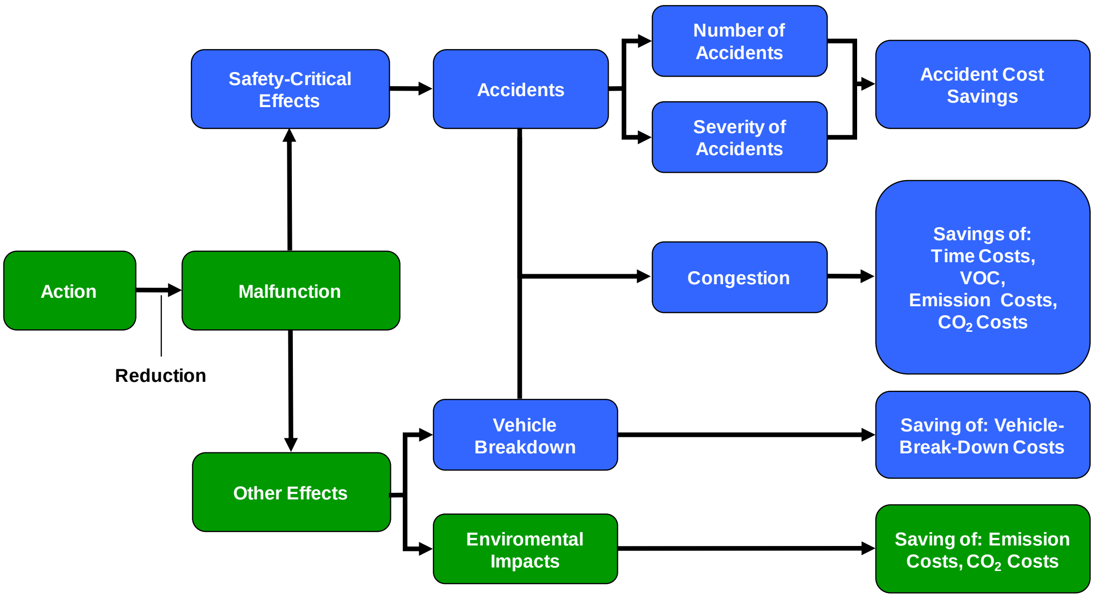

Figure 40. General impact channels of vehicle inspection measures on economic costs

5.1.2 Benefits, Costs and Steps to CBA

As already indicated in the previous introductory chapter, a clear distinction between costs and benefits is indispensable. Benefits are understood in mathematical sense as a positive difference. I.e. in this project it is understood as positive differences in resource costs. Differences are calculated on the basis of a with and without situation. The without situation is usually the current situation, whereas the with-situation defines the new situation in which a new measure, technology, etc. is introduced.

The economic questions is what resource amount had to be used to introduce something new. This resource amount determines the cost-side of the cost-benefit analysis. It is defined as the amount that is needed to change the current situation. This means that the cost-side is determined by actual factor prices for the used amount of resources, whereas the benefit is the result of a difference-calculation.

In order to provide a comprehensive picture of the socio-economic benefit-cost ratio that can be expected from the introduction of new measures (in this case of new thresholds for emission testing and the combination of OBD reading and tailpipe measurement), it is crucial to form comparable dimensions. Therefore, costs and benefits are represented in monetary values.

However, neither taxes nor individual profits are considered within a cost-benefit analysis. It exclusively focuses on socio-economic effects. This also means that car-owner-individual costs are not taken into account (for example resulting from additional repairs). The missing inclusion of individual costs is often used to fundamentally criticise and question the results of cost-benefit analyses. This is because interest groups often claim to keep costs for car-owners as low as possible. An increased detection rate, in turn, would lead to additional costs for car owners as more defects would be detected and more repairs would be required.

However, this argument is a false friend.

Firstly, car owners are by law obliged to keep their car in a functioning condition. This means, not undertaking the relevant repairs leads to a car that does not fulfil the legal requirements. Consequently, it is the car owner's responsibility to pay the costs of guaranteeing the functioning of his car. It must be clear that in the optimal situation, the car owner has full information and is thus informed about the condition of his car at any time. In consequence, PTI or emission testing would not be necessary. However, real world is marked by incomplete information. Most car owners do not have the knowledge or the capabilities to be fully informed about their car. PTI and emission testing is the logical consequence. Repair costs are, thus, not the result of the testing but of the legal requirements for the car. Secondly, an inclusion of the repair costs would lead to an economic misbalance in the calculation of the benefit-cost ratio. This is because the repair costs should then not only be considered as costs for the car owners but also as spending in the industry. It becomes clear that from a general economic point of view, repair costs are only a shift of money from the consumers (=car-owner) to the car repair shops and automotive industry.

The general methodological approach is as follows:

In a first step, a clear definition of the with- and without-case is conducted. “Without” is the current emission testing with the current thresholds and the current way of exhaust emission testing in Europe. “With”, in turn, refers to the new thresholds. Gross polluters are passenger cars with major defects of the emission control system and exceeding the thresholds significantly.

Then, the impact of the new threshold is quantified in terms of additional cars detected. The result is a new detection rate.

In a next step, the calculated detection rates are set into proportion with the development of the vehicle stock. For this purpose, the vehicle stock estimations for 2015 and 2030 as calculated in TREMOVE are used. From the development of the vehicle stock the number of inspected vehicles is derived. It must be mentioned that an increase of cars that have to be inspected are expected to increase over time. This is because vehicles tend to become older. However, with an increase in the average age, the PTI-cycle becomes more frequent. For the number of inspected vehicles the additionally detected cars with exhaust defects are, then, calculated.

In a final step, the resource effects are calculated. These effects are defined as the emission savings resulting from more cars with lower emissions.

Finally, it is assumed that the implementation of a new threshold or the OBD reading comes along with additional costs, such as time or equipment costs. These costs are calculated and then set into proportion to the benefits. This leads to a benefits-cost ratio.

5.1.3 Monetary Evaluation

The execution of European economic costs-benefit analysis orientates itself with the assessment methodology and assessment approaches of the following projects:

- HEATCO, Developing Harmonized European Approaches for Transport Costing and Project Assessment, Deliverable 2, State-of-the-art in project assessment, Stuttgart 2005
- SEiSS (Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles, Study for the Directorate General Information Society), Brussels 2006
- AUTOFORE (Study on the Future Options for Roadworthiness Enforcement in European Union, Study for the Directorate-General for Transport and Energy), Brussels 2007
- eIMPACT (Assessing the Impacts of Intelligent Vehicle Safety Systems, Contract no: 027421, Sixth Framework Programme DG Information Society and Media), Brussels 2008
- Handbook on estimation of external costs in the transport sector. Produced within the study Internalization Measures and Policies for All external Cost of Transport (IMPACT), Version 1.1, Delft 2008, (Maibach 2007, Maibach 2008)
- Ökonomische Bewertung von Umweltschäden, Methodenkonvention zur Schätzung externer Umweltkosten, Dessau 2007
- DIRECTIVE 2009/33/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles

Altogether, this ensures that the calculated results of the economic costs-benefit analysis are comparable with other national as well as European CBA and that these represent the current scientific state-of-the-art.

5.2 Modelling

5.2.1 Calculation Model

Figure 41 presents the calculation model, which consists of three modules:

- The first module is the vehicle and engine measurement calculation procedure. Based on findings of the other SET work packages, it is determined which kind of defaults can be additionally detected by the new testing methods
- The second module is the vehicle stock module. Here the numbers of investigated diesel euro 4 cars, diesel euro 5 cars, petrol cars Euro 3, petrol cars Euro 4 and petrol cars Euro 5 for EU-28 are calculated. Further the vehicle kilometres on an average basis for diesel cars and petrol cars are determined on the basis of the country specific diesel car shares, and also on the country specific total vehicle kilometres. The vehicle stock is based on the European TREMOVE-model (http://ec.europa.eu/environment/air/pollutants/models/tremove.htm). TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the transport sector for all European countries
- The third module covers the resource effects. Emission factors, toxicity factors and cost unit rates are used to calculate the monetary values of the emissions. This module is based on the DIRECTIVE 2009/33/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles

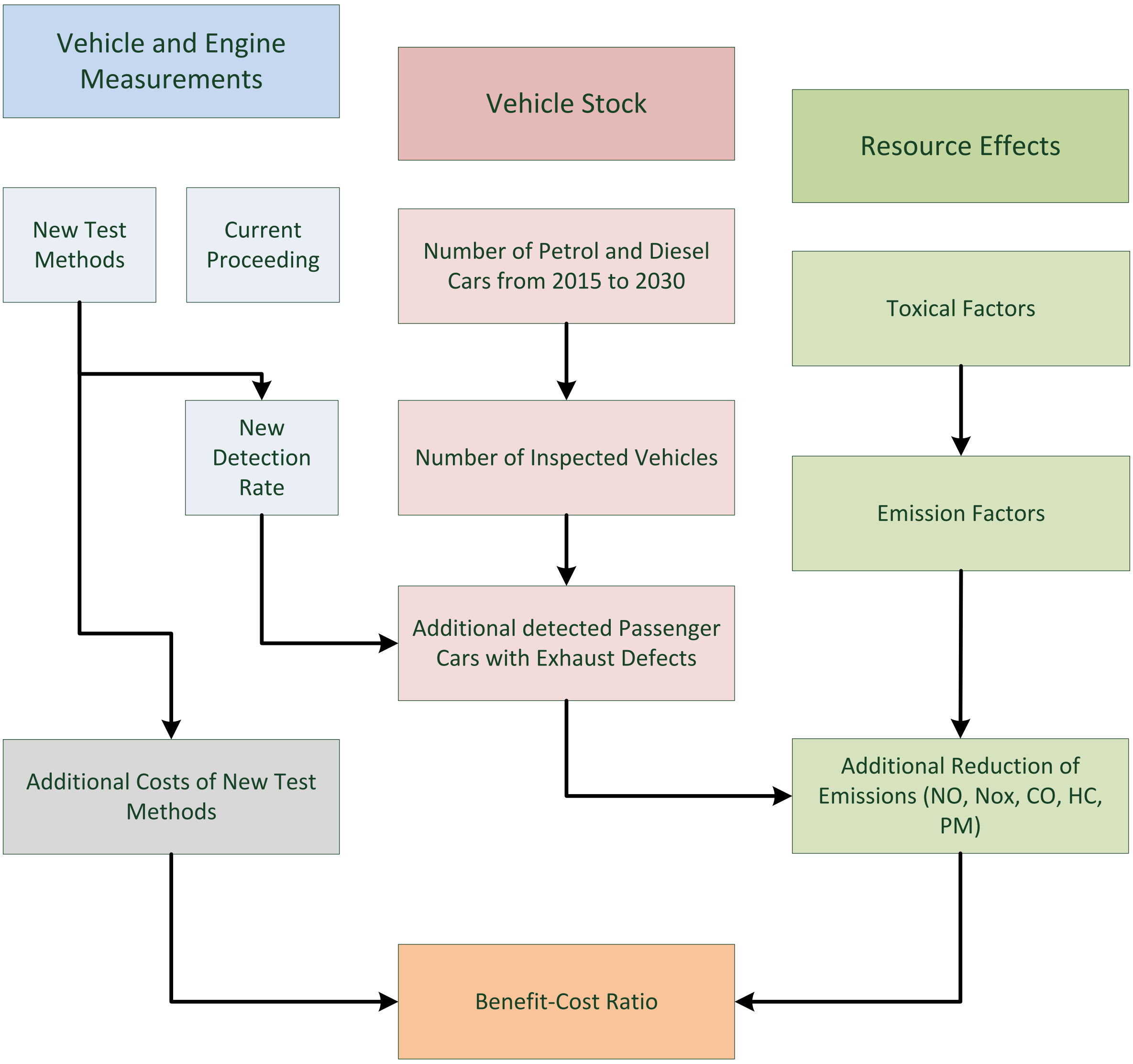

Figure 41. Calculation Model

It must be mentioned that only resource effects are calculated for this model. Safety and traffic related effects are not relevant in this case.

5.2.2 Vehicle Stock

Table 27 shows the vehicle stock of diesel and petrol cars in EU-28.

Table 27. Development of the vehicle stock (passenger cars) for the time period from 2015 to 2030

Year	Total Passenger cars	Total Petrol	Petrol Higher than Euro 3	Diesel Total	Diesel Euro4	Diesel Euro5
2015	249,477,960	143,830,976	107,209,872	105,646,984	18,597,783	38,519,607
2016	252,568,226	143,752,614	111,171,895	108,815,612	17,294,118	37,487,710
2017	255,658,493	143,674,253	115,133,918	111,984,240	15,990,453	36,455,813
2018	258,748,759	143,595,891	119,095,941	115,152,868	14,686,788	35,423,916
2019	261,839,027	143,517,530	123,057,964	118,321,497	13,383,123	34,392,019
2020	264,929,293	143,439,168	127,019,986	121,490,125	12,079,458	33,360,121
2021	267,785,701	144,067,660	129,550,872	123,718,041	10,726,581	30,641,776
2022	270,642,110	144,696,153	132,081,759	125,945,957	9,373,704	27,923,431
2023	273,498,518	145,324,645	134,612,645	128,173,873	8,020,827	25,205,085
2024	276,354,928	145,953,138	137,143,532	130,401,790	6,667,951	22,486,740
2025	279,211,336	146,581,630	139,674,418	132,629,706	5,315,074	19,768,394
2026	282,074,896	147,550,369	141,376,542	134,524,527	4,784,572	17,513,547
2027	284,938,456	148,519,108	143,078,666	136,419,348	4,254,070	15,258,700
2028	287,802,016	149,487,847	144,780,790	138,314,169	3,723,567	13,003,853
2029	290,665,577	150,456,586	146,482,914	140,208,991	3,193,065	10,749,006
2030	293,529,136	151,425,324	148,185,038	142,103,812	2,662,562	8,494,158

Source: Based on TREMOVE Model version 3.3.2, Brussels 2010 (www.tremove.org); own calculations

Figure 42 illustrates the fleet development:

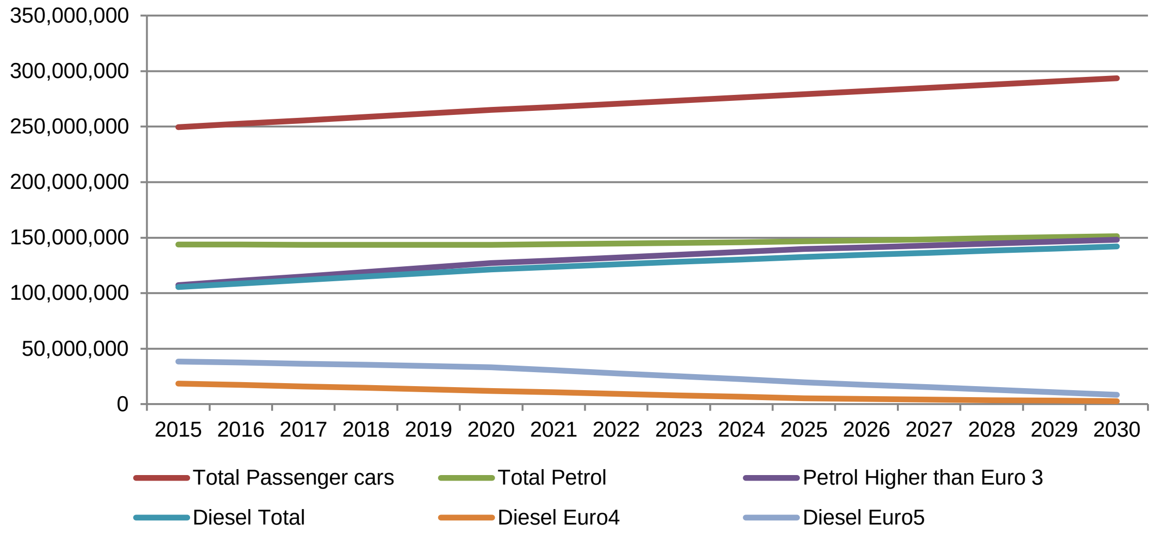

Figure 42: Development of the vehicle stock according emission classes

The annual average kilometres are derived on basis of the TREMOVE Model:

- Petrol cars have on average 9,828 vehicle-km per year.
- The average annual kilometres of a diesel car are 21,878 km.

5.2.3 Resource Effects

Resource effects were measured in test series. A variety of test situations were created in order to fully capture the resource effects resulting from a change in the threshold. For the measuring exhaust emission tests, OBD tests and a combination were conducted.

Table 28: Overview of the tested vehicles

	Total number of vehicles	Total number of vehicles - Euro 4	Total number of vehicles - Euro 5
Petrol	1374	818	435
Diesel	1654	1052	464
Total	**3028**	**1870**	**899**

Table 29, the tested effects of a new threshold can be seen as an overview. These data served as input for the later benefit calculation.

Table 29: Tested effects of a change in threshold differentiating exhaust emission tests and a combination with OBD

	Total tested vehicles	State of threshold	Threshold	Vehicles failing by exhaust emissions testing	Total number of failed vehicles (%) by exhaust emission testing	Number of vehicles with DTC	Additional number of vehicles failed by OBD	Share of failed vehicles (%) by OBD testing	Total number of failed vehicles	Share of failed vehicles (%)
All petrol - CO high idle (%)	1374	old	>0.2	51	3.71	63	51	4.6	102	7.42
	1374	proposed	>0.1	88	6.40	63	50	4.6	138	10.04
Petrol EURO 5 - CO high idle (%)	435	old	>0.2	19	4.37	12	9	2.8	28	6.44
	435	proposed	>0.1	35	8.05	12	9	2.8	44	10.11
All petrol - CO idle (%)	1374	old	>0.3	30	2.18	63	55	4.6	85	6.19
	1374	proposed	>0.2	42	3.06	63	54	4.6	96	6.99
Petrol EURO 5 - CO idle (%)	435	old	>0.3	13	2.99	12	10	2.8	23	5.29
	435	proposed	>0.2	17	3.91	12	9	2.8	26	5.98
Diesel EURO 5 - k-value (m^{-1})	464	old	>1.5	6	1.29	14	14	3.0	20	4.31
	464	proposed	>0.2	43	9.27	14	10	3.0	53	11.42
Diesel EURO 4 - k-value (m^{-1})	1052	old	>1.5	153	14.54	154	114	14.6	267	25.38
	1052	proposed	>1.0	243	23.10	154	100	14.6	343	32.60

It can directly be seen that an decrease of the threshold, e. g. of CO Vol. from 0.2 % to 0.1 %, or the combination of OBD-reading and tailpipe measurement directly leads to an increased number of vehicles that are detected with insufficient emission standards. As a consequence, it can be concluded, the more cars are detected as not fulfilling the standards, the more cars have to improve and adapt their standards. The consequence is reduction in the emissions which is discussed in the next chapter. Additionally, it has to be taken into account that a reduction of CO-values also goes along with a reduction of a number of further emissions: NO_x, HC and PM.

The calculation approach for the actual emission savings resulting from the increased number of detected vehicles is explained in the next section.

For calculating the emission effects, it is necessary to differentiate two kind of vehicles: normal cars (i.e. cars that are within the legal emission threshold) and gross polluters (i.e. cars that exceed the legal threshold). Especially the calculation of emission effects is two folded because of the data availability:

- The emission effects due to detecting cars with defects of the exhaust system for diesel cars can be empirically based on the results of the TEDDIE-Study
- Unfortunately, comparable empirical results for petrol cars did not exist until now. However, based on the European Commission 2012 related relations it is possible to quantify on an average basis for emission difference between a normal petrol car and a gross polluting car

To derive the quantities of NO_x, HC and CO emissions for normal diesel cars emission factors are used:

- The emission factor for NO_x is 0.0845 g per km
- for HC the emission factor has the value 0.0663 g per km
- the emission factor for CO is 0.9808 g per km

The typical emissions for petrol cars are shown in *Table 30*.

Table 30. Additional emissions by petrol cars due to emission defects

	Empirical measured emission factors for petrol cars in g/km		
	CO	**NOx**	**THC**
without exhaust defects	0.9808	0.0845	0.0663
with exhaust defects	6.2000	0.53235	0.41769
Emission factor for additional emissions by petrol cars with exhaust defects	5.2192	0.44785	0.35139

Source: European Commission 2012; own calculations

The emissions of CO, HC, and NO_x are transformed by toxicity factors into NO_x equivalents. The toxicity factors are: HC 1.5; CO 0.003; NO and NO_2: 1. The emission factor used for PM is 0.00303 g per km (TEDDIE 2011).

From experience, it can be said that around 5% contribute to 25% of all CO-emissions. In turn, 95% of the cars cause 75% of all CO-emissions (European Commission 2012).

From this the following general equation for the calculation of emissions can be derived:

$$number\ of\ cars\ [C] * weighting\ factor[WF] * emission\ factor[EF] * residual\ \ variables[R] = share\ of\ emission[SE] * emissions[E]$$

Inserting the values for normal cars, the following is the result for the CO-emissions:

$$(1) \qquad C * 0.95 * 0.9808 * R = 0.75 * E$$

0.9808, hereby, reflects the emission factor resulting from normal cars.
For gross polluters, the equation has this form:

$$(2) \qquad C * 0.05 * X * R = 0.25 * E$$

X in this case is a representative for an unknown emission factor. It, therefore, shows the factor that is emitted by cars that exceed the legal threshold. The transformation of (2) gives the following equation for the calculation of X:

$$(2.1) \qquad X = \frac{0.25}{0.05} * \frac{E}{C * R}$$

To reduce the number of unknown variables, equation 1 is transformed to:

$$(1.1) \qquad E = \frac{C * 0.95 * 0.9808 * R}{0.75} \rightarrow E = 1.24 * C * R$$

And inserted in (2.1):

$$(2.2) \qquad X = \frac{0.25}{0.05} * \frac{1.24 * C * R}{C * R} = 6.2 g/km$$

An elimination of the number of cars and the residual variable in nominator and denominator results in an emission factor of 6.2 g/km for gross polluter cars. Additional measures by DEKRA have shown that the emission factors for CO in g/km are directly correlated with a factor of around 10 to the volume percent values, which are measured to prove the derivation of the threshold values.

For diesel cars the emission factors due to exhaust defects, shown in *Table 31*, are used:

Table 31: Additional emissions by diesel cars due to exhaust defects

	Empirical measured emission factors for diesel cars in g/km			
	CO	**NOx**	**THC**	**PM**
without exhaust defects	0.09654	0.134000	0.001978	0.000365
with exhaust defects	0.301835	0.446355	0.046745	0.043358
Emission factor for additional emissions by diesel cars with exhaust defects	0.205295	0.312355	0.026965	0.042993

Source: Schulz, W.H., Weitz, K.-U., TEDDIE: A new roadworthiness emission test for diesel vehicles using NO/ NO_2, Work package 6: Cost-Benefit Analysis, Brussels 2012

5.3 Benefits

After now having quantified the resource/emission effects of the implementation of a new threshold and the combination of OBD reading and tailpipe measurement, in the next step the quantified effects are monetised. In consequence, so called cost-unit rates are needed.

For the calculation of benefits following cost unit rates for 2015 are used:

- NO_x -Equivalent: 5,096 Euro per ton
- PM: 100,777 Euro per ton

The costs for emissions in road transport are based on the EC-Directive 2009/33. In accordance to the Directive, the cost unit rates given by the Directive were adapted to inflation by using the Harmonized Index of Consumer Prices (HICP). For the time period 2007 to 2015 the average price increase is 2.0% per year.

Some assumptions of the TEDDIE-study are relevant for the calculation of emission effects in this study

- The empirical data on the emission reductions, which can be reached, is derived for five vehicles. These five vehicles can be considered as representative for the European car fleet of diesel vehicles. It is stated that vehicle 1 represents 40% of the European diesel passenger car fleet, vehicle 2 30%, vehicle 3 10%, vehicle 4 10%, and vehicle 5 10%
- The vehicles were selected to guarantee that the response of the vehicles to faults would be broadly representative of Euro 4/5/6 technologies

- The emission of CO, HC, NO and NO_2 are transformed by toxicity factors into NO_x equivalents. The toxicity factors are: HC 1,5; CO 0,003; NO and NO_2: 1
- Positive values represent emission savings. Negative values are the result of side-effects, which lead to an increase of emissions. Some defects have an unexpected side-effect that due to the defect some kind of emissions will reduced. However, other emissions increase

Based on the vehicle stock developments until 2030 the number of inspected vehicles was predicted. This prediction served as basis for the extrapolation of the number of vehicles detected with the old respectively the new threshold and OBD-testing. This was then transformed into emission savings based on the calculation shown in the previous chapter.

In the next step, the in advance presented cost-unit rates are applied and benefits can be calculated. For the benefit calculation two methods of testing are differentiated: simple exhaust emission testing and a combination with OBD-testing. "Old EM" refers to the current test procedure and limits whereas "New EM" refers to the new thresholds.

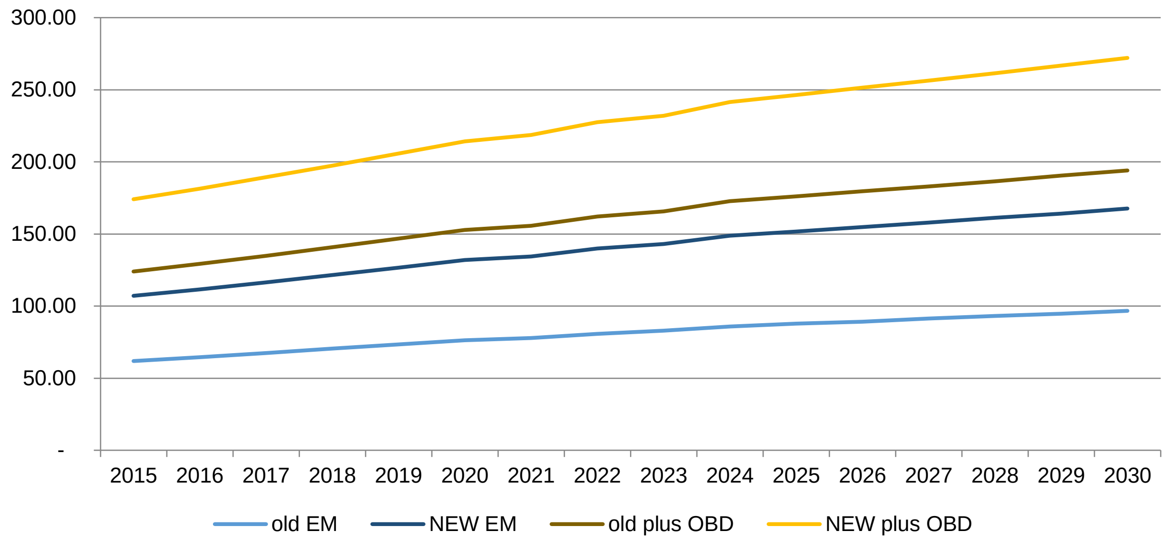

Figure 43. Development of the benefits in million Euros with old and new thresholds for petrol vehicles

An upwards trend over time can be clearly identified for all benefits. Nevertheless, the calculation also reveals that the introduction of a new threshold definitely leads to higher benefits than a situation with the current threshold.

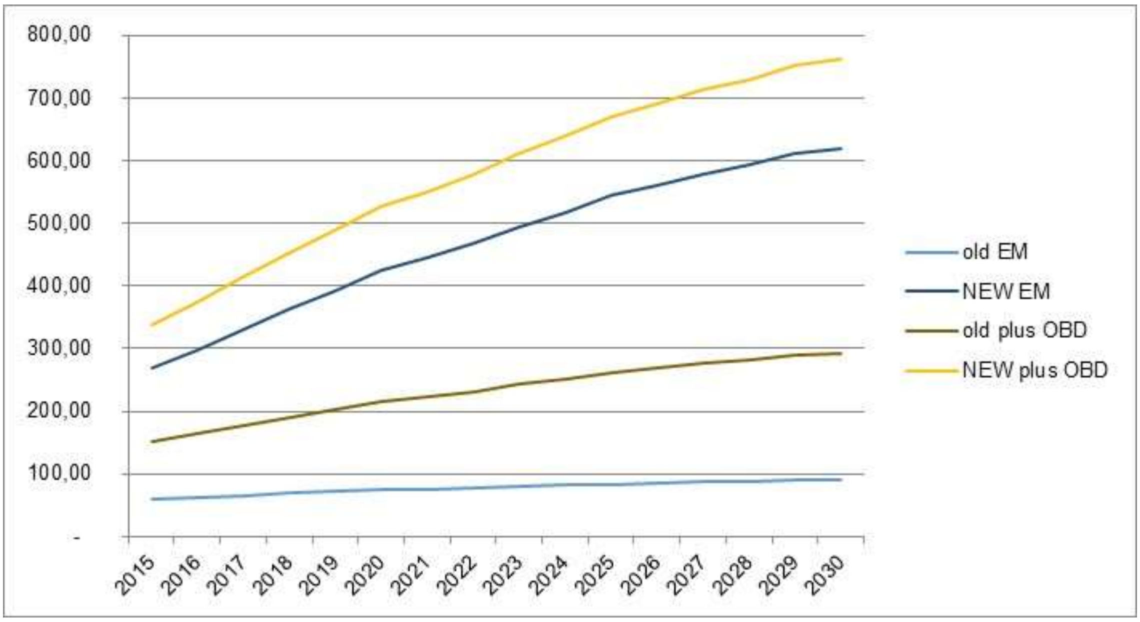

Figure 44. Development of the benefits in million EUR with old and new thresholds for diesel vehicles

Also for diesel vehicles an increase in the benefits due to more restrictive thresholds can be found. However, two differences compared to the benefit results of the petrol vehicles have to be pointed out:

First of all, the benefits from diesel vehicles are generally a lot higher and the increase is even graver. Secondly, it can immediately be seen that for diesel vehicles the benefits decline over time. This can easily be explained by the development of the vehicles stocks. Whereas an increase in petrol cars is assumed until 2030, for diesel vehicles, in turn, a strong decline is predicted. This has, of course, effects on the absolute benefits in million Euros.

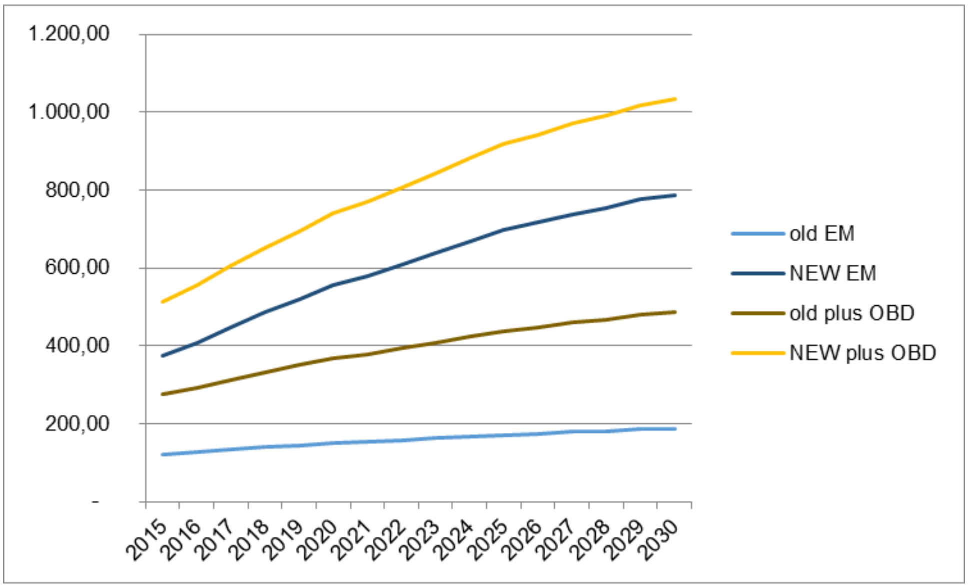

Figure 45. Development of the total benefits in million Euros with old and new threshold

5.4 Costs

The cost-side is assumed to be relatively small as no additional technology is included. The chosen threshold of 0.1% CO for petrol vehicles and 1,0 m^{-1} k-value (Euro 4) respectively 0,2 m^{-1} k-value (Euro 5) for diesel vehicles is still feasible with the current technology of measurement equipment. This only shows that up to now, emission testing does not fully use the potential of the technology.

However, additional labour costs are to be expected as a mandatory combination of OBD reading and tailpipe measurement comes along with additional inspection time.

Based on estimations from DEKRA, TÜV SÜD and CITA, it can be said that a testing procedure with additional exhaust emission testing requires in average 300 seconds extra in Germany, Netherlands and Sweden, (17% of all in Europe inspected vehicles) where nowadays the OBD reading is normally sufficient. The mixed procedure (exhaust emission testing and additional OBD reading) requires up to 120 seconds extra in all other European Member States (without Germany, Netherland, Sweden). As hourly labour cost-rate for the EU28 an average resource based wage* of 24.6 Euro per hour is used (Eurostat 2015). The testing with OBD requires additionally an OBD unit. The costs for one OBD unit are 750 Euro in average. The depreciation period is set to 5 years. Following the TEDDIE-study the number of needed OBD Unit for Europe is assumed to be 80,000. *Figure 46* shows the development of the costs for both different emission testing types up to 2030.

*the average wage represents only the resource costs, it does not contain any kind of taxes or social costs (e.g. payroll taxes, church tax, social insurance contributions, health insurance, pension fund)

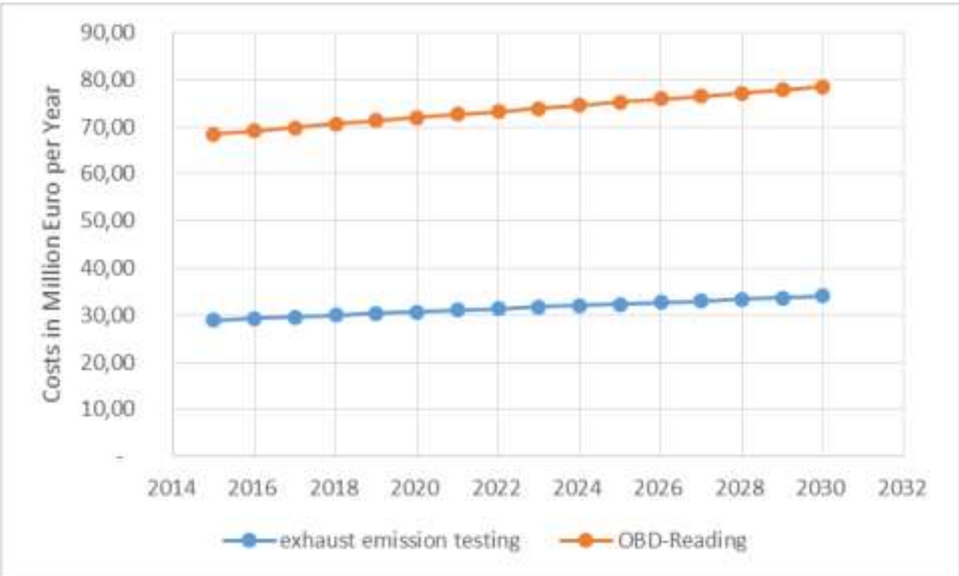

Figure 46. Development of costs in million Euros for additional exhaust emission testing and additional OBD-reading

5.5 Benefit-Cost Results

As argued in the previous section, four testing procedure of exhaust emission testing are considered.

Figure 47 shows that the benefit-cost ratio is excellent for all years. It starts with a very high ratio and increases over time.

It has to be said that the ratio now shows a much lower BCR for testing processes that include the OBD-testing. This is a result of the higher inspection costs (due to more time and equipment). Nevertheless, it must be clearly stated that the ecological benefits are significantly better. If the additional 120 seconds for OBD-testing could be reduced, for example by a standardisation of the testing procedure for all countries, the BCR would improve.

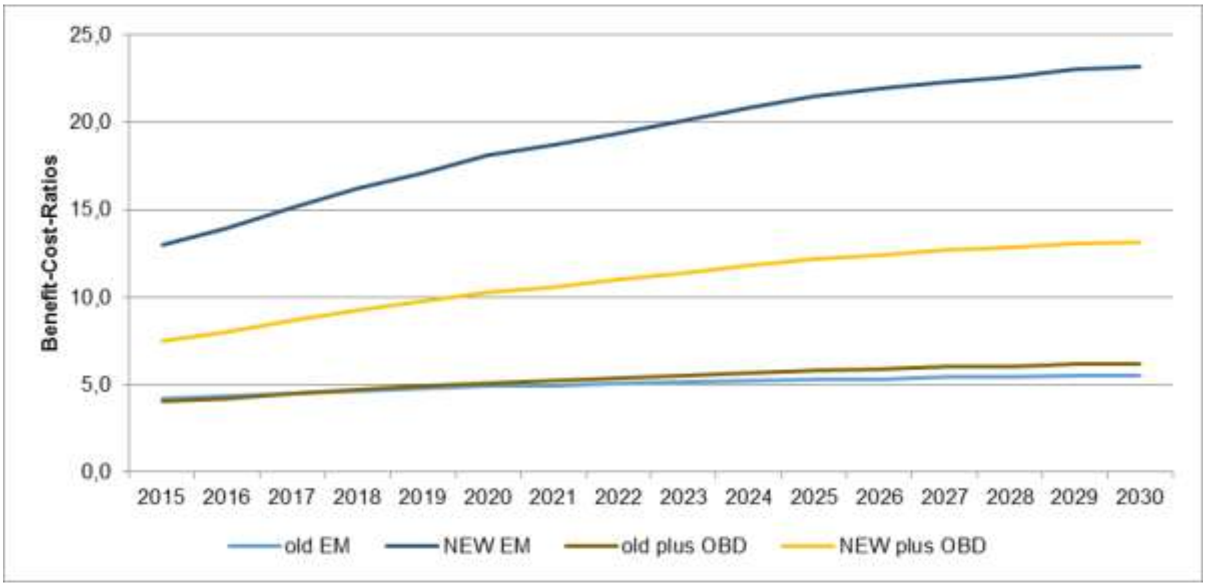

Figure 47. Development of the Benefit-Cost-Ratio

6 SUMMARY AND RECOMMENDATIONS

It is important to ensure that vehicles on European roads are maintained to a high degree of technical roadworthiness, taking into account the latest developments in vehicle and measurement technology, and the need for economically viable solutions. For modern-technology vehicles and engines with OBD, and after-treatment systems such as exhaust gas recirculation (EGR), diesel particulate filters (DPFs), selective catalytic reduction (SCR), etc., there is a need to improve the regulations which apply to the Periodic Technical Inspection (PTI). The specific aim of this study was to investigate the possibility of defining an improved test procedure for the measurement of particulate matter (PM), to be included in PTI tests for modern diesel cars with different types of exhaust after-treatment system. In addition, an improved test has been investigated to measure CO emissions from modern petrol cars.

The aim of the SET study was to follow up the TEDDIE study with a large scale measurement (field tests) including petrol vehicles in different Member States:

- Comparison of OBD read out (fault codes, RC Status, status information) versus the tailpipe emission test (CO, k values for PM)
- Definition of suitable thresholds for PM-measurement devices (m^{-1}; mg/m^3) for diesel vehicles, taking into account, accuracy of measurement devices as well as the level of gross pollutants today
- Definition of new thresholds for CO measurement, taking into account, accuracy of measurement devices as well as level of gross pollutants today
- Compiling a precise recommendation including a cost-benefit analysis for the European Commission to adjust the PTI directive

Field trials were performed at 16 test stations located in various EU Member States: Belgium, France, Germany, The Netherlands, Spain and Sweden. A test procedure was developed for these field trials which included tailpipe measurements and also a check on the OBD system for both petrol and diesel vehicles. MAHA, Capelec and AVL provided dedicated test equipment specifically for the field trials which had been programmed with the SET test procedure.

A centralised training session was held in Brussels, hosted by GOCA & CITA, on 11 June 2014. The aim of this training session was to ensure that all the tests at all the different test centres would be performed in the same way. MAHA, Capelec and AVL all provided test equipment programmed with the SET test procedures plus one or more personnel to carry out the training. GOCA also provided some vehicles to perform tests on.

By the end of November 2014, the test results from over 3,000 tests had been submitted for analysis. This comprised of 1654 diesel tests and 1374 petrol tests. The majority of vehicles were Euro 4 and 5 together with some Euro 3 vehicles and a few Euro 6 vehicles.

For petrol vehicles, there was little variation by Euro standard, showing that a common limit could be used for all classes. It also showed that lower limits could be applied to Euro 3 vehicles onwards to detect faulty vehicles.

For the diesel vehicles, there was a distinct difference between the Euro 4 and Euro 5 results. For Euro 4 vehicles, some were equipped with DPF while others were not. Therefore, the limits should be set dependant on whether the vehicle is fitted with a DPF or not. Euro 5 diesel vehicles are normally equipped with a DPF. However, the current limits according to 2010/48/EC are too high.

The effect of the distance driven by the vehicle (i.e. odometer reading) appeared to have no effect on the CO emissions for petrol vehicles. There did appear to be a relationship for diesel vehicles – the higher the distance covered the higher the smoke emissions which could indicate worn out components as well as by defective particulate traps. Age also showed no clear effect on CO emissions from petrol vehicles when looking at the entire data set. However, five vehicles under three years old (of which, four had covered less than 50,000 km) had extremely high emissions (one over 6% CO) which distorted the results. When these five/four vehicles were removed from their particular dataset, there was a clear increase in fast idle CO emissions with vehicle age and with the kilometres the vehicle had covered. For diesel vehicles, there was also a clear correlation between smoke k values and vehicle age.

An issue investigated was the effect of the acceleration time (rising time) during the FAS test on the smoke k values. Some of the acceleration times were very long (over 3.5 seconds). It was noted that acceleration times above 2 seconds lead to lower k values.

Another area investigated was the maximum engine speed. The FAS test relies on the engine being revved up to its maximum engine speed. A speed limiter prevents excessive engine speeds being reached under normal driving to avoid damage to the engine. However, some of the vehicles tested had a much lower than the normal maximum engine speed during the FAS test. This was much more common on modern Euro 5 vehicles. Lower engine speeds during the test could result in lower loads being applied to the engine producing lower emissions.

In addition to measuring smoke, some of the analysers were also equipped with PM measurement using a laser light scattering (LLS) technique. The PM values showed agreement with the smoke k values measured at the same time. These devices would be capable of measuring very low concentration should greater precision be required in the future.

One of the most important issues for the SET study was to have within one test procedure the full overview on all relevant data concerning tailpipe measurement together with OBD scanning. Of all the vehicles tested only 14 (0.46%) had their MIL illuminated, although 41 (1.35%) had their MIL status set to “On”. 244 vehicles (8.06%) had one of more DTC stored.

Comparing the results from the different MS showed that in MS where OBD scanning is already performed and affecting the pass/fail decision, the percentage is lower than in MS were OBD is not used within the inspection.

However, for both petrol and diesel vehicles there was no correlation between DTCs and tailpipe emissions. The best fault detection rate was observed when both the tailpipe result and the OBD scan were performed. The most frequent DTC was the misfire codes (P1351). This was found on 58 petrol vehicles. For standardised OBD functionality, only P0 codes are required, but in practice most of the OEM`s also use P1 codes. For diesel vehicles P0670 Glow plug module control circuit was the most common fault (35 vehicles).

A limited number of tests were performed in the laboratory to investigate the engine speed limiter problem and acceleration time during the FAS test. With a lower maximum speed, a lower smoke k value was obtained (0.22 m^{-1} compared to 0.29 m^{-1}). However, using a slower acceleration produced a much greater effect – 0.22 m^{-1} compared to 0.06m^{-1}. This shows the importance of the acceleration time. Further tests are necessary to prove these findings.

The laboratory test also looked at the usefulness of chassis dynamometer based tests. The results obtained for smoke showed little advantage compared to a FAS test. However, a dynamometer test might be useful for applying constant load to a vehicle in order to measure NO_x, although a large investment would be needed.

A cost benefit analysis was performed on the proposed SET test procedure. This was based on the time taken to perform the tests and the additional faulty vehicles detected and repaired. The equipment needed was assumed to be as currently used apart from the addition of OBD scan tools. This was applied to the European fleet. The benefit-cost ratio for the new testing procedure (combination of OBD-reading and tailpipe measurement including new thresholds) starts with approximately 8 and increases up to 13 in 2030.

The analysis shows that the benefit-cost ratio (BCR) is excellent for all years.

6.1 Recommendations

This project has arrived at a number of recommendations

- There is no clear correlation between an emissions test and OBD check for ether petrol or diesel vehicles. It is therefore recommended that for Euro 4 or later vehicles, both an emission test and an OBD check should be performed.
- For petrol vehicles:
    - For Euro 3 vehicles, the current limit is suitable
    - For Euro 4 or later vehicles, a revised limit of 0.1% CO should be used for the fast idle test
    - A stricter of limit of 0.05% CO could be introduced for Euro 4 or later vehicles, but some Member States might require new equipment to test to this level
    - The current limit is suitable for the natural idle test
- For diesel vehicles
    - For Euro 3 vehicles, the current limit is suitable
    - For Euro 4 vehicles, because some are fitted with DPFs whereas other are not, the limit should be the plate value, but maximum 1.0 m^{-1}
    - For Euro 5 or later vehicles, a general limit is practical to apply to all diesel vehicles. It is recommended that a limit of 0.2 m^{-1} is used in the future
- During the OBD test, any vehicles with a "P0…" DTC should fail the test. Some trouble codes might only affect cold-start emissions (e.g. glow plug function) which would not show up in a free acceleration test. But it is still important that these vehicles are rectified to avoid excessive cold start emissions
- Introduction of OBD – scanning and tailpipe measurement will have the best benefit and ability to find most of the emission behaviour affecting failures on modern passenger cars
- The use of OBD will also provide additional information useful for the emissions test for both petrol and diesel vehicles:
    - Engine coolant temperature
    - Engine speed
- For diesel vehicles, the following parameters should also be recorded and evaluated:
    - Maximum engine speed
    - Rising time

According to the EU DIRECTIVE position about NO_x:

> *"Possibilities for improving test cycles to match on-road conditions should be closely examined in order to develop future solutions, including the establishment of test methods for the measurement of NO_x levels and of limit values for NO_x emissions. "*

CITA is expecting to be able to set, with extra funding, a dedicated test campaign to validate a low emission NO_x level procedure.

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8 ABBREVIATIONS

CO	Carbon monoxide
DTC	Diagnostic trouble codes (OBD)
EGR	Exhaust Gas Recirculation
GDI	Gasoline direct injection
IPR	Intellectual property rights
k value	The smoke opacity measured in m^{-1}
MS	Member States of the European Union
NDUV	Non-Dispersive Ultra-Violet
NEDC	New European Driving Cycle – the current test cycle used for type approval
NO_x	Oxides of nitrogen
OBD	On-board diagnostics
PID	Parameter IDs (On-board diagnostics)
PM	Particulate matter
PTI	Periodic technical inspection
RC status	Readiness codes (OBD)
WLTC	World Harmonised Light-duty Test Cycle – the new test cycles included in the WLTP
WLTP	World Harmonised Light-duty Test Procedure – the new type approval test procedure that is due to be used for type approval purposes from about 2017.

APPENDIX A. TEST PROCEDURES

The following pages contain:

- The test procedure flow diagram for the diesel test
- The test procedure flow diagram for the petrol test
- The file format for the test results

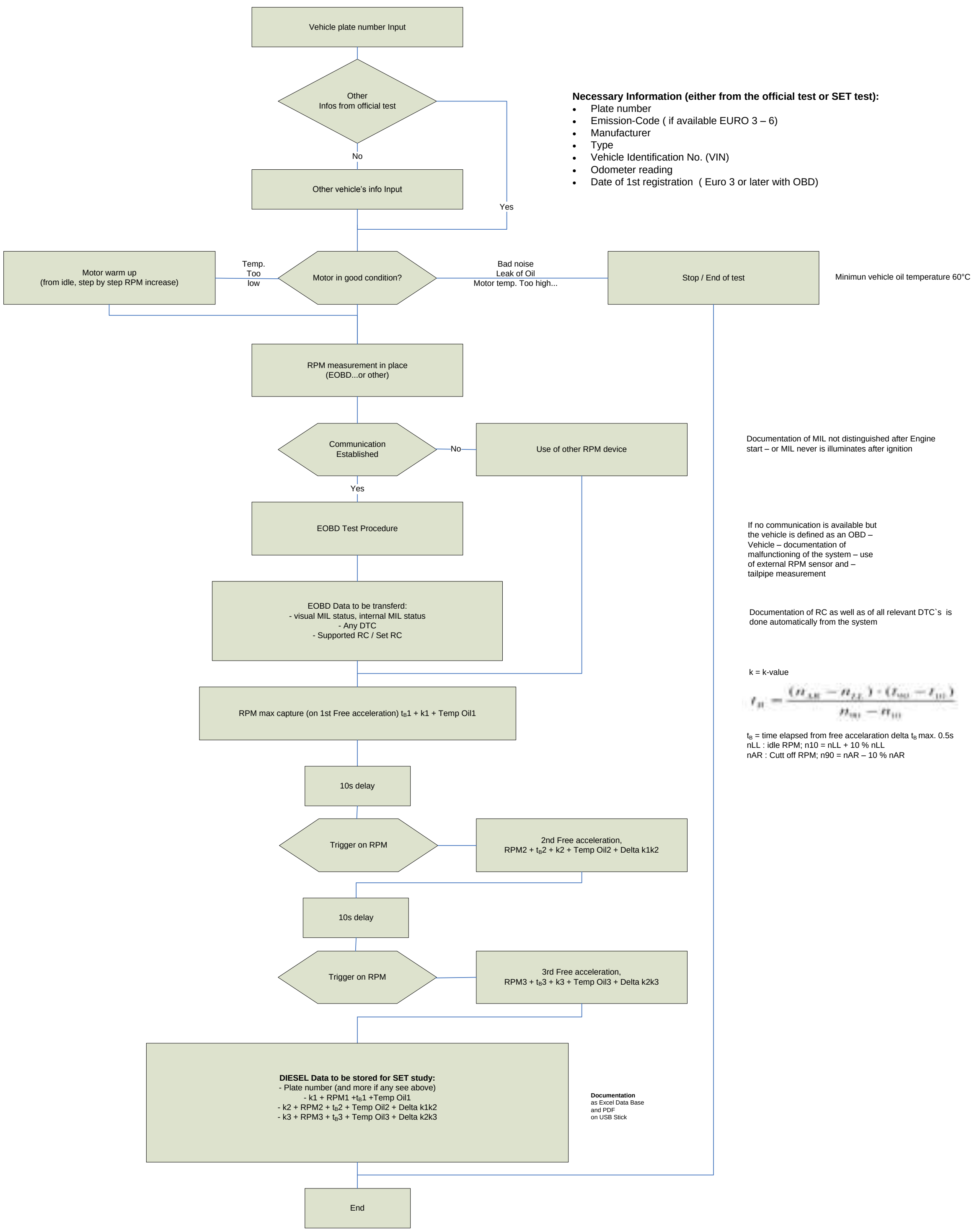

Figure 48. Diesel test procedure

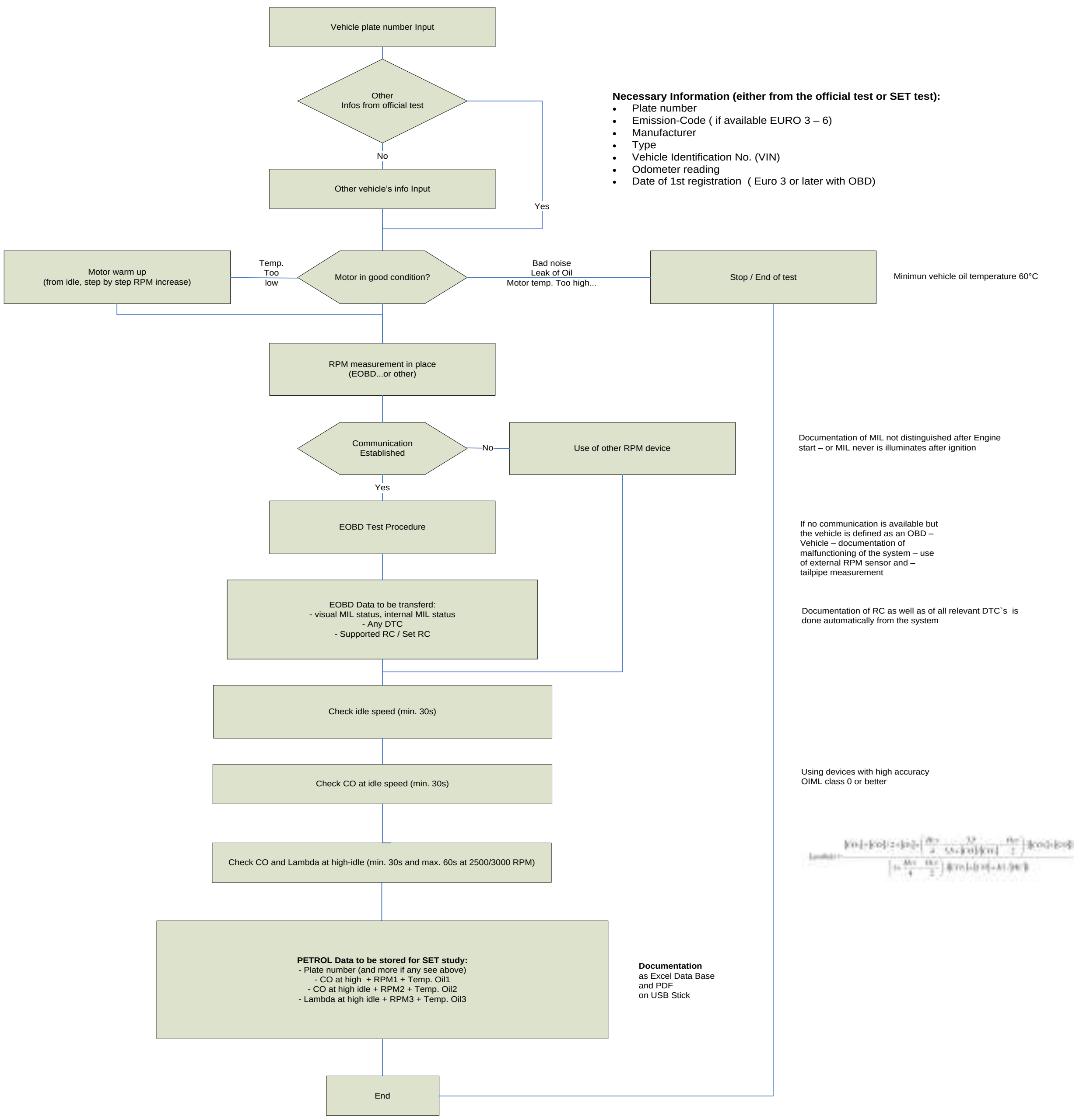

Figure 49. Petrol test procedure

SET procedure file structure

File Naming

VehiclePlateNumber.set

Example: AM218MS.SET

File structure

File results are text files.

5 sections tags exist:

- IDENTIFICATION
- EOBD
- DIESEL
- PETROL
- SECURITY

Each file needs 4 of them:

Petrol vehicle:	Diesel vehicle:
• IDENTIFICATION • EOBD • PETROL • SECURITY	• IDENTIFICATION • EOBD • DIESEL • SECURITY

Each section is followed by tag names and value related to this section.

If the value related to the tag name is missing, the tag is not present.

Each tag names is followed by “=” and the value, no space is required before, after…

The ranking of tag name has to be respected. SETI1 and then SETI2.

Example if only the plate number is input then the identification section is like this.

[IDENTIFICATION]

SETI1= AM218MS

SETI9= 01052014115930

Security

Data security is insured by a calculation of the data foot print. This calculation is done with a SHA-1

This has to be done from the first character until the last "=" after the tag name SETS1

(Hexadecimal in ASCII capital letter)

Example, the data footprint's computation is done over the yellow area.

```
[IDENTIFICATION]
SETI1=AM218MS
SETI9=01052014115930

[EOBD]
SETO1=1
SETO2=VF123456789123456
SETO3=2
SETO4=0
SETO5=1
SETO6=1
SETO7=1
SETO8=P03FF P1128
SETO14=Evaluation Misfire
SETO15=2
SETO16=Evaluation fuel system
SETO17=2
SETO18=Evaluation Comprehensive component
SETO19=2
SETO20=Catalyst
SETO21=2
SETO22=Heated Catalyst
SETO23=2
SETO24=Evaporative system
SETO25=2
SETO26=Secondary air system
SETO27=0
SETO28=A/C system
SETO29=0
SETO30=O2 sensor
SETO31=2
SETO32=O2 heater
SETO33=2
SETO34=EGR system
SETO35=2

[DIESEL]
SETD1=4578
SETD2=1803
SETD3=K
SETD4=0.11
SETD5=4555
SETD6=0.4
SETD7=0.12
SETD8=4468
SETD9=0.39
```

```
SETD10=-0.01
SETD11=0.119
SETD12=4568
SETD13=0.41
SETD14=0.001
[SECURITY]
SETS=BB93EB1872284023EBF224B8B89B65A4397E4B6B
```

Data fields

IDENTIFICATION			
Code Message	Longueur	Format	Description
SETI1	11a	alpha	Plate number
SETI2	n	numeric	Emission-Code (if available EURO 3 – 6)
SETI3	50a	alpha	Manufacturer
SETI4	30a	alpha	Type
SETI5	17a	alpha	Vehicle Identification No. (VIN)
SETI6	7n	km	Odometer reading
SETI7	JJMMAAAA	date	Date of 1st registration (Euro 3 or later with OBD)
SETI9	14n	JJMMAAAAHHMMSS	Date & time of beginning of test

OBD			
Code Message	Width	Unit/type	Description
SETO1	3n	Status	OBD protocol detected : '1'=ISO9141 '2'=ISO14230 '3'=SAE J1850 VPW (ISO 11519) '4'=SAE J1850 PWM (ISO 11519) '5'=ISO 15765 (CAN) '6'=SAE J1939 (CAN TRUCK) Frame ended with “space” Ex: (1)ISO9141 detected -> "1 " (2)ISO 14230 and ISO 15765 -> "25 " (3)No protocol identified -> " 0
SETO2	17a	Data	Vehicle VIN number
SETO3	3n	Status	Total number of DTC stored in the various ECU involved
SETO4	n	Status	MIL lamp status at engine power on '0'= MIL turned ON '1'= MIL did not turn ON
SETO5	n	Status	MIL lamp status after engine cranking, engine running '0'= OFF

			'1'= ON ‘2’ = Blinking
SETO6	n	Status	MIL status from ECU (read by EOBD reader) '0'= OFF '1'= ON ‘2’ = Blinking
SETO7	n	Status	Test conclusion : "0" – OBD System OK "1" - OBD System Non OK "2" – No protocol identified
SETO8	53a	Status	DTC read –10 codes per line , space as separator Ex VL : «P03FF P1128 U012A » Ex SAE J1939 « SPN0123/03…»
SETO9	53a	Status	DTC read –10 codes per line , space as separator Ex VL : «P03FF P1128 U012A » Ex SAE J1939 « SPN0123/03…»
SETO10	53a	Status	DTC read –10 codes per line , space as separator Ex VL : «P03FF P1128 U012A » Ex SAE J1939 « SPN0123/03…»
SETO11	53a	Status	DTC read –10 codes per line , space as separator Ex VL : «P03FF P1128 U012A » Ex SAE J1939 « SPN0123/03…»
SETO12	53a	Status	DTC read –10 codes per line , space as separator Ex VL : «P03FF P1128 U012A » Ex SAE J1939 « SPN0123/03…»
SETO13	53a	Status	DTC read –10 codes per line , space as separator Ex VL : «P03FF P1128 U012A » Ex SAE J1939 « SPN0123/03…»
SETO14	11n (3 dans le byte B + 8 sur le byte C)		0= not supported, 1= supported
SETO15	11n (3 dans le byte B + 8 sur le byte D)		0= complete, 1= not complete

DIESEL			
Code Message	Width	Unit/type	Description
SETD1	nnnn	tr/min	Cut off speed - RPM Max determined
SETD2	nnnn	tr/min	Idle RPM
SETD3	a	type of unit	K for m-1, M for mg/m3
SETD4	n.nnn	m-1	Free acceleration n°1 value in K
SETD5	nnn.nn	mg/m3	Free acceleration n°1 value of PM
SETD6	n.nnnn	mg/m3	Free acceleration n°1 value of Opacity
SETD7	nnnn	tr/min	RPM related to Free acceleration n°1
SETD8	n.nn	s	Rising time related to Free acceleration n°1
SETD9	n.nnn	m-1	Free acceleration n°2 value in K
SETD10	nnn.nn	mg/m3	Free acceleration n°2 value of PM
SETD11	n.nnnn	mg/m3	Free acceleration n°2 value of Opacity
SETD12	nnnn	tr/min	RPM related to Free acceleration n°2

SETD13	n.nn	s	Rising time related to Free acceleration n°2
SETD14	sn.nnn	m-1	Delta between K1 and K2
SETD15	sn.nnnn	mg/m3	Delta between Opacity1 and Opacity2
SETD16	n.nnn	m-1	Free acceleration n°3 value in K
SETD17	nnn.nn	mg/m3	Free acceleration n°3 value of PM
SETD18	n.nnnn	mg/m3	Free acceleration n°3 value of Opacity
SETD19	nnnn	tr/min	RPM related to Free acceleration n°3
SETD20	n.nn	s	Rising time related to Free acceleration n°3
SETD21	sn.nnn	m-1	Delta between K2 and K3
SETD22	sn.nnnn	mg/m3	Delta between Opacity2 and Opacity3

PETROL			
Code Message	Width	Unit/type	Description
SETP1	3n	°C	Engine temperature
SETP2	4n	tr/min	Fast idle engine speed
SETP3	snn.nn	%	CO Fast idle
SETP4	n.nnn	-	Lambda Fast idle
SETP5	4n	tr/min	idle engine speed
SETP6	snn.nn	%	CO idle
SETP7	snn.nn	%	CO2 idle
SETP8	nn.nn	%	CO corrected idle
SETP9	snnnnn*	ppm	HC idle

APPENDIX B. PETROL CARS WITH NON STANDARD TEST CONDITIONS

The following information provided by RDW, shows petrol vehicles that need special methods applied to them during the test procedure.

Table 32. Non-standard test requirements

MAKE	MODEL	MOTOR CODE (on motor or model plate)	MAX. CO% AT INCREASED RPM	LAMBDA VALUE AT INCREASED RPM	INCREASED RPM BETWEEN
Aston Martin	V8 Virage Volante	6,3 behind engine number.	3,5.	1,2 – 1,4	2500 - 2700
	If the car is equipped with a fully automatic gearbox, the motor may only run for a maximum of 1 minute at 2500 RPM to bring the emission system up to temperature. It is recommended to make a test drive to bring the motor up to temperature (min. 80o C).				
BMW	All types	N43.. . N53…	0,2 0,2	0,97 – 4,0 0,97 – 4,0	2300 - 2700 2300 - 2700
Citroën	ZX and Xantia ZX, Xsara and Xantia C5 2.0 HPI	XU5JP (BFZ) XU7JP (LFZ) RLZ	0,3 0,3 > 0,3	0,97 - 1,03 0,97 - 1,03 > 4,00 of 0,97 – 1,03 with loosened EGR valve	1400-1600 1400-1600 2250 - 3000
	The following functions must be switched on at increased RPM: Headlights, rear window heating, interior ventilator (highest setting), and maximum steering lock for cars with power assisted steering. If the car is equipped with a fully automatic gearbox, the increased RPM without a load must not be higher than 2400 RPM.				
Daimler	If the car is equipped with a fully automatic gearbox, the motor may only run for a maximum of 1 minute at 2500 RPM to bring the emission system up to temperature. It is recommended to make a test drive to bring the motor up to temperature (min. 80o C).				
Ford	All types		0,3	0,95 - 1,09	2000 - 3200
	Fiesta 1.4 i Escort 1.4 i Orion 1.4 i Type CVH	Motor CVH Code F6E Code F6G Code F6F	0,3 0,3 0,3 0,3	0,95 - 1,09 0,95 - 1,09 0,95 - 1,09 0,95 - 1,09	3600 - 3900 3600 - 3900 3600 - 3900 3600 - 3900
Ford	Mustang		0,3	1,57 - 1,79	2500 - 3200
	Applies to cars where the 8th position of the vehicle identification number is the letter T. The air pump must not be switched off during the measurement.				
Jaguar	If the car is equipped with a fully automatic gearbox, the motor may only run for a maximum of 1 minute at 2500 RPM to bring the emission system up to temperature. It is recommended to make a test drive to bring the motor up to temperature (min. 80o C).				
Rover Landrover Mini MG	all models idem idem idem		0,3	0,95 - 1,09	2000 - 3200
Mitsubishi	Carisma GDI		0,3	3,50 - 4,00 of 0,97 - 1,03 with functions switched on	2500 - 3000
Peugeot	306 405 405 406 406	XU7JP (LFZ) XU5JP (BFZ) XU7JP (LFZ) XU5JP (BFZ) RLZ	0,3 0,3 0,3 0,3 > 0,3	0,97 - 1,03 0,97 - 1,03 0,97 - 1,03 0,97 - 1,03 > 4,00 of 0,97 - 1,03 with loosened EGR valve	1400 - 1600 1400 - 1600 1400 - 1600 1400 - 1600 2250 - 3000
	The following functions must be switched on at increased RPM: Headlights, rear window heating, interior ventilator (highest setting), and maximum steering lock for cars with power assisted steering. If the car is equipped with a fully automatic gearbox, the increased RPM without a load must not be higher than 2400 RPM.				
Toyota	Carina 1600/1800	4AFE 7AFE	0,3 0,3	0,97 - 1,60 0,97 - 1,60	2400 - 2600 2400 - 2600
	If the car is equipped with a fully automatic gearbox, a test drive of at least 5 km must be made to bring the emission control system and the motor up to temperature.				
Volvo	400 series 850 series 940 series 960 series		0,3 0,3 0,3 0,3	0,96 - 1,04 0,96 - 1,04 0,96 - 1,04 0,96 - 1,04	2000 - 3200 2000 - 3200 2000 - 3200 2000 - 3200
	If cars of the 400 series are equipped with a fully automatic gearbox, the increased RPM must not be higher than 1500 RPM.				

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APPENDIX C. LIST OF IDENTIFIED DTCs

Codes	Count	Text
P1351	58	Manufacturer Controlled Ignition System or Misfire
P0670	35	Glow Plug Module Control Circuit
P0401	13	Exhaust Gas Recirculation Flow Insufficient Detected
P1461	9	Manufacturer Controlled Auxiliary Emission Controls
P0381	6	Glow Plug/Heater Indicator Circuit
P0409	6	Exhaust Gas Recirculation Sensor "A" Circuit
P0400	5	Exhaust Gas Recirculation Flow
P0490	5	Exhaust Gas Recirculation Control Circuit High
P1462	5	Manufacturer Controlled Auxiliary Emission Controls
P0135	4	O2 Sensor Heater Circuit
P0300	4	Random/Multiple Cylinder Misfire Detected
P0403	4	Exhaust Gas Recirculation Control Circuit
P0420	4	Catalyst System Efficiency Below Threshold - Bank 1
P2002	4	Particulate Trap Efficiency Below Threshold - Bank 1
P0011	3	"A" Camshaft Position - Timing Over-Advanced or System Performance - Bank 1
P0335	3	Crankshaft Position Sensor "A" Circuit
P0340	3	Crankshaft Position Sensor "A" Circuit - Bank 1 or Single Sensor
P0471	3	Exhaust Pressure Sensor Range/Performance
P1162	3	Manufacturer Controlled Fuel and Air Metering
P14A3	3	Manufacturer Controlled Auxiliary Emission Controls
P0014	2	"B" Camshaft Position - Timing Over-Advanced or System Performance - Bank 1
P0016	2	Crankshaft Position - Camshaft Position Correlation - Bank 1 Sensor A
P0030	2	HO2S Heater Control Circuit - Bank 1 Sensor 1
P0101	2	Mass or Volume Air Flow Circuit Range/Performance
P0120	2	Throttle/Pedal Position Sensor/Switch "A" Circuit
P0122	2	Throttle/Pedal Position Sensor/Switch "A" Circuit Low
P0123	2	Throttle/Pedal Position Sensor/Switch "A" Circuit High
P0130	2	O2 Sensor Circuit
P0172	2	System Too Rich - Bank 1
P0183	2	Fuel Temperature Sensor a Circuit High
P0222	2	Throttle/Pedal Position Sensor/Switch "B" Circuit Low
P0303	2	Cylinder 3 Misfire Detected
P0380	2	Glow Plug/Heater Circuit "A"
P0487	2	Exhaust Gas Recirculation Throttle Position Control Circuit
P0562	2	System Voltage Low
P0597	2	Thermostat Heater Control Circuit/Open
P1235	2	Manufacturer Controlled Fuel and Air Metering
P1445	2	Manufacturer Controlled Auxiliary Emission Controls
P1459	2	Manufacturer Controlled Auxiliary Emission Controls
P1693	2	Manufacturer Controlled Computer and Auxiliary Outputs
P16A4	2	Manufacturer Controlled Computer and Auxiliary Outputs
P1955	2	Manufacturer Controlled Transmission
P2A00	2	O2 Sensor Circuit Range/Performance
P0015	1	"B" Camshaft Position - Timing Over-Retarded - Bank 1
P0054	1	HO2S Heater Resistance
P0073	1	Ambient Air Temperature Sensor Circuit High

P0088	1	Fuel Rail/System Pressure - Too High
P0100	1	Mass or Volume Air Flow Circuit
P0104	1	Mass or Volume Air Flow Circuit Intermittent
P0105	1	Manifold Absolute Pressure/Barometric Pressure Circuit
P0116	1	Engine Coolant Temperature Circuit Range/Performance
P0117	1	Engine Coolant Temperature Circuit Low
P0136	1	O2 Sensor Circuit - Bank1 Sensor 2
P0138	1	O2 Sensor Circuit High Voltage - Bank 1 Sensor 2
P0171	1	System Too Lean - Bank 1
P0182	1	Fuel Temperature Sensor a Circuit Low
P0193	1	Fuel Rail Pressure Sensor Circuit High
P0219	1	Engine Overspeed Condition
P0234	1	Turbo/Super Charger Overboost Condition
P0238	1	Turbo/Super Charger Boost Sensor "A" Circuit High
P0245	1	Turbo/Super Charger Wastegate Solenoid "A" Low
P0304	1	Cylinder 4 Misfire Detected
P0325	1	Knock Sensor 1 Circuit - Bank 1 or Single Sensor
P0341	1	Crankshaft Position Sensor "A" Circuit Range/Performance - Bank 1 or Single Sensor
P0342	1	Camshaft Position Sensor "A" Circuit Low - Bank 1 or Single Sensor
P0352	1	Ignition Coil "B" Primary/Secondary Circuit
P0402	1	Exhaust Gas Recirculation Flow Excessive Detected
P0405	1	Exhaust Gas Recirculation Sensor "A" Circuit Low
P0489	1	Exhaust Gas Recirculation Control Circuit Low
P0500	1	Vehicle Speed Sensor "A"
P0530	1	A/C Refrigerant Pressure Sensor "A" Circuit
P0546	1	Exhaust Gas Temperature Sensor Circuit High
P0598	1	Thermostat Heater Control Circuit Low
P0599	1	Thermostat Heater Control Circuit High
P0620	1	Generator Control Circuit
P0638	1	Throttle Actuator Control Range/Performance
P0691	1	Fan 1 Control Circuit Low
P0693	1	Fan 2 Control Circuit Low
P1101	1	Manufacturer Controlled Fuel and Air Metering
P1110	1	Manufacturer Controlled Fuel and Air Metering
P1144	1	Manufacturer Controlled Fuel and Air Metering
P1152	1	Manufacturer Controlled Fuel and Air Metering
P1153	1	Manufacturer Controlled Fuel and Air Metering
P1161	1	Manufacturer Controlled Fuel and Air Metering
P11A8	1	Manufacturer Controlled Fuel and Air Metering
P1250	1	Manufacturer Controlled Fuel and Air Metering
P1303	1	Manufacturer Controlled Ignition System or Misfire
P1402	1	Manufacturer Controlled Auxiliary Emission Controls
P1405	1	Manufacturer Controlled Auxiliary Emission Controls
P1412	1	Manufacturer Controlled Auxiliary Emission Controls
P1434	1	Manufacturer Controlled Auxiliary Emission Controls
P14A7	1	Manufacturer Controlled Auxiliary Emission Controls
P1661	1	Manufacturer Controlled Computer and Auxiliary Outputs
P1670	1	Manufacturer Controlled Computer and Auxiliary Outputs
P2008	1	Intake Manifold Runner Control Circuit/Open - Bank 1
P2015	1	Intake Manifold Runner Position Sensor/Switch Circuit Range/Performance - Bank 1

P2020	1	Intake Manifold Runner Position Sensor/Switch Circuit Range/Performance - Bank 2
P2101	1	Throttle Actuator Control Motor Circuit Range/Performance
P2108	1	Throttle Actuator Control Module Performance
P2112	1	Throttle Actuator Control System - Stuck Closed
P2185	1	Engine Coolant Temperature Sensor 2 Circuit High
P2188	1	System Too Rich at Idle - Bank 1
P2238	1	O2 Sensor Positive Current Control Circuit Low
P2263	1	Turbo/Super Charger Boost System Performance
P2408	1	Fuel Cap Sensor/Switch Circuit
P242F	1	Auxiliary Emission Controls
P2453	1	Auxiliary Emission Controls
P2454	1	Auxiliary Emission Controls
P3263	1	Fuel and Air Metering and Auxiliary Emission Controls
U0415	1	Invalid Data Received From Anti-Lock Brake System Control Module

Greyed out rows in the table above indicate that the DTCs are not relevant to the exhaust emissions.

APPENDIX D. ADDITIONAL GRAPHED DATA FROM THE FIELD TRIALS

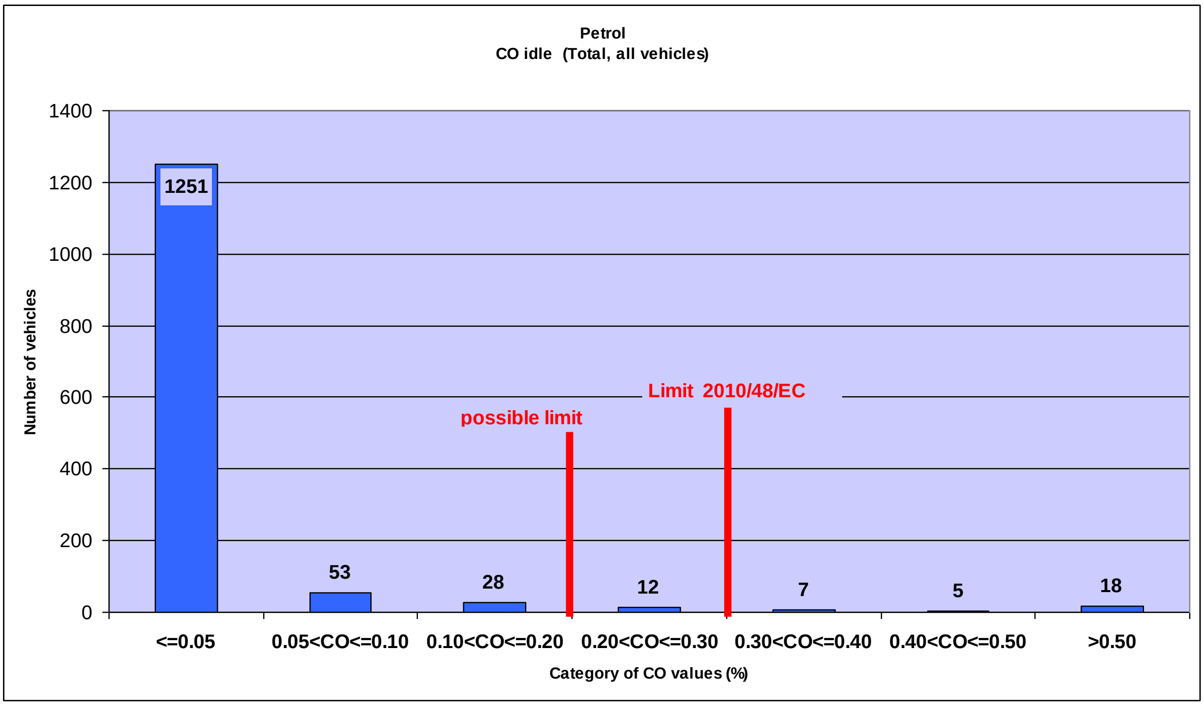

Figure 50. Distribution of CO natural idle emission tests – all petrol vehicles

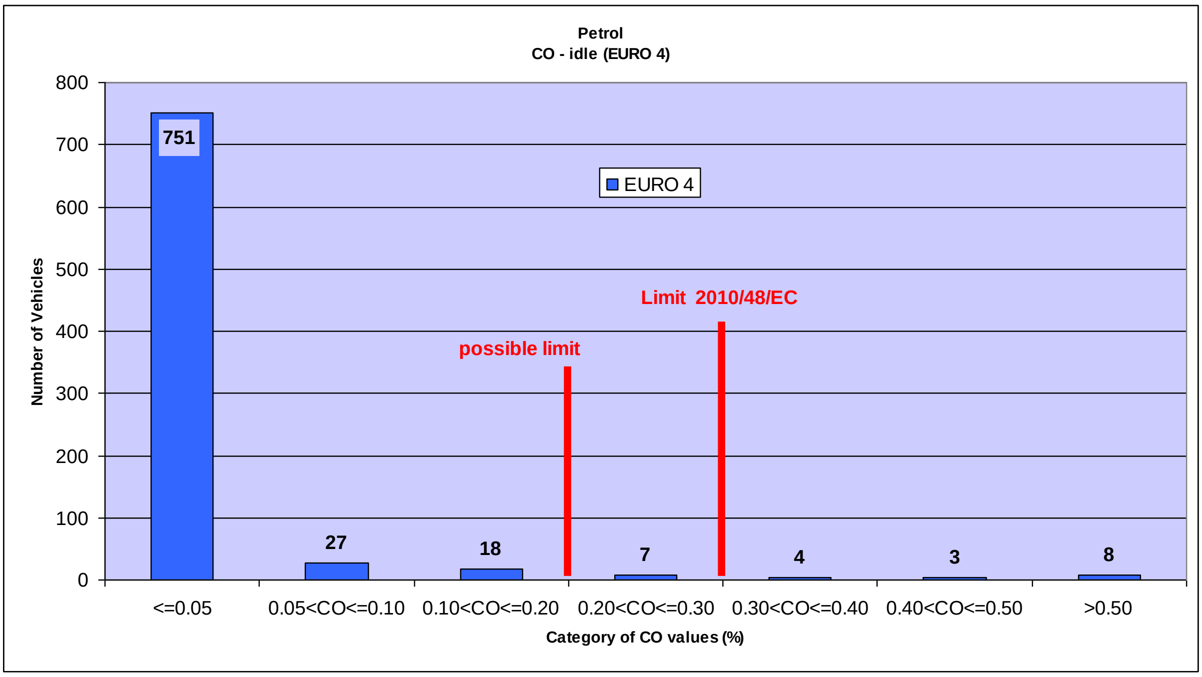

Figure 51. Distribution of CO natural idle emission tests – Euro 4 petrol vehicles

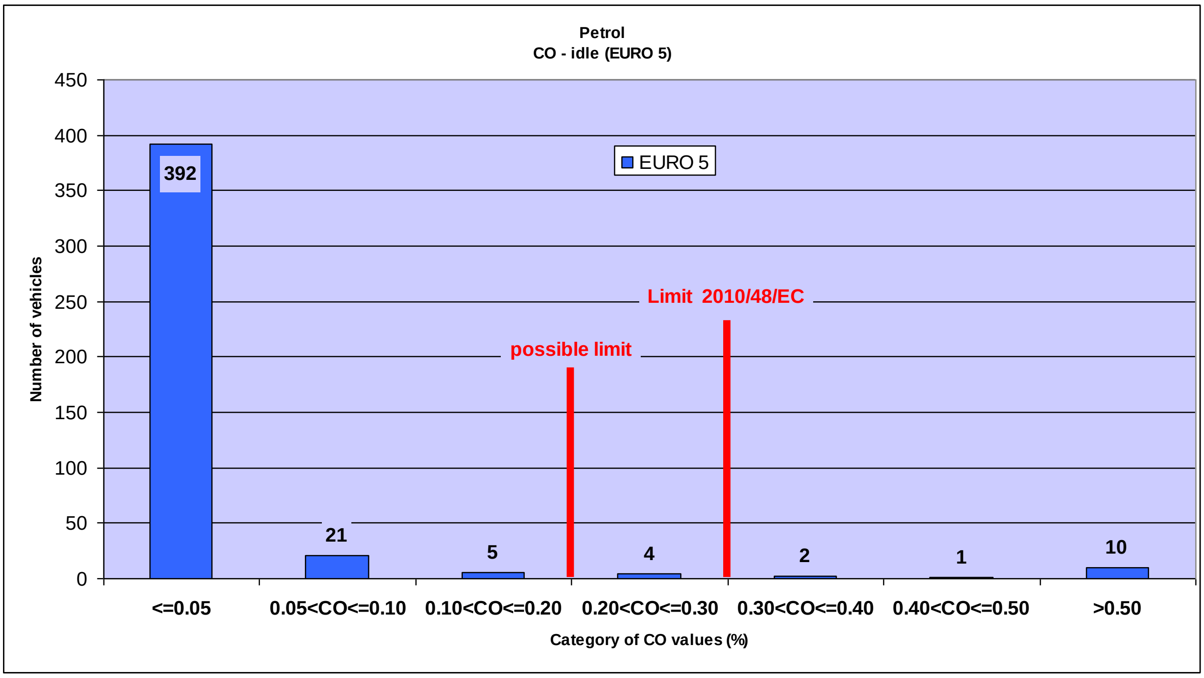

Figure 52. Distribution of CO natural idle emission tests – Euro 5 petrol vehicles

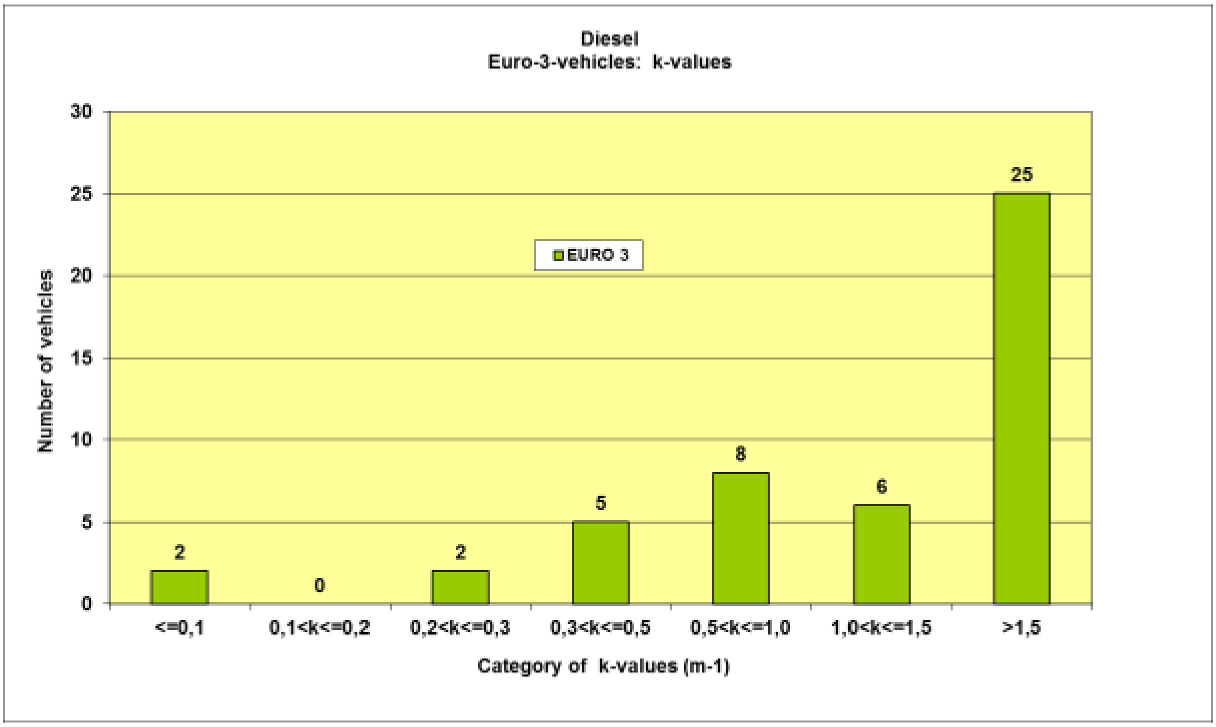

Figure 53. Distribution of the FAS test results – Euro 3 diesel vehicles

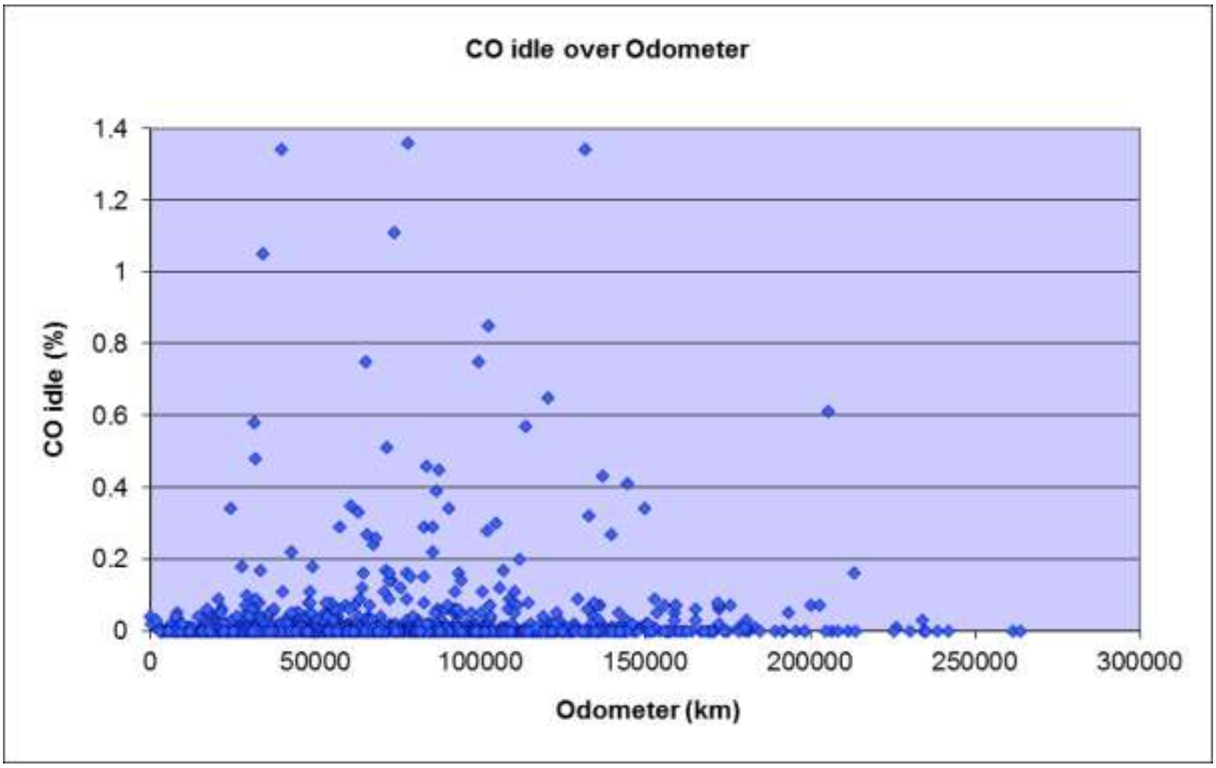

Figure 54. Natural idle CO emissions plotted against odometer reading

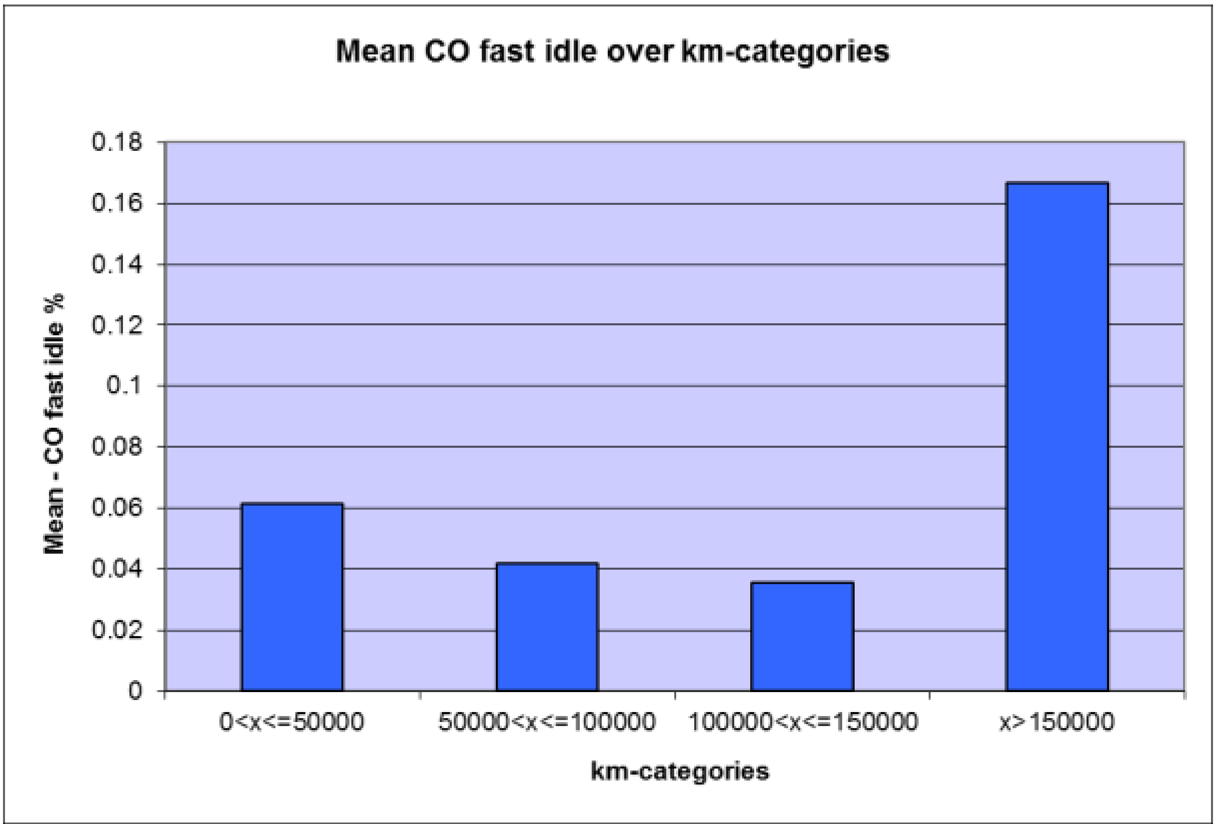

Figure 55. Average fast idle CO emissions by odometer reading range

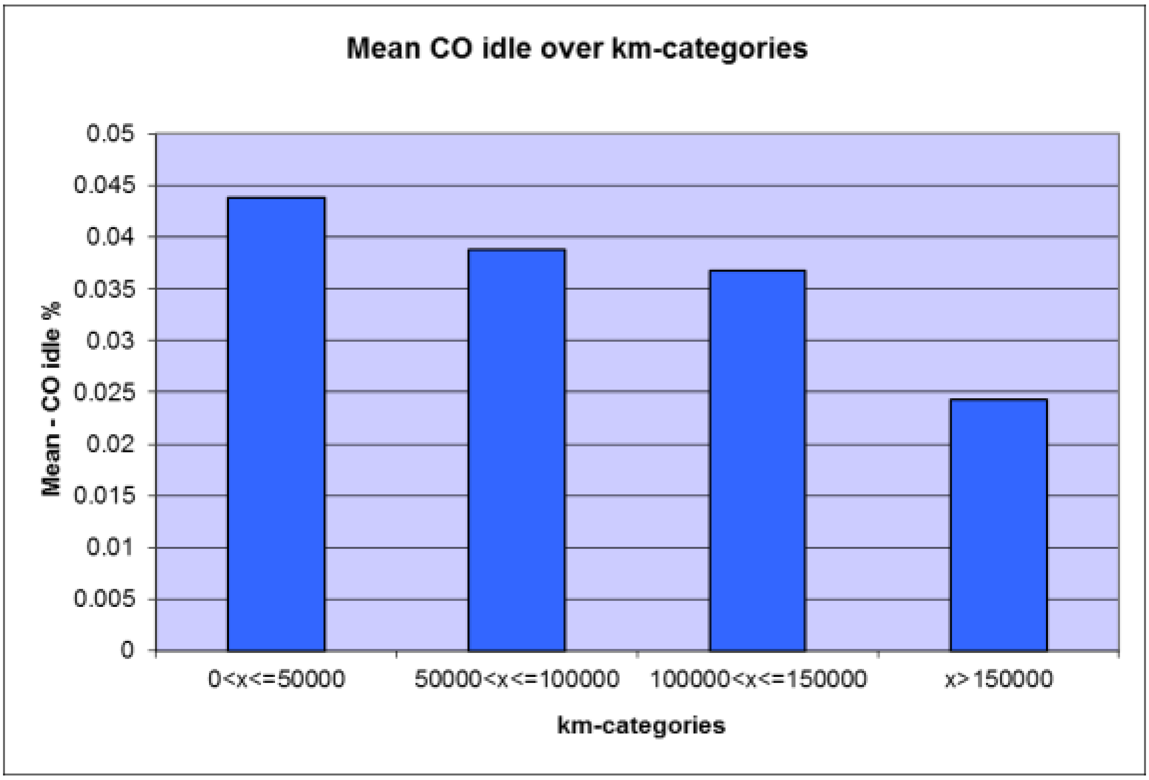

Figure 56. Average natural idle CO emissions by odometer reading range

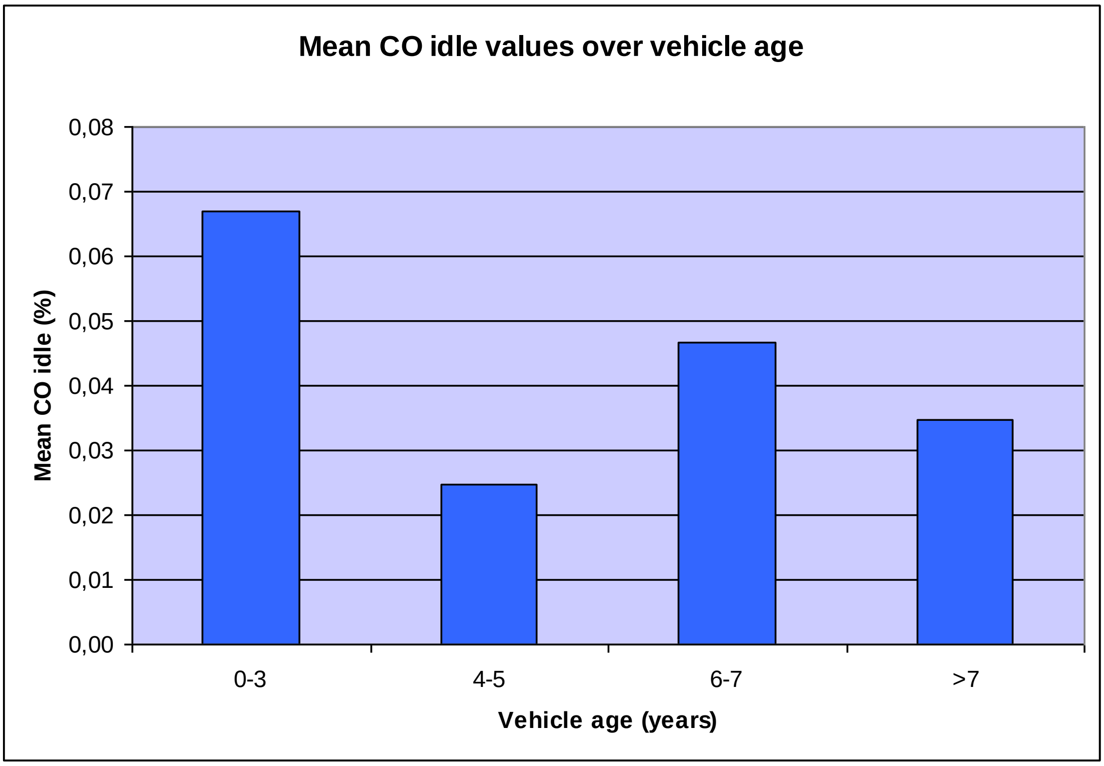

Figure 57. Natural idle CO emissions plotted against vehicle age band