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Impact assessment/ On Board Diagnostic (OBD) systems for passenger cars

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Summary

This report presents the work carried out in the framework of the project "*Impact assessment/On Board Diagnostic (OBD) systems for passenger cars*". In the first section, the updates in the Californian OBD legislation are reviewed, and the current situation in the EU legislation is presented. The second section describes the methodology followed to gather the necessary data, and to perform the analysis of the environmental, financial and social impacts. In the third section, a review of the current experience from EOBD systems performance is presented, based on manufacturer experience (OBD development, calibration and fleet testing), as well as from vehicle maintenance (workshops). The fourth section presents the findings from the impact assessment of different policy options, including environmental, financial and social effects from the establishment of new OBD threshold limit values. In the last sections, specific issues associated with the adoption of new OBD threshold limit values for gas-fuelled and non lambda 1 engines are presented. Finally, the conclusions are summarized based on the quantitative results of the study regarding the policy options examined as regards the specification of future OBD thresholds.

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On Board Diagnostics, impact assessment, passenger cars.

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Abbreviations, Notation

ACEA	Association des Constructeurs Européens d' Automobiles (European Association of Automobile Manufacturers)
CARB	California Air Resources Board
CITA	Comité Internationale de l'Inspection Automobile (International Motor Vehicle Inspection Committee)
CLEPA	European Association of Automotive Suppliers
CNG	Compressed Natural Gas
DISI	Direct Injection Spark Ignition
DPF	Diesel Particulate Filter
EC	European Commission
(E)OBD	(European) On-Board Diagnostics
EPA	Environmental protection Agency (USA)
EU	European Union
GDI	Gasoline Direct Injection
JAMA	Japan Automobile Manufacturers Association
I/M	Inspection and Maintenance
HC	Hydrocarbons
MI(L)	Malfunction Indicator (Light)
NEDC	New European Driving Cycle
NPV	Net Present Value
OSC	Oxygen Storage Capacity
TA	Type Approval
TH	Higher threshold of the OBD system detection area
TL	Lower threshold of the OBD system detection area
SMEs	Small and Medium Enterprises
SULEV	Super Ultra-Low Emission Vehicles

1 Introduction

1.1 Scope of the study

According to the tender requirements, the specific tasks in relation to this study are:

- Study of the likely positive and negative impacts, of the introduction of the proposed OBD threshold limit values, economically (i.e. for different agents in the EU vehicle market, for market structure and competitiveness, etc.), as well as the likely positive and negative impacts that the introduction of the new threshold limit values will produce from an environmental and social point of view.

- An assessment of direct and secondary effects, if possible in monetary terms, that the new OBD thresholds will impose from the industrial point of view (i.e. effects in product diversity, in market access, in small and medium enterprises, etc).

- An assessment of the current stage of development of OBD for vehicles for the Euro 4 (2005/6) stage, whether the thresholds can be effectively applied from 2005/6 or whether there are valid industrial reasons why a later date of application may be more suitable.

- The study shall provide additional technical, economic or other reasons for not proposing at this time new threshold limit values for non lambda-1 engines (lean burn gasoline engines), gaseous fuelled positive-ignition engines and diesel engines. The study will provide an assessment of when reduced OBD thresholds for these vehicles may be applicable and the level of OBD threshold that might be expected for them in the future.

- The study should include a comprehensive analysis covering the above mentioned issues and will present a series of recommendations indicating which package of OBD threshold limits should be the most appropriate, indicating its positive and negative impact, including impact over time, from a technical, economic, social and environment point of view, with respect to the already proposed threshold limit values.

1.2 Background

According to the tender invitation document, the Commission of the European Communities wishes to carry out an impact assessment of its policy options to amend Directive 70/220/EEC with regard to pollutant emissions from light-duty vehicles.

For new vehicle registrations in the EU, OBD became mandatory for vehicles of category M_1 (≤2,500 kg) and N_1 class I equipped with a positive-ignition engine from 1 January 2001 (1 January 2002 for vehicles of category M_1 ≥2,500 kg and N_1 classes II and III).

From 1 January 2004, OBD becomes mandatory for the registration of new vehicles of category M_1 (≤2,500 kg or vehicles designed to carry not more than 6 occupants) equipped with a compression-ignition engine. Later dates apply in the case of heavier vehicles of category M_1 and category N_1 vehicles.

Article 3 of Directive 98/69/EC, amending Directive 70/220/EEC, requires the Commission to submit a proposal to the European Parliament and to the Council complementing Directive 98/69/EC in a number of areas and, in particular, with regard to the threshold limit values for OBD (on-board diagnostic systems) applicable in 2005/6 for M_1 and N_1 vehicles.

According to the dates in the paragraphs above, data on the in-service performance of OBD systems has only been available for vehicles equipped with a positive-ignition (petrol fuelled) engine. It is on this basis that the Commission proposes to introduce, at this time, reduced OBD thresholds for category M_1 and N_1 vehicles equipped with a positive-ignition engine (petrol fuelled), to the applicable from 1 January 2005 for the purpose of EU type-approval and 1 January 2006 for new registrations.

Vehicles equipped with direct injection engines (GDI) and compression-ignition engines are therefore outside of the scope of the proposal at this time but reduced OBD threshold limits will be considered in the future for application, where justified, post 2005 (date to be determined).

Setting the level of the reduced OBD thresholds is a balance depending on the performance of the monitoring technology, the effectiveness of the OBD calibration, the need to reliably determine “real failures” and to accurately distinguish between real and false failures.

In practice, the application of new reduced OBD threshold limit values aims to contribute to an environmental improvement, due to the fact that the car driver will be informed in real time if any of the anti-pollution system devices are not properly working and can take the action to have a repair carried out.

This study will provide input to the Commission's extended impact assessment of its foreseen proposal for measures to be taken against air pollution by emissions from motor vehicles. It follows the Commission's new impact assessment procedure, applicable as of 2003.

1.3 CARB position regarding OBD thresholds

CARB recently regulated new OBD thresholds to be applied in 2004 and subsequent model-year passenger cars, light-duty trucks and medium duty vehicles and engines certified in California [1, 2]. A summary of the proposed revisions compared to OBD II legislation is presented in Appendix 1.

In all cases, the setting of new OBD thresholds follows a “multiplicative” approach, e.g the thresholds are defined by multiplying the respective type approval limits by a factor of 1.5 (1.75 is used in some exceptional cases). Moreover, CARB made significant modifications in the entire OBD regulations framework, by addressing stricter specifications regarding the frequency of monitoring, requirement for NOx efficiency catalyst monitoring, standardization requirements, certification procedures and production vehicle evaluation testing. The automobile manufacturing industry contends that the CARB proposed MIL illumination thresholds are too stringent and impose unfair economic costs on consumers. In this regard, some manufacturers have suggested that the low malfunction criteria thresholds would result in consumers having to replace components that would produce minimal emission benefits and would not be cost-effective. The CARB staff however still believes that the proposed MIL illumination thresholds are necessary to ensure that manufacturers design durable emission control systems whose emissions remain close to the certification standards for the entire life of the vehicle. Further, CARB believes that this can be done cost-effectively.

In so finding that the proposed malfunction emission criteria levels are appropriate, the CARB staff also rejects the motor vehicle industry's objections that the proposed levels do not provide a sufficient emission compliance margin. The manufacturers contend that the proposed MIL illumination thresholds affect an OBDII monitor's ability to report valid test results (i.e., to correctly detect a malfunction as opposed to indicating a malfunction when no fault is actually present). They argue that if they fail to provide enough "separation" between the certification emission level of the vehicle and the emission level at which the MIL illuminates, the MIL could illuminate prematurely, leading to customer dissatisfaction. The staff, however, believes that the proposed thresholds provide a sufficient emission compliance margin to avoid such problems. Accordingly, the proposed MIL illumination thresholds would promote lower average emissions from the vehicle fleet.

Many believe that with higher MIL illumination thresholds, detection of malfunctions would not be as frequent, resulting in fewer replacements and repairs. However, as stated above, the CARB staff is concerned that higher thresholds would encourage manufacturers to reduce the long-term durability and performance of their emission control components.

The CARB staff further disagrees with motor vehicle manufacturers' contentions that the proposed malfunction criteria thresholds are not cost-effective. While the ARB staff proposes, in general, that components be replaced when they cause emissions to increase to 50 percent above the standards, manufacturers argue that it would be more cost-effective to repair vehicles when emissions increase to 7 times the standards or more. For example, they claim that under the ARB's proposed thresholds, a consumer would be required to replace a SULEV catalyst system when it is still 98 percent efficient at a cost of $750. In contrast, under their proposed thresholds, the catalyst system would be replaced at 95 percent efficiency. The staff believes that proper assessment of a program cannot be based on worst case scenarios. Rather, a proper analysis requires that conclusions be drawn after thoroughly reviewing the program in its entirety.

By examining the overall program (as opposed to just one example), the staff determined that implementing industry's proposed higher MIL illumination thresholds would be less cost-effective than CARB's proposed thresholds. The higher thresholds proposed by industry would result in substantially lower emission reductions with little cost savings relative to the staff's proposal. The shortfall in emission reductions substantially affects the cost-effectiveness of industry's proposal, in that it is difficult to recover the loss in reductions at a comparable cost-effectiveness value. Further, as mentioned earlier, stricter emission thresholds lead to more durable components, which benefits consumers.

1.4 Current situation and draft Commission proposal

The proposal of the European Commission regarding the OBD limit thresholds for Euro 4 level vehicles was made public in 2003 [3]. The main points of this proposal are presented below.

The Euro 3 tailpipe emission limits and the OBD thresholds laid down in Directive 70/220/EEC are shown in Table 1.1 for light-duty vehicles equipped with positive-ignition engines. The 'EOBD decision tolerance' for each vehicle category is also indicated.

Table 1.1: Euro 3 (year 2000) tailpipe emission limits and OBD thresholds:

Vehicle category (positive-ignition)	2000	CO (g/km)	THC (g/km)	NOx (g/km)
M & N1 class I	Type-approval limit	2.3	0.20	0.15
	OBD threshold	3.20	0.40	0.60
	Decision tolerance	*0.90*	*0.20*	*0.45*
N1 class II	Type-approval limit	4.17	0.25	0.18
	OBD threshold	5.80	0.50	0.70
	Decision tolerance	*1.63*	*0.25*	*0.52*
N1 class III	Type-approval limit	5.22	0.29	0.21
	OBD threshold	7.30	0.60	0.80
	Decision tolerance	*2.08*	*0.31*	*0.59*

One may argue that with a reduction in tailpipe emission limits for Euro 4 (year 2005), it is also appropriate to lower the EOBD thresholds in proportion at the same time. However, on doing so, the 'decision tolerance' will be effectively reduced and so the potential for errors in monitoring could increase.

For Euro 4, we may see the introduction of new types of positive-ignition engines, for example gasoline direct injection (GDI) engines, which offer beneficial reductions in pollutant emissions and CO_2. How full OBD monitoring will be carried out on these types of engines, that may be equipped with deNOx catalyst technology, seems at this time to be problematical.

It is therefore perhaps correct to consider treating such engines, with respect to OBD, slightly differently than stoichiometric positive-ignition engines, if reduced OBD thresholds will apply to such engines.

Today, there is a distinctly limited knowledge of how OBD-equipped vehicles actually perform on the road in the EU. New vehicles equipped with OBD systems have been on the road in the EU for only two years now and there is a distinct lack of evidence today that supports the case for lower OBD thresholds. It seems reasonable to therefore consider what we want OBD to deliver and whether there is a real need to lower the OBD thresholds for the Euro 4 stage.

The Commission believes that it is not necessary to relate the type-approval limit and the OBD threshold laid down in Directive 70/220/EEC by a multiplier which then automatically reduces the OBD thresholds to much lower levels for Euro 4 and so on in the future (Euro 5 perhaps). Such an approach does nothing to increase the effectiveness of the emission reduction technology but merely reduces the OBD 'decision-area'. The consequence is a great increase in the allocation of development resources to OBD.

However, the Commission has been given a political mandate in Article 3 of Directive 98/69/EC to consider a reduction in the OBD thresholds for Euro 4. As regards the lowering of OBD thresholds, the position of the Commission is as follows:

Lower OBD thresholds for Euro 4

With limited in-use knowledge of OBD, it is reasonable to consider to allow a continuation of an appropriate 'decision tolerance' for the Euro 4 stage. In this regard, it is therefore reasonable to develop the tolerance band in which the OBD system has to make a decision and which remains sufficiently wide to allow reliable and accurate failure decisions to be made.

Therefore, the continuation of the Euro 3 decision tolerance for the Euro 4 stage could be a reasonable first approach. However, this may be the case for some pollutants but may not be the case for other pollutants.

Using the OBD 'decision tolerances' from Table 1.1, possible OBD thresholds are calculated for the Euro 4 stage and are shown in Table 1.2 for the various vehicle categories.

A manufacturer's tailpipe emissions at type-approval may not equate accurately to in-service performance so it is wise to allow some latitude for production variability and also for monitoring reliability. Indeed, as mentioned earlier, these calculated OBD thresholds for some pollutants could still be a concern for reliable monitoring capability.

Table 1.2: Euro 4 (year 2005) tailpipe emission limits and possible OBD thresholds:

Vehicle category (positive-ignition)	2005	CO (g/km)	THC (g/km)	NOx (g/km)
M & N1 class I	Type-approval limit	1.0	0.10	0.08
	Decision tolerance	*0.90*	*0.20*	*0.45*
	Calculated OBD threshold	**1.9**	**0.30**	**0.53**
N1 class II	Type-approval limit	1.81	0.13	0.10
	Decision tolerance	*1.63*	*0.25*	*0.52*
	Calculated OBD threshold	**3.44**	**0.38**	**0.62**
N1 class III	Type-approval limit	2.27	0.16	0.11
	Decision tolerance	*2.08*	*0.31*	*0.59*
	Calculated OBD threshold	**4.35**	**0.47**	**0.70**

At this stage there is no data to indicate a possible differential OBD threshold for GDI engines (non-λ1 engines) and it would be reasonable to study this further before proposing any possible adjustment of OBD thresholds for non-λ1 vehicles. However, industrial lead-time before application of the revised OBD thresholds from 1 January 2005 is running out.

Therefore at this time, the proposal for Euro 4 OBD thresholds for vehicles with positive-ignition engines using petrol fuel is summarized below:

Table 1.3: Euro 4 (year 2005) - possible OBD thresholds for vehicles equipped with positive-ignition engines and using petrol fuel

Vehicle category (positive-ignition)	OBD 2005	CO (g/km)	THC (g/km)	NOx (g/km)
M & N1 class I	**λ1 engines**	**1.9**	**0.30**	**0.53**
	non-λ1 engines	**[...]**	**[...]**	**[...]**
N1 class II	**λ1 engines**	**3.44**	**0.38**	**0.62**
	non-λ1 engines	**[...]**	**[...]**	**[...]**
N1 class III	**λ1 engines**	**4.35**	**0.47**	**0.70**
	non-λ1 engines	**[...]**	**[...]**	**[...]**

It is also clarified that these lower OBD thresholds will be applicable to vehicles with positive-ignition engines using petrol only, and not to vehicles with gas fuelled engines (for which OBD applies from 2003) or to vehicles with compression-ignition engines (for which OBD applies from 2003).

In addition to the above, the Commission is also considering catalyst monitoring for NOx emissions. At the moment, the European OBD requirements require that a three-way catalyst on a vehicle equipped with a positive-ignition engine has to be monitored for hydrocarbon (HC) conversion efficiency only.

In the year 2002, CARB reflected on field data from vehicles equipped with OBD-II systems. CARB concluded that for Low Emission Vehicle 1 applications (LEV1, for which the 100,000 mile useful-life NOx standard is 0.3 g/mile and the 100,000 mile useful-life NMOG standard is 0.09 g/mile) the catalyst HC and NOx conversion performance degraded at approximately equal rates.

On the other hand, for Low Emission Vehicle 2 applications (LEV2), the 120,000 mile useful life NOx standard is 0.07 g/mile while the NMOG standard is the same as LEV1.

This led CARB to conclude that in order to protect against high in-use emissions and to maintain the emission benefits of the LEV2 vehicle program, the OBD-II system on LEV2 vehicles should monitor the catalyst for NOx conversion efficiency.

It is envisaged that manufacturers will modify their current catalyst monitoring strategies (oxygen storage capacity - OSC) to determine new oxygen storage thresholds appropriate to the pollutants HC or NOx, whichever exceeds the OBD-II thresholds first.

It is understood that the EPA will adopt the same measure in the Federal OBD requirements.

For Euro 4, both the THC and NOx limits are reduced by the same level over the Euro 3 limits (approximately 50%). While the case made by CARB for the inclusion of catalyst monitoring for NOx reduction efficiency is perhaps not so clear-cut for the EU, there remains the fact that the difference in tailpipe emissions between a Euro 4 and a Euro 3 vehicle is substantial.

In this respect it is worthwhile considering whether to also apply the requirement to monitor for catalyst NOx conversion efficiency in European OBD. Of course, for some future catalysts (deNOx), NOx conversion efficiency is more relevant than HC.

2 Methodology

In order to respond to the requirements of this project, it was necessary to develop and apply methodologies in order to quantify the environmental, economic and social impact of various approaches regarding future OBD thresholds. These methodologies should rely on input data based on the in-use experience of OBD systems, including emissions performance, cost-effectiveness and social acceptance. Moreover, information on the emission control technology for the Euro 4 stage and the expected OBD issues for new vehicles would also be necessary, in order to support such methodologies. Obviously, at this stage, the publicly available information on the above subjects is extremely limited, due to limited in-use experience in Europe, as well as confidentiality issues of the automotive industry.

The following sections describe the methodologies being used for collecting the data and using them as input to models for the assessment of the environmental and cost impacts.

2.1 Data gathering

The data necessary to support this study may be categorized into the following areas:

- Data or other experience from manufacturer fleet testing of vehicles with EOBD
- Technological solutions applied in Euro 3 and Euro 4 level vehicles, regarding emissions control and On-Board Diagnosis.
- Technological solutions applied in Euro 3 and Euro 4 level vehicles, and restrictions regarding emissions control and On-Board Diagnosis of non lambda 1 engines.
- Cost figures regarding the extra cost of developing Euro 4 level compliant OBD systems, both in terms of necessary hardware (sensors etc) and R&D.
- Other views from vehicle and components manufacturers regarding the technological feasibility of reducing OBD threshold limit values.
- Data regarding the applications of EOBD in vehicle maintenance.

In order to collect the necessary data, LAT has taken the following actions:

- Compilation of a questionnaire regarding technological and financial issues of OBD systems and distribution to manufacturers (both through ACEA and individually). The questionnaire is included in Appendix 2.
- Meetings with key persons and organizations to present the project aims and needs and discuss the issues raised in the questionnaire. Meetings were held with

ACEA, JAMA/Toyota, CLEPA and AECC, where the methodology was presented, and feedback was provided to us.

- Compilation of a questionnaire regarding the application of OBD systems in vehicle maintenance, and interviews with authorised workshops to discuss the issues raised in the questionnaire and collect the relevant data. This second questionnaire is included in Appendix 3.

- Review of the relevant literature.

2.2 Vehicle life emissions modelling

A specially formulated methodology, designated as Vehicle Life Emissions Modelling, is applied to assess the impact of OBD thresholds on the pollutant emissions during the useful life of a vehicle. The proposed methodology calculates the pollutant emissions as a function of vehicle mileage for a fleet of vehicles, taking into account the MIL activations and replacements of deteriorating parts during each vehicle's life. The target is to assess the evolution of the emissions of a representative fleet as a function of the applied OBD thresholds.

The principle idea underpinning this methodology is that the failures which should be detected by the OBD system can be divided into two categories:

- Failures not related to OBD thresholds. These are mostly electrical failures (disconnection or breaking of wires, short circuits, total sensor failures etc). These failures generate a clear monitoring result without any “grey band”: an electrical connection is either performing properly or it is defective. When an electrical failure occurs, the emissions will change immediately from a fixed level (emissions of the fault-free vehicle) to another fixed level (depending on the affected component or system).

- Failures related to OBD thresholds. These are failures that cause the emissions to increase steadily, and can be monitored against OBD thresholds. In order for the OBD system to identify those failures, the system must recognise deviations of sensed parameters. This will cause the OBD system to compare this deviation with its stored information and generate a response that can be correlated to an increase of the emissions. From all the monitored malfunctions, the ones that can be included in this category are lambda sensor deterioration and catalyst deterioration.

Further analysis of the two types of failures, and their effect on OBD system calibration will be presented in the following section. The failures of the first category will be diagnosed by any properly functioning OBD system, irrespective of the OBD threshold limit values. Therefore in order to identify the effect of OBD thresholds on pollutant emissions during a vehicle's life, one needs to take into account only the emission increase which is due to failures of the second category, i.e. lambda sensor deterioration and catalytic converter deterioration. For each of these components, a degradation function of mileage can be assumed or determined. Based on this function, the frequency of MIL illuminations and replacement of deteriorating parts can be calculated. This allows calculation of the emissions increase due to OBD thresholds related malfunctions, as a function of vehicle mileage, using different OBD policy options. Therefore, the emissions reduction potential from each policy option can be evaluated. Details for the application of this methodology and results are discussed in section 4.2.

This methodology is also extended to calculate the emission degradation functions for a fleet of vehicles, taking into account various statistical factors that may cause deviations between the emissions of each vehicle in the fleet.

The same methodology is also used to calculate the number of deteriorated parts which are detected by the OBD system and replaced, which is used as input for the calculation of the inspection and maintenance cost (see section 2.4).

2.3 Calculations of fleet emissions

As a next step, the mass of pollutants emitted from the entire fleet is calculated.

The cumulative mass of pollutants emitted is calculated for two reference time intervals: 2008-2015, and 2008-2023. In order to perform this calculation, both the total number and its age distribution of the Euro 4 level passenger cars for two reference years (2015 and 2023) are used. The data used for this purpose are based on the draft baseline of the TREMOVE model [4]. The distribution for the year 2023 was obtained by extrapolating the data of 2020.

Using the age distribution of the Euro 4 level vehicles and the respective mileage distribution, and taking the emission functions as input from the previous section, the cumulative mass of pollutants emitted during the above mentioned time intervals can be calculated.

This way, the comparative benefits to the environment can be potentially quantified as mass of pollutants saved by implementing different threshold limit values.

It has to be underlined that all fleet emissions calculations are based on the rough assumption that the emission factors of Euro 4 vehicles are equal to their cold start NEDC emissions. This approximation is necessary in view of the lack of available real-world emission factors for Euro 4 vehicles. Although the real emissions will probably be falsely (under-) estimated, the above assumption will not affect the comparative character of the analysis regarding the efficiency of different OBD policy options.

2.4 Cost effectiveness analysis

Stricter threshold limit values will probably require substantial modifications in the OBD technology for emission control. Therefore, additional investments in Research & Development and hardware will be required by the manufacturers. In order to examine the cost-effectiveness of each policy option for the proposed threshold limit values, we made an attempt to gather the necessary costs regarding the technologies and system components that are required to meet the desired values. These costs were gathered mainly from open literature, from ACEA's response to the questionnaire and via contacts with few suppliers involved in the OBD technology. Moreover, other similar studies were also used (mainly, from EPA [5] and CARB) for further cost comparison and estimation. The gathered costs can be classified in 3 main categories:

- Technology costs (e.g. Research and Development, Production, Hardware).
- Users' costs (e.g. time losses by driver).
- Inspection & Maintenance costs.

The cost-effectiveness analysis focuses, mainly, on vehicles equipped with positive ignition engines.

Based on these cost estimates, the study assessed whether the proposed threshold limit values will have positive or negative impacts on market structure compared to a baseline scenario, in order to establish whether the introduction of the new threshold limit values may affect the competition.

All the financial effects from the proposed threshold limit values are examined through the resulting Net Present Values (NPV) for the implementation and operation of each policy option. Thus, the incremental costs for each policy option are made available in order to assess the effectiveness of each one. These Values are then divided with the figure of reduced emissions in order to obtain the cost-effectiveness of each policy option. This way, all options can be compared, leading to the identification of the most cost-effective solution.

More specifically, the methodology that was followed for the calculation of cost-effectiveness of each scenario and was used to assess the economic impact that each one has on both consumers and manufacturers, is described by the following steps:

<u>Step 1</u>: Data gathering of costs for the implementation of every investigating scenario.

<u>Step 2</u>: Distribution of total abatement costs to each pollutant.

<u>Step 3</u>: Calculation of Net Present Value of costs, for two different investigating timeframes: from 2008 to 2015 and from 2008 to 2023, with 2004 as the reference year.

Step 4: Development of the total cost–effectiveness, from the resulting total emissions, for each scenario (in €/kg ≡ M€/ktonne pollutant avoided).

Step 5: Mapping of the outputs in the form of tables and figures (e.g. figures with cost-effectiveness for each pollutant for the different scenarios). Years 2015 and 2023 are considered to be our reference time points.

Step 6: Performance of sensitivity analyses with different values of the discount rate (or else, interest rate).

Step 7: Summary of the proposed regulatory steps.

2.5 Social impact analysis

The methodology that was followed for the identification and characterization of the social impacts of each investigated policy option is described below:

Step 1: External Impacts are defined as identical to the Social Impacts. For example, improved air quality, willingness of customers to purchase a more expensive and more environmentally friendly vehicle, viability of SMEs, etc. are all regarded as Social Impacts.

Step 2: Search of appropriate data from similar studies and according to the proposed form of an impact assessment from the EC [6].

Step 3: Development of an impact matrix, for capturing the most significant impacts, as for example in the following form:

Scenarios		**IMPACTS**				
		Impact to SMEs 1	**Impact to SMEs 2**	**Impact to consumers 1**	**Impact to consumers 2**	**etc**
Scenario I	Likelihood of an impact	Certain	Probable	Unlikely	Unlikely	
	Characterization of the impact	Positive	Negative	Uncertain	Positive	
Scenario II	Likelihood of an impact	Certain	Probable	Unlikely	Unlikely	
	Characterization of the impact	Positive	Negative	Uncertain	Positive	

Step 4: Development of a matrix capturing the main results, as for example in the following form:

Scenarios		Qualitative Description	Quantitative Description	Monetized Value
Social/ External impacts	Impact 1	Fewer health problems	100 deaths fewer every year	Not monetized
	Impact 2			
	etc.			

Step 5: Summary and recommendations.

3 Current experience with EOBD systems

3.1 Experience from vehicle manufacturers

3.1.1 Introduction – data sources

The manufacturer's experience is reviewed based on:

- The questionnaire included in appendix 2. ACEA has collected and compiled the answers of BMW Group, DC, Fiat, Ford Group, GME, Porsche, PSA, Renault and Volkswagen Group. Answers to the questionnaire were based on the knowledge and experiences gained during the OBD development phase on several vehicles (typically 20 vehicles per model/engine type and 100.000 km per vehicle). Moreover, Toyota has also responded actively to our invitation to complete the questionnaire.

- Presentations in SAE OBD TOPTEC meetings from 1998 to 2002, most important of which were the one from Ford (2002) [7], including data from fleet testing and Volkswagen (1998) [8].

- Two draft papers compiled by ACEA, which describe the position of ACEA on the definition of OBD thresholds [9, 10]

The basic findings seem to be common for most manufacturers. An analysis of the data gathered is presented in the following paragraphs. The information included in this section (3.1) stems directly from the sources listed above, and reflects their position.

3.1.2 Usefulness of OBD

The OBD system is considered to be an effective instrument for environmental protection. It detects emission-related failures timely and reliably and notifies the driver by means of a malfunction indicator (MI), as required by legislation. The OBD system has an improved ability to diagnose faults compared to the tests involved in periodic emissions measurements. Therefore, it helps reduce the time and mileage driven between failure and repair, therefore resulting in reduced pollutant emissions. Furthermore, the OBD system assists in cost-effective repairs of emission-related failures by providing fault codes and other information, for example values indicating the status of the engine at the first detection of a failure.

3.1.3 Failure types and OBD calibration

The task of designing, calibrating and proving an OBD system poses several technical difficulties and challenges for the manufacturers. The software and calibration must be fully validated to avoid the indication of false failures even in unusual operating conditions, for example extreme temperatures and altitudes, rapid changes of ambient temperature (e.g. from heated garages to cold ambient conditions), steep slopes, misuse of the vehicle. The indication of false failures would bring the OBD system in disrepute, thereby losing much of its benefits. The customers or manufacturers would have to pay for unnecessary repairs, and the legislators may lose a powerful instrument for the protection of the environment.

3.1.3.1 First failure type: continuously developing failures

Failures of this type may develop continuously and may therefore cause a continuous increase in emissions. Examples are the degradation of the catalytic converter efficiency, obstacles in the lines of secondary air or exhaust gas recirculation systems, or changes of sensor characteristics. The failures falling under this type are either listed in the regulation, as in OBD II, or are partially listed, while the rest is defined by the manufacturer, as in EOBD. In the latter case a failure must be monitored, if it in general may result in emissions exceeding the OBD thresholds. The OBD thresholds defined in the regulations are normally emission thresholds. All thresholds are defined as upper thresholds in a sense that failures must be indicated at the latest when the threshold is reached, but may also be indicated earlier. Lower thresholds are not defined. For practical purposes the type-approval (TA) emission limits are normally used by the manufacturers as lower thresholds, however in some cases manufacturers may also indicate failures even below the TA limits. The limited correlation between the development of a failure of this type and the increase of emissions, as discussed above, may be illustrated by the example of catalytic converter monitoring: No primary physical effect is available to determine the conversion efficiency of a catalytic converter. As a substitute OBD determines a secondary physical effect, the oxygen storage capability. The result of this measurement is usually very reliable. However, the correlation between the oxygen storage capability and the conversion efficiency may be very weak, depending on numerous conditions, one of the most important being the fuel quality. The effects discussed above can be summarised in Fig. 3.1:

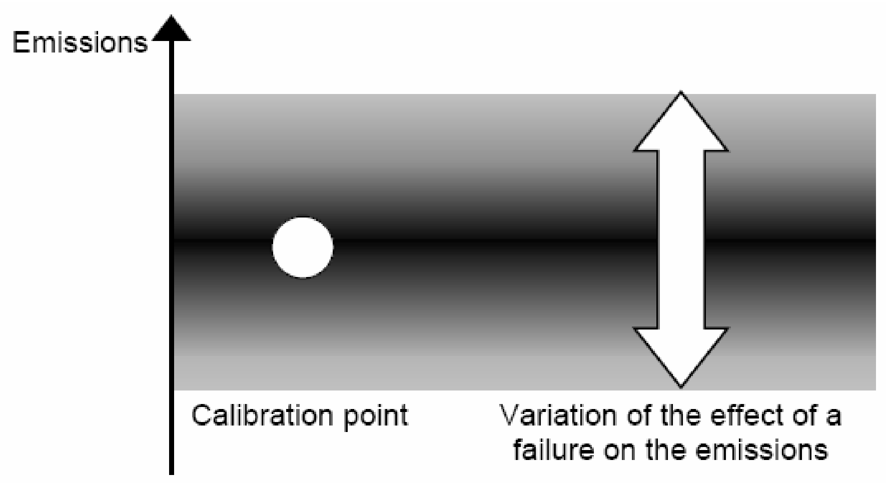


Fig. 3.1: Correlation between OBD failure indication and the effect of a failure on the emissions [10]

To determine the calibration point of an OBD monitor, strictly controlled conditions are necessary. Usually artificially deteriorated parts with stable failure parameters are used to simulate a malfunctioning component. With these parts and controlled ambient conditions, e.g. temperature and fuel quality, the simulated failure has a relatively constant effect on the emissions (calibration point in Fig. 3.1). Under the much less controlled conditions described above, e.g. real malfunctioning parts, variation from vehicle to vehicle and varying adaptation quality, the calibration point will enlarge to a variation band (grey band in Fig. 3.1). Also under the conditions in the field a failure will be detected at the same physical parameters as before, but the corresponding emissions may vary in the grey band (bandwidth dependent on the type of monitor). To guarantee that the whole band is below the OBD thresholds, as requested by the OBD regulations, the monitor calibration point must be set well below the OBD thresholds. It should be pointed out that neither the calibration point nor the variation band can be derived theoretically but must be measured and verified with testing on dynamometers and on the road under all ambient conditions.

With growing vehicle age the variation band normally rises towards higher emissions. To ensure that ageing does not compromise the timely detection of failures, OBD systems are calibrated and demonstrated on vehicles that are aged to the end of their useful life. All considerations apply only to single failures. An attempt to predict the emission effect of multiple failures would multiply the difficulties described above. Therefore all OBD regulations describe only single failures. The calibration and the behaviour of OBD systems for continuously developing failures is shown in Fig. 3.2:

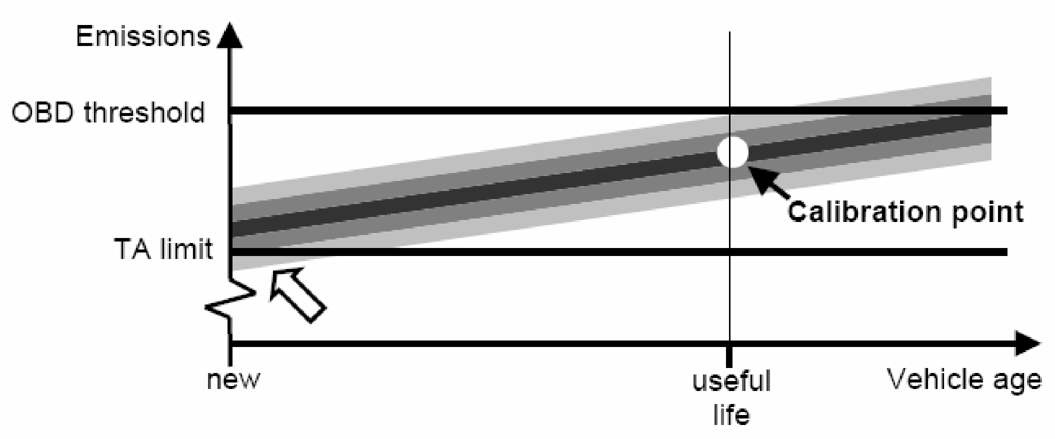


Fig. 3.2: Calibration and behaviour of OBD systems [10]

The figure shows the variation band between the failure detection and the emission effect and additionally the effect of vehicle ageing. It also shows how the variation band and the monitor calibration point must be placed between the TA limits and the OBD thresholds. To address the ageing effect, all regulations require that OBD systems are demonstrated using vehicles aged to the end of their useful life. To comply with this requirement, manufacturers must set the monitor calibration point well below the OBD thresholds to ensure that the complete variation band is below the OBD thresholds for vehicles at the end of their useful life and that therefore all failures are indicated before the OBD thresholds are exceeded. It is allowed to indicate failures at any emissions below the OBD thresholds, also below the TA limits. However, if the distance between the TA limits and the OBD thresholds, called the OBD working gap, is sufficiently wide, it is possible to indicate failures also on new vehicles only when the TA limits are exceeded. Only few exceptions should arise under these conditions (grey triangle below the TA limits at the "new" point, marked by an arrow).

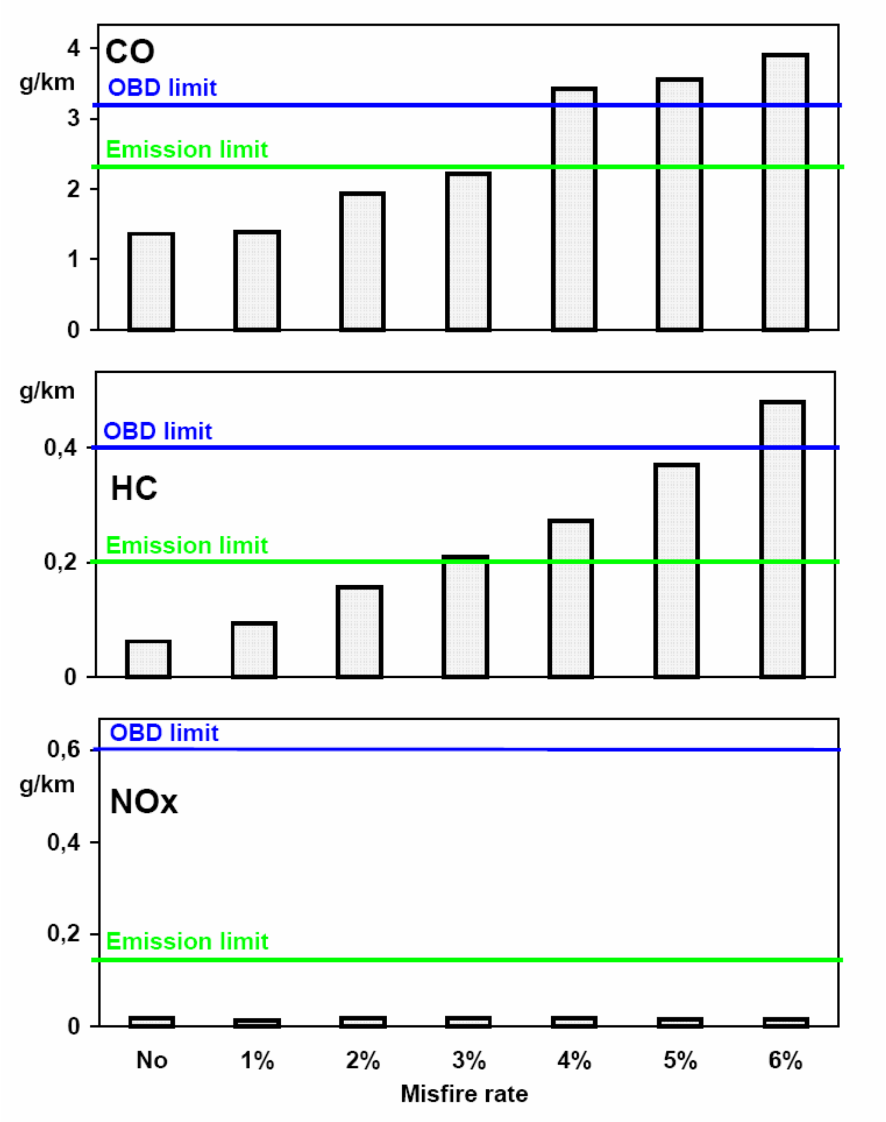


Fig. 3.3: Effect of increasing misfire rate on NEDC pollutant emissions [8]

Failures of this type include catalytic converter deterioration, which may be due to thermal ageing or poisoning and lambda sensor deterioration, which is also attributable to poisoning. Misfire, by nature could be considered a continuously developing failure, as different levels of misfire cause increase in pollutant emissions, as shown in Fig. 3.3. However, in the real world there are no known failures which can cause misfire levels lower than 20%. Fig. 3.3 shows that even Euro 3 OBD thresholds are expected to be exceeded, when a misfire rate higher than 5% occurs. Therefore, in real applications, for

OBD purposes, misfire is treated as a rapidly developing failure, because as soon as misfire occurs, the OBD thresholds will be exceeded whatsoever.

3.1.3.2 Second failure type: Rapidly developing failures

Failures of this type are normally circuit continuity failures of electrical components (short circuit to ground or battery plus, open circuit). Circuit continuity failures can be detected without any doubt. However, these failures cannot be correlated to thresholds because the effect on the emissions is a step function that may be in the range from unchanged to the multiple of the OBD thresholds. Moreover, the amount of the step change cannot be predicted in most cases. The powertrain control modules contain many open-loop controls, closed-loop controls and adaptations that form a net of mutual dependencies. The reaction on circuit continuity failures depends on the actual condition of this net. As a consequence, the effect of a circuit continuity failure of e.g. a sensor on the vehicle emissions may not only vary from vehicle type to vehicle type, but also from vehicle to vehicle of the same type and even from day to day on the same vehicle. An extreme example is a circuit continuity failure of the most important sensor, the front oxygen sensor. This sensor provides a closed-loop correction to the fuel injection quantity that is calculated from engine speed, load, temperatures, etc. Additionally, a feedback algorithm called adaptation sets the value of a corrective term to the fuel quantity calculation in a way that the average amount of the closed-loop correction becomes zero. If the vehicle is perfectly adapted when a circuit continuity failure occurs, the air-fuel ratio may stay close to stoichiometric and the effect on emissions may be negligible. On the other hand, when the vehicle is not adapted or when ambient conditions (temperature, elevation, fuel quality, etc.) change, there may be a dramatic emission effect of the same failure.

3.1.4 Experience from fleet testing

According to the responses received by the manufacturers, the most common malfunctions, in order of frequency of appearance, are included in Table 3.1. The results are qualitative, as the manufacturers are reluctant to provide detailed data on the frequency of appearance of each malfunction, for reasons of confidentiality.

According to the Ford fleet testing data [7], approximately 40% of the failures triggering MIL illumination result in small emissions increase, and the vehicle may still meet type approval emission standards. The majority of these failures are expected to be electrical failures. Another 40% of the failures cause the vehicle emission to exceed type approval limits, but still not exceed OBD thresholds by more than 20%, while the remaining 20% of the failures cause the vehicle to become a high emitter, emitting more than 1.2 times the OBD threshold. At the initial stages of EOBD, a significant amount of MIL activations has been attributed to false failures, due to bugs in the diagnostic software. According to respective data from other manufacturers, these percentages are 0% (failures resulting to emissions below type approval limit), 30% (between type approval limit and OBD threshold) and 70% (greater than the OBD threshold).

Table 3.1: Most common malfunctions, which induce MIL activation.

1	Misfire
2	Oxygen sensor (front)
3	Catalytic converter
4	Coolant temperature sensor
5	Oxygen sensor (rear)
6	Fuel system components

Regarding readiness status issues, real world data by Ford indicate that approximately 80% of vehicles have completed all their OBD monitors within 200 km of normal use (Fig. 3.4). Experience from other manufacturers shows that 10-50 km of mixed driving conditions may be sufficient for most algorithms to execute.

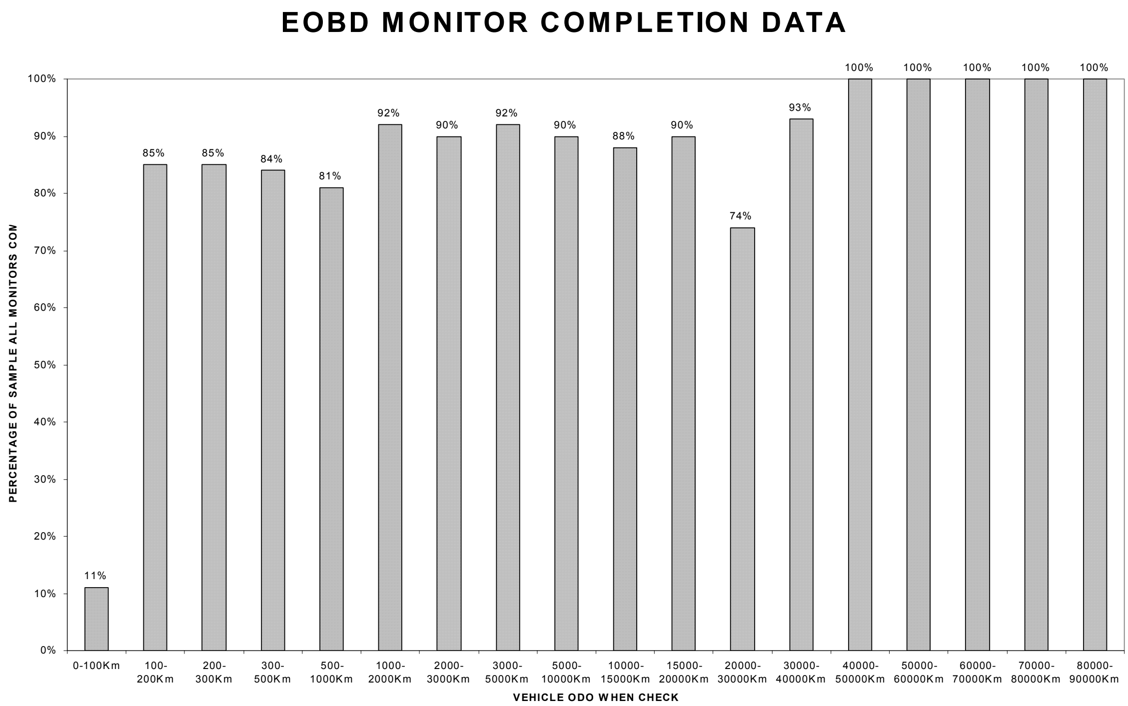


Fig. 3.4: EOBD monitor completion data [7]

Finally, according to the manufacturers, the driver's driving style may affect the OBD system performance under certain circumstances, such as driving in congested city traffic. On the other hand, OBD system operation is not expected to be affected by the country where the vehicle is used, provided that the fuel used meets the EU standards.

3.2 Experience from vehicle maintenance

The effects of EOBD systems in the maintenance procedure have been investigated by contacting workshop owners and repair technicians. According to them, it appears that OBD is a powerful tool, which allows fast and accurate diagnosis of failures. Compared to previous diagnostic systems, the main advantages of OBD in the diagnosis and repair procedure are:

- Shorter times for connection and communication with the ECU
- Easier connections, since only one port is used
- More user friendly diagnostic system – requires less time for training
- Universality

The independent workshops have profited the most from the application of EOBD, since the cost of the respective equipment is significantly lower than the cost of older diagnostic equipment, and the universal applicability of OBD systems allows a workshop to diagnose and repair failures in vehicles of more than one manufacturer, which is very important for the independent workshop for broadening the target group of potential clients. These benefits will become even more important if the OBD regulations are extended to other vehicle subsystems apart from the engine, such as brakes, traction control systems, safety systems etc. On the other hand, the workshops affiliated with a single manufacturer have seen less significant benefits from the use of OBD.

Regarding the customer perception of EOBD system, the workshop owners and technicians reported that for the vehicle user the OBD system may create a hassle, especially when the MIL illuminates too often. Since most users are not aware of the mission and function of the OBD system, it is unlikely that they will develop a feeling of confidence in technology towards an OBD-equipped vehicle. Therefore, despite the obvious advantages of diagnosing malfunctions in time (especially for less experienced drivers, who would not notice the presence of a malfunction otherwise), the customers develop a rather negative perception of the OBD system. This is made worse by some workshops, which take advantage of frequent MIL illumination to charge excessive prices for repairs which are not necessary at that time.

4 Impact assessment of different policy options

4.1 Description of policy options

4.1.1 OBD threshold levels

Four different OBD threshold levels are examined, to highlight the environmental, financial and social effects of OBD thresholds for Euro 4 compliant, gasoline lambda-1 passenger cars. These OBD threshold levels are briefly examined below:

1. **The "no policy change" approach**: according to this approach, no new OBD threshold limit values are introduced for Euro 4 level vehicles. Instead, the OBD thresholds used for Euro 3 level vehicles are applied. This scenario involves an increased difference between type approval emission limits and OBD thresholds. This scenario represents the current status in the EU, where vehicles certified as Euro 4 compliant use OBD systems calibrated to meet the Euro 3 threshold limit values.

2. **The "standard decision tolerance" approach**: this approach assumes that the OBD threshold limit values will be reduced compared to the ones applied in Euro 3 level vehicles, but will maintain a constant "decision tolerance" between the type approval limit and the OBD threshold for each pollutant. This scenario reflects the position of the European Commission for Euro 4 OBD, as expressed in [3].

3. **The "proportional reduction" approach**: this approach assumes that the OBD threshold limit values will be reduced proportionally to the reductions of TA limits between Euro 3 and Euro 4, i.e. the same ratio of OBD threshold to type approval limit will be maintained in Euro 4 level vehicles. This ratio is different for each pollutant. This scenario results in more stringer OBD thresholds.

4. **The "California approach"**: according to this approach, the OBD thresholds are set to a value equal to 1.5 times of the type approval limit. This is probably the most stringer approach that can be adopted.

Based on the above, the OBD threshold limit values for each different level for Euro 4 vehicles are summarized in Table 4.1.

It is interesting to present the differences in the OBD policies in terms of conversion efficiencies of the emission control system. The analysis assumes that the raw emissions of the engine remain stable, and therefore OBD is required to detect the reduction in the conversion efficiency of the catalytic after-treatment system. Moreover the analysis is based on values of the raw emissions taken from our experience with mid-size Euro 3 passenger cars. However, it is expected that the level of raw emissions will not be substantially different in Euro 4 vehicles, as confirmed by the ACEA answers to the questionnaire.

Table 4.1: Type approval limits and OBD thresholds for M category vehicles, according to the examined scenaria [g/km]

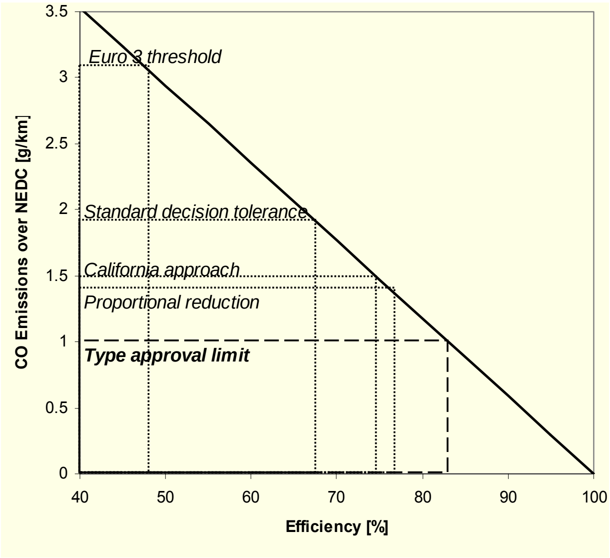
	Euro 4 Type approval limit	OBD thresholds			
		1. No policy change	2. Standard decision tolerance	3. Proportional reduction	5. California approach
CO	1	3.2	1.9	1.4	1.5
HC	0.1	0.4	0.3	0.2	0.15
NOx	0.08	0.6	0.53	0.32	0.12

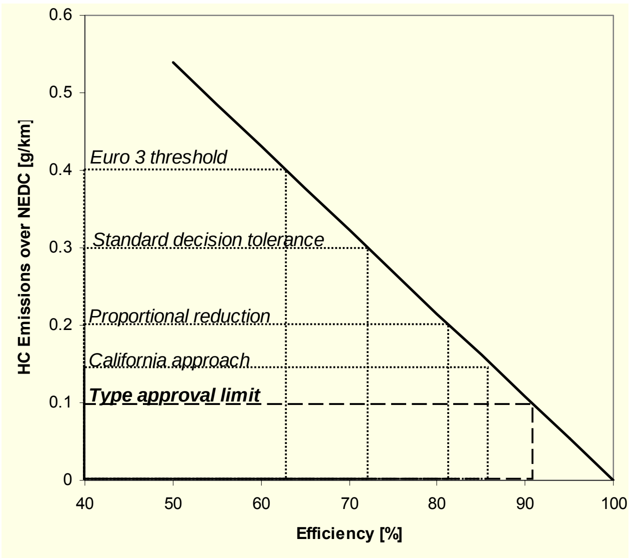
From the Euro 4 data available up to now (e.g. [13]), it is expected that the manufacturers achieve certification levels equal to appr. 50% the type approval limit (Fig. 4.1). Taking HC as an example, the initial conversion efficiency of the system would be appr. 95%. The Type approval limit will be exceeded as soon as the efficiency drops to 90%. With the Euro 3 OBD thresholds, the MIL should be illuminated before the efficiency falls to 63%, which seems really low. With the proposed “standard decision tolerance” thresholds, the respective “threshold” efficiency would be 72%. The threshold efficiencies for the “proportional reduction” policy would be 82% and for the California appr. 86%.

For CO, the Euro 3 threshold would require MIL illumination at a conversion efficiency of the order of only 50%. With the standard decision tolerance, the threshold efficiency increases to 68%, which seems technologically feasible. With the more stringent “proportional reduction” policy, the threshold efficiency increases to 77%.

In the case of NOx one would assume that the thresholds in the OBD threshold levels 1, 2 and 3 are very relaxed looking at the absolute emissions values of Table 4.1. The picture is somewhat different if one looks at the “efficiency thresholds”. According to these, even with the most relaxed Euro 3 threshold, the MIL should illuminate at a conversion efficiency of appr. 70%, which increases to 75% in the case of “standard decision tolerance” policy. With the adoption of a proportional reduction policy the threshold efficiency would go up to 85% and in the case of the California approach the threshold efficiency would be appr. 93%.

It has to be stressed once more that the above calculations depend strongly on the raw emissions of the vehicles which may vary significantly over the engine size range and also on the manufacturer engine tuning strategies.





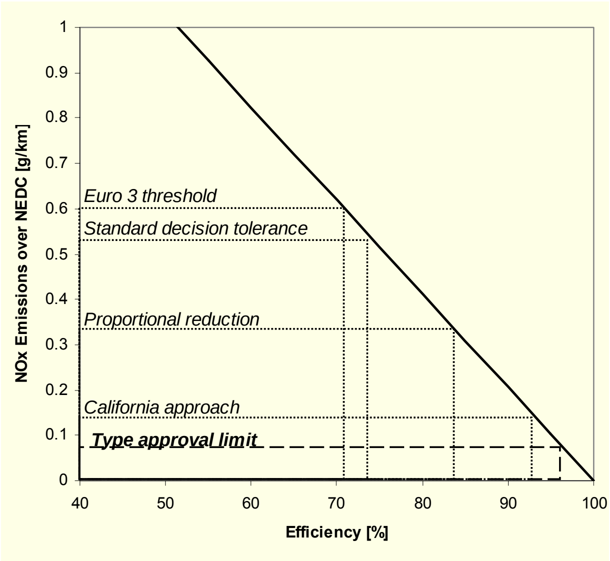


Fig. 4.1: OBD thresholds for different OBD threshold levels, expressed in terms of emission control efficiency (raw emissions are assumed equal to Euro 3 representative vehicles)

4.1.2 Implementation of new OBD thresholds

The initial target of the Commission was to introduce the new OBD thresholds on 1.1.2005. However, given that this report is compiled in the middle of 2004, the implementation of the different OBD threshold levels presented in the previous section needs to take into account the following issues and restrictions:

- The introduction of new OBD thresholds, taking into account the time required for a change in the legislation, and the required lead time by the manufacturers, seems difficult to be performed before 2008.
- Even longer lead time may be required by the manufacturers, in case the OBD thresholds are stricter than the ones proposed by the Commission ("Standard decision tolerance" approach)

- Euro 5 level vehicles are planned to be introduced in 2010, therefore it may appear rational to have the introduction of new OBD thresholds at the same time.

Based on the above, 8 different policy options are examined regarding the implementation of new OBD threshold limit values, all starting on 1.1.2008. These policy options are described in Table 4.2.

Table 4.2: Different policy options examined, regarding the implementation of new OBD threshold limit values

Policy Option	2008-2010	2010-2012	2012-2023
1	No policy change		
2	Standard decision tolerance		
3	Standard decision tolerance		Proportional reduction
4	Standard decision tolerance		California approach
5	No policy change	Proportional reduction	
6	No policy change	California approach	
7	Proportional reduction		
8	California approach		

4.2 Vehicle life emissions modelling

As mentioned in the Methodology section, a specially formulated methodology is applied to assess the effect of OBD thresholds on the pollutant emissions during the vehicle's life. This methodology relies on the calculation of emissions increase due to malfunctions related to OBD thresholds, as a function of mileage. These malfunctions include lambda sensor deterioration and catalytic converter deterioration. Other failures detected by the OBD system, and their effects on pollutant emissions are not modelled by this methodology, since they are not related to OBD thresholds.

4.2.1 Emissions from a single vehicle

At any given time, the emissions from a single vehicle is calculated by the formula

$$E = E_{init} + \Delta E_{lambda} + \Delta E_{cat} \qquad \textbf{Eq. 4.1}$$

where E_{init} is the emission of the new vehicle over NEDC, ΔE_{lambda} is the emission increase due to lambda sensor deterioration and ΔE_{cat} is the emission increase due to catalyst deterioration. As a fair approximation, the last two terms can be considered as polynomial functions of mileage, i.e.

$$\Delta E_{lambda} = a_{lambda} \cdot M^5 \qquad \textbf{Eq. 4.2}$$

$$\Delta E_{cat} = a_{cat} \cdot M^{5}$$ **Eq. 4.3**

The effect of emissions increase on mileage is assumed to be a power function rather than a linear function. This is based on the assumption that the effect of a “physical” system deterioration (lambda sensor or catalyst) on tailpipe emissions is not linear. Under the term “physical” deterioration in the case of a catalyst one may understand the reduction in catalytically active surface area or the oxygen storage capacity. For the lambda sensor the respective deterioration would involve the reduction in electrochemical activity and/or increase in response time due to chemical poisoning. Although these “physical” mechanisms can be assumed to be linear functions of mileage, their effect on emissions is not linear. This has been illustrated in a modelling study for the case of catalytic converters in [11]. In this context, although the value of 5 selected for the exponent of the power function is at this stage rather arbitrary, it is used, nevertheless, to reflect a realistic evolution of the emissions of an average vehicle, taking into account the useful life guaranteed by the manufacturer.

A typical example of the emissions increase due to catalytic converter and lambda sensor deterioration for an average vehicle is depicted in Fig. 4.2. A "baseline" deterioration factor is determined both for the catalytic converter and for the lambda sensor, based on previous emission degradation measurements [12], and discussions with component suppliers.

According to these curves, for an average Euro 4 vehicle, the lambda sensor will be able to work efficiently, keeping the emissions below type approval limits, for a mileage of about 100 000 km. The respective mileage for the catalyst is appr. 150 000 km.

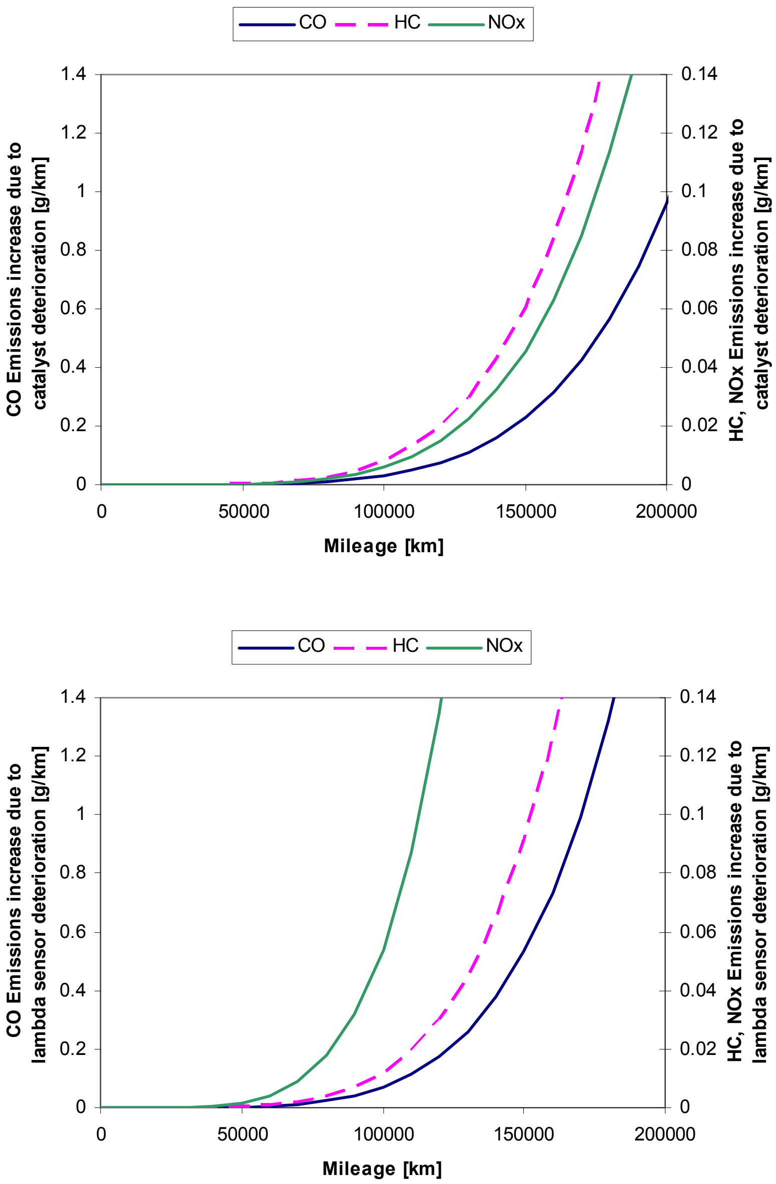


Fig. 4.2: Emissions increase over NEDC due to catalytic converter (top) and lambda sensor (bottom) deterioration for an average vehicle

The OBD system is calibrated to illuminate the MIL, when the monitored parameters reach a level which corresponds to a specific emissions level. However, due to the loose correlation between monitored parameters and tailpipe emissions (e.g. correlation between catalyst oxygen storage and HC emissions), the calibration point may be anywhere within the "decision area", which is the emissions area where the OBD system should detect a malfunction and turn the MIL on. This area is defined by the lower diagnosis threshold, TL and the higher diagnosis threshold, TH. The width of this decision area is linked to the capabilities of the diagnostic technologies. With advanced calibrations based on more sophisticated software and more in-use experience the magnitude of this decision area can be reduced. However, significant reductions would probably require additional hardware, such as linear oxygen sensors and possibly NOx sensors.

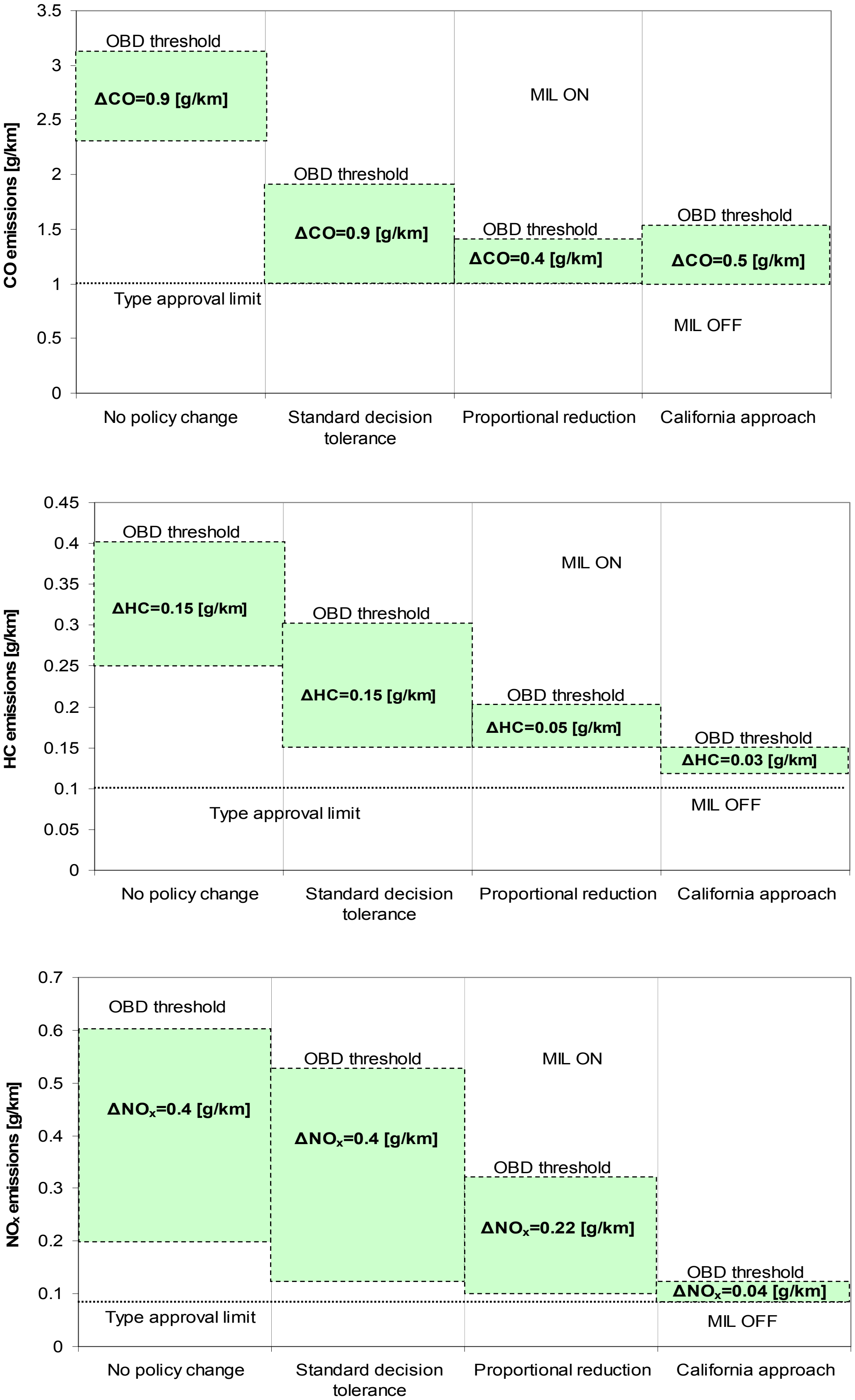


Fig. 4.3: Schematic description of the OBD system decision areas assumed for the calculations for the different OBD threshold levels examined

Fig. 4.3 presents the OBD system decision areas we assumed for the calculations. As a first approximation, we assume that the decision area for the current OBD threshold and current diagnostic technologies is smaller than the deviation between type approval limit and OBD threshold. Therefore, for HC the width of the decision area is ΔHC=0.15 [g/km]. In the case of threshold level 2, the width of the decision area remains unchanged, because the same diagnostic technologies are expected to be used. In the cases of threshold levels 3 and 4, the bandwidth is expected to be smaller, using new diagnostic technologies that will allow more accurate diagnosis (at increased cost). The lower and higher limits of the detection area for each scenario examined are included in Table 4.3.

When the pollutant emissions increase above TL, the OBD system enters the decision area. The two deteriorating components (lambda sensor and catalytic converter) are essentially monitored independent of each other. This means that each diagnostic algorithm may correlate the state of each component to the emissions increase caused by that particular component, and not to the total emissions of the vehicle. As a result, the necessary conditions for the OBD system to enter the decision area are:

$$E_{init} + \Delta E_{lambda} \geq TL \text{ or} \quad \textbf{Eq. 4.4}$$

$$E_{init} + \Delta E_{cat} \geq TL \quad \textbf{Eq. 4.5}$$

Once the pollutant emissions increase to a level, which causes the OBD system to enter the decision area, the time when MIL illuminates depends on the mileage driven since the vehicle has entered the decision area, and the pollutant emissions level, *E*. For the needs of this study, for each vehicle which has entered the OBD system decision area, the emissions level at which the MIL illuminates is considered to be equally dispersed within the decision area. This means that each point inside the detection area shown in Fig. 4.4, the OBD system has an equal probability to illuminate the MIL.

Table 4.3: Maximum mileage M_{max} required for a vehicle with emissions equal to the higher diagnosis threshold to be detected by the OBD system [km] and decision area limits [HC g/km]

OBD threshold levels	Decision area					
	CO		HC		NOx	
	TL [g/km]	TH [g/km]	TL [g/km]	TH [g/km]	TL [g/km]	TH [g/km]
1. No policy change	2.3	3.2	0.25	0.4	0.2	0.6
2. Standard decision tolerance	1	1.9	0.15	0.3	0.13	0.53
3. Proportional reduction	1	1.4	0.15	0.2	0.10	0.32
4. California approach	1	1.5	0.12	0.15	0.08	0.12

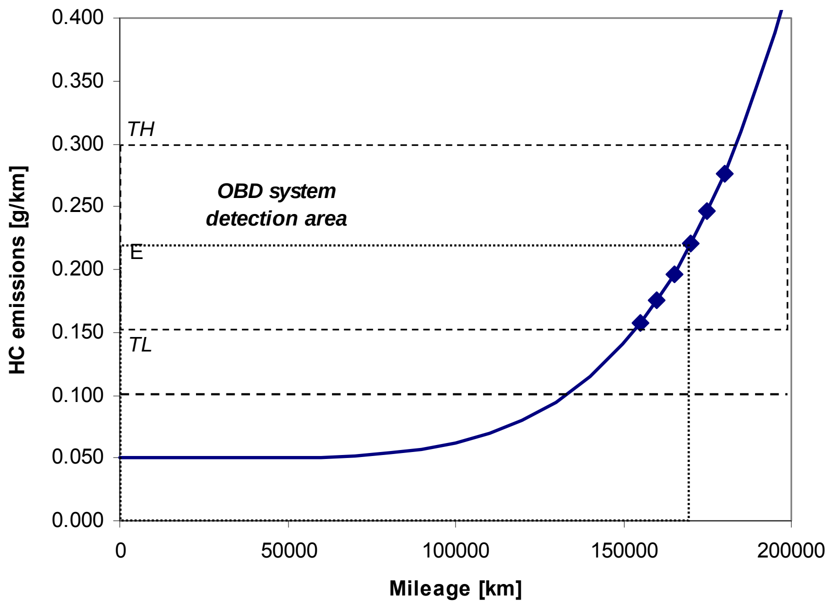
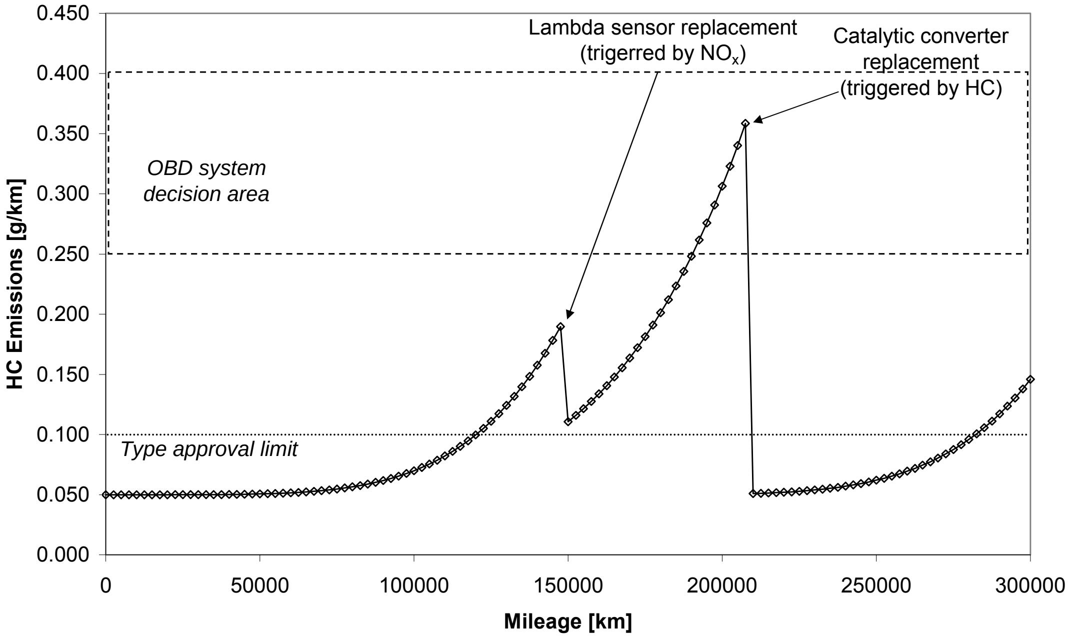


Fig. 4.4: Schematic description of the parameters affecting MIL illumination, once the pollutant emissions exceed the lower limit of the detection area (TL)

Once the MIL is activated, the deteriorated part which caused the activation is replaced, and the respective emissions increase term in Eq. 4.1 is set to zero. The time between MIL activation and failure repair is not considered in the present study, since it can be easily lumped into the time required for MIL activation.

A typical emission vs. mileage plot for a single vehicle is plotted in Fig. 4.5. The first plot presents the HC emissions and the second plot the NOx emissions of a vehicle with the baseline deterioration factors, operating under the "no policy change" scenario, i.e. the OBD thresholds are the same as in Euro 3. Due to the higher sensitivity of NOx emissions on lambda sensor deterioration, the NOx emissions rise faster as the lambda sensor deteriorates, and this increase in NOx emissions triggers the OBD system which detects the need for a lambda sensor replacement. On the other hand, the OBD algorithm for catalytic converter replacement is triggered by the increase in HC emissions. Since the OBD thresholds are significantly higher than the type approval limits, the malfunctioning parts are replaced after they have undergone a relatively severe deterioration.



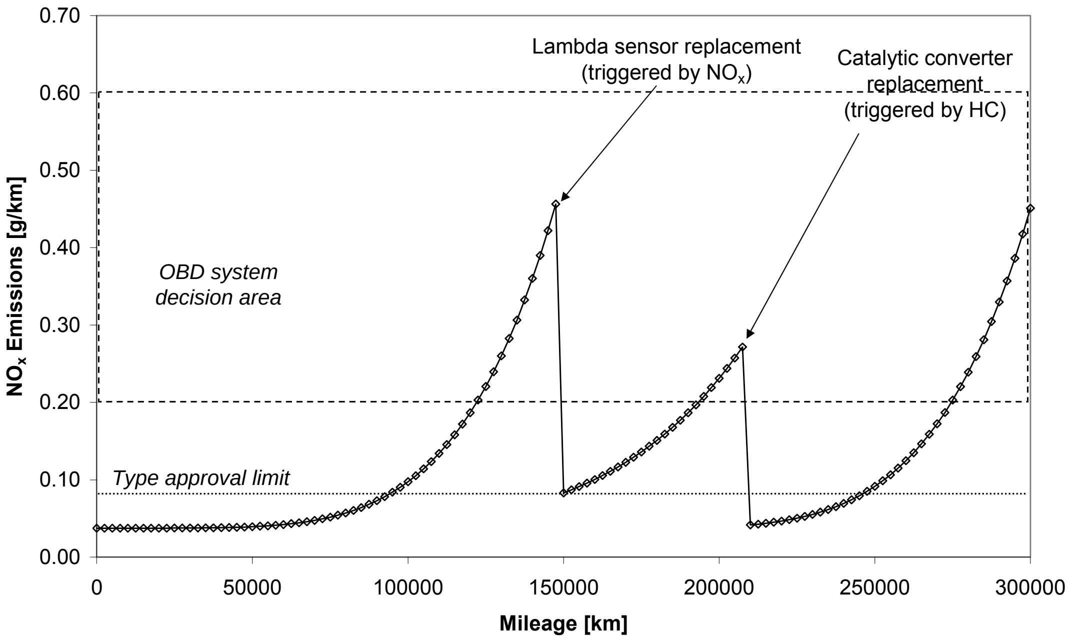
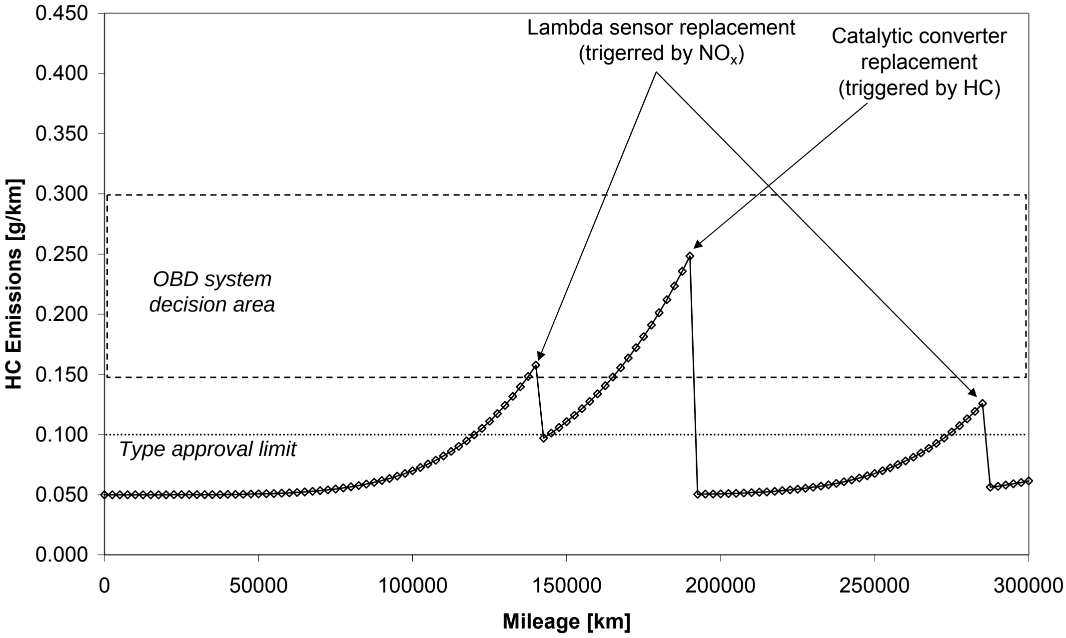


Fig. 4.5: Calculated pollutant emissions (over NEDC) vs. mileage, for an average vehicle complying with the OBD regulations of the "no policy change" scenario. HC (top) and NOx (bottom).

Fig. 4.6 presents the same vehicle operating with the "standard decision tolerance" scenario, which corresponds to the OBD thresholds proposed by the Commission. In this case, MIL illuminations are more frequent, and part replacements are necessary more often, thus resulting in a benefit for air quality.



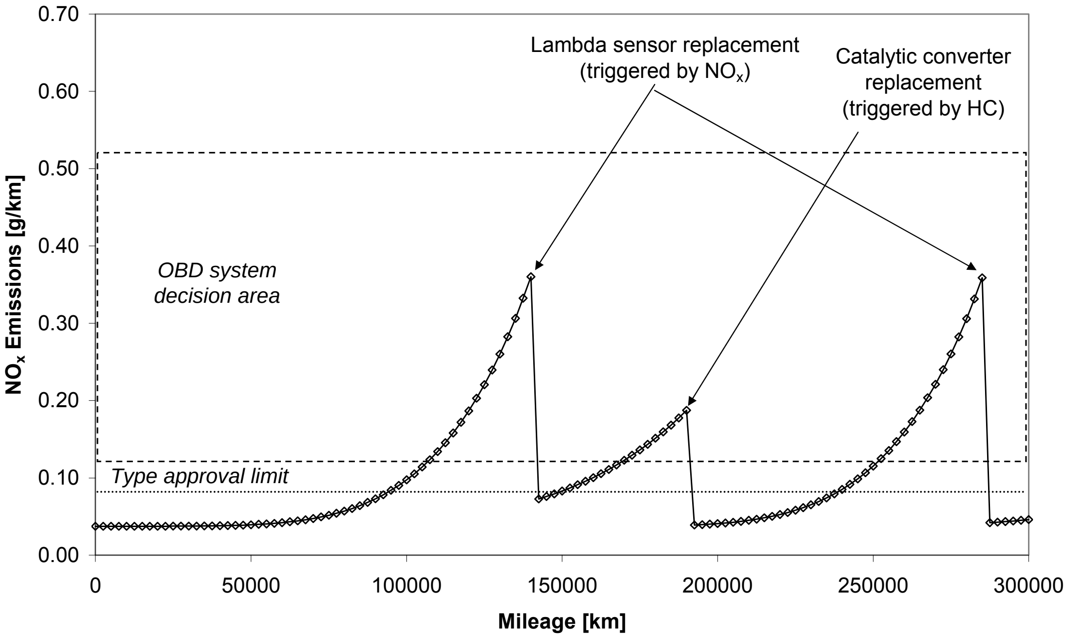


Fig. 4.6: Calculated pollutant emissions (over NEDC) vs. mileage, for a vehicle complying with the OBD regulations of the "standard decision tolerance" scenario. HC (top) and NOx (bottom).

The same plots expressed in terms of conversion efficiency vs. vehicle mileage, are shown in Fig. 4.7. It is demonstrated that under the "No policy change" scenario, the MIL is triggered at pollutant conversion levels of 70-75%, while in the "Standard decision tolerance" approach the respective efficiency levels at which the MIL is triggered are in the order of 80-85%. As mentioned in Section 4.1.1, the calculation of the efficiency is based on values of the raw emissions taken from our experience with mid-size Euro 3 passenger cars, assuming that the raw emissions have negligible degradation with vehicle mileage.

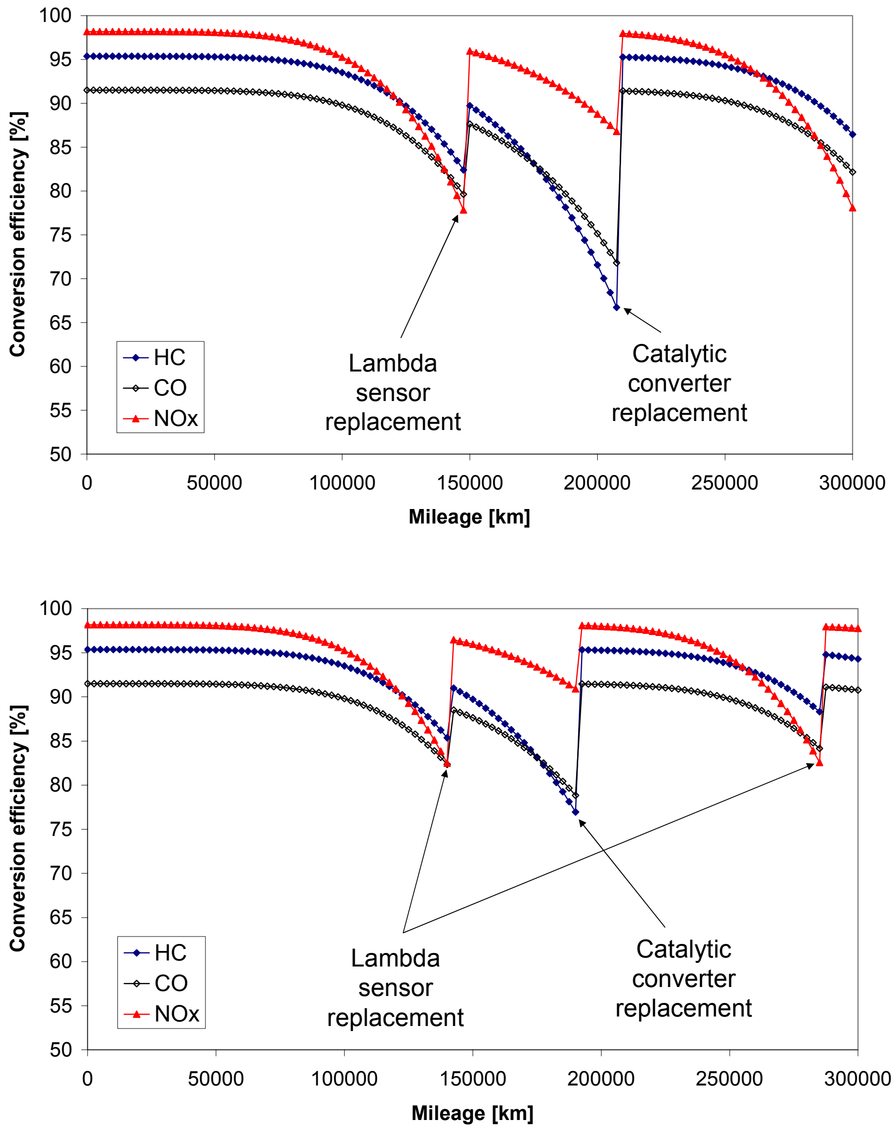


Fig. 4.7: Calculated conversion efficiency (over NEDC) vs. mileage, for a vehicle complying with the OBD regulations of the "no policy change" approach (top) and the "standard decision tolerance" approach (bottom).

4.2.2 Emissions from a fleet of vehicles

The methodology presented above, which calculates the emissions during the life of a single vehicle, can be extended to calculate emissions from a fleet of vehicles. For this purpose, the following factors are considered, to account for the statistical deviation of the emissions between different vehicles:

- Some vehicles/components may present faster deterioration rates than others. Therefore, the values of a_{lambda} and a_{cat}, used in Eq. 4.2 and Eq. 4.3 are expected to present a statistical distribution among the different vehicles. Starting from the baseline values, which were determined based on previous emission degradation measurements [12], and discussions with component suppliers, an artificial distribution of deterioration factors was created, assuming that some vehicles or components will present faster degradation than the average vehicle while others slower. Thus, five different bins were created, according to the component degradation factors. 50% of the vehicles in the fleet are assumed to have the baseline deterioration factors, and the rest are divided in the other four bins. An example of the distribution of the degradation factors for the case of HC emissions is shown in Fig. 4.8.

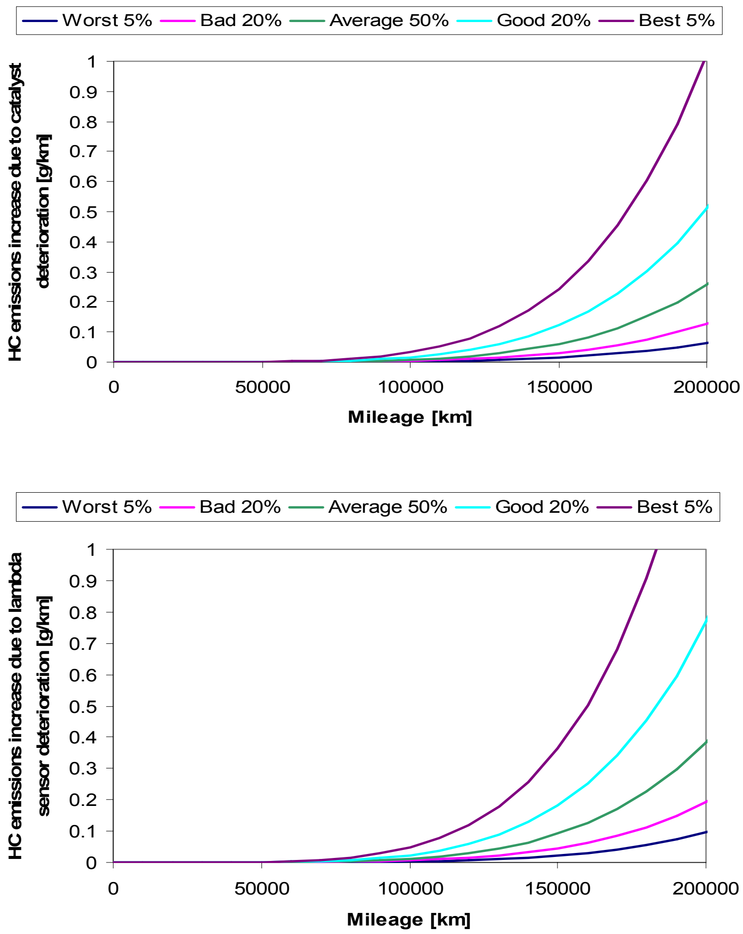


Fig. 4.8: HC Emissions increase due to catalytic converter (top) and lambda sensor (bottom) deterioration for vehicles with different degradation factors

Taking into account the statistical differences in the deterioration rates of catalytic converter and oxygen sensor, the emissions during the vehicle useful life, as well as the number of parts that require replacement may present variations from vehicle to vehicle. Fig. 4.9 presents the HC emissions during a vehicle's life, for vehicles with different component deterioration rates. It is observed that the "best" performing components require fewer replacements and result in lower emissions during the vehicle life, as expected. It can be seen that the lambda sensor is replaced before HC emissions exceed the lower MIL activation threshold. In these cases the diagnostic is triggered by NOx emissions increase.

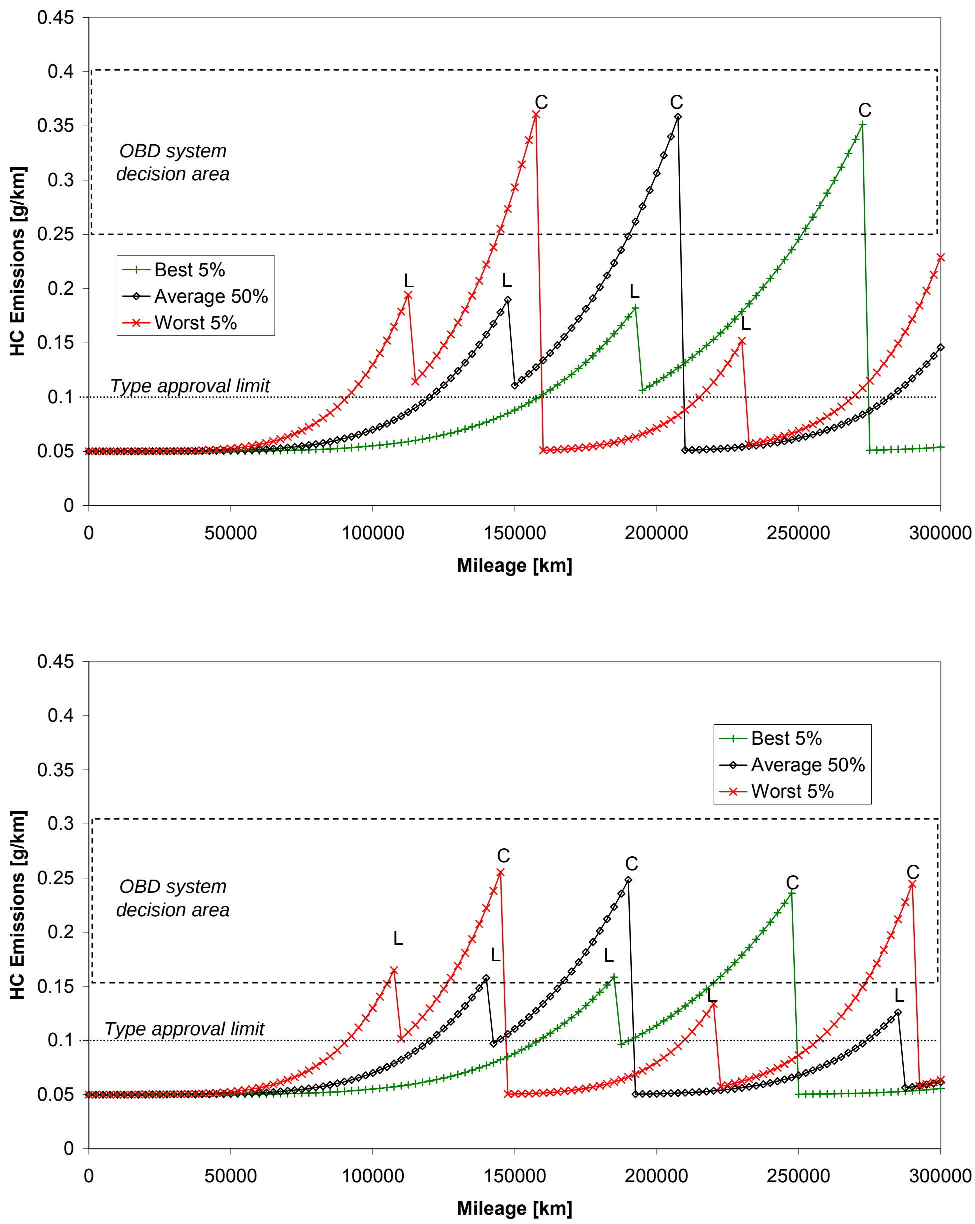
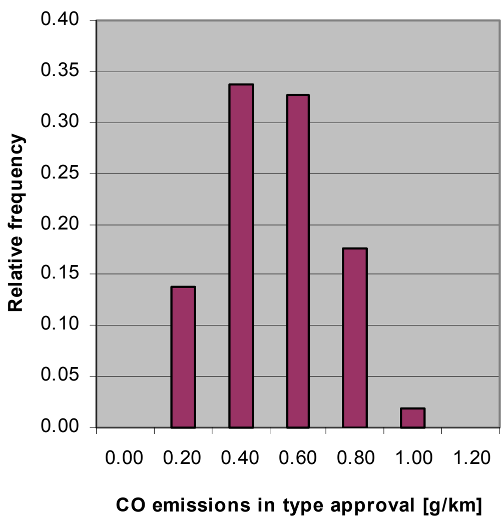
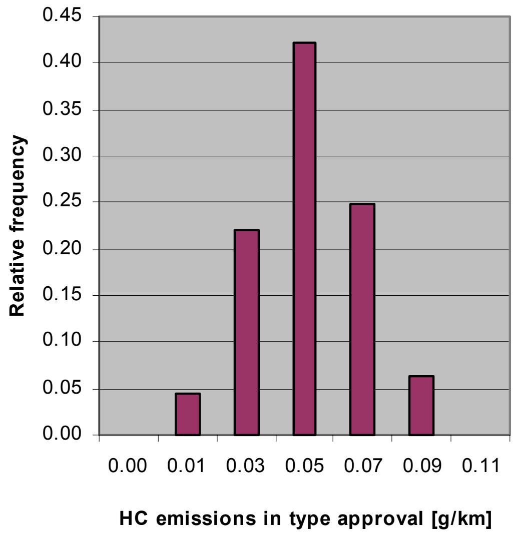


Fig. 4.9: Hydrocarbon emissions vs. mileage, for vehicles with different deterioration rates, complying with the OBD regulations of the "no policy change" scenario (top) and the "standard decision tolerance" scenario. L=lambda sensor replacement, C=catalytic converter replacement

- Not all vehicles have the same levels of initial emissions, when they are new. This affects the frequency of MIL illuminations, since a vehicle with high initial emissions may require part replacement more often. Therefore, five different bins of vehicles were created, according to their initial emissions. Data for the initial emissions of Euro 4 level vehicles were taken from the UK type approval [13]. The distribution of initial emissions for each bin is shown in Fig. 4.10.





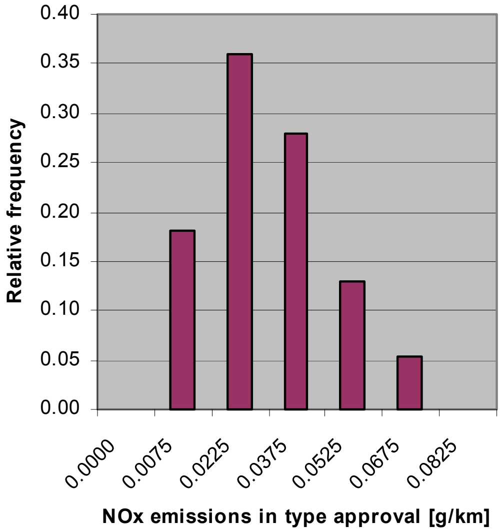


Fig. 4.10: Classification of Euro 4 vehicles in bins according to the pollutant emissions during type approval.

- Even vehicles with the same initial emissions and the same emission degradation factors may present different behaviour of the OBD system, and therefore different tailpipe emissions, due to the stochastic parameters involved in the detection of a malfunctioning component. Therefore, the vehicle life emissions calculation was repeated 10 times for each vehicle, in order to dampen such stochastic effects.

This way an artificial fleet, consisting of 250 vehicles, was created:

5 (deterioration level bins) x 5 (initial emission bins) x 10 (vehicles in each bin) = 250

The pollutant emissions factors in [g/km] over the first 300000 km of the life of a vehicle was calculated for each of the above mentioned vehicles, and a weighted average of the fleet emission factors as a function of mileage is calculated. As an example, the fleet CO emissions as function of mileage for the first two OBD threshold levels are plotted in Fig. 4.11. It is observed that after a certain mileage, which is between 100000 and 150000 km, the emissions appear to have a periodic oscillation, which is due to the periodic replacement of malfunctioning parts, identified by the OBD system.

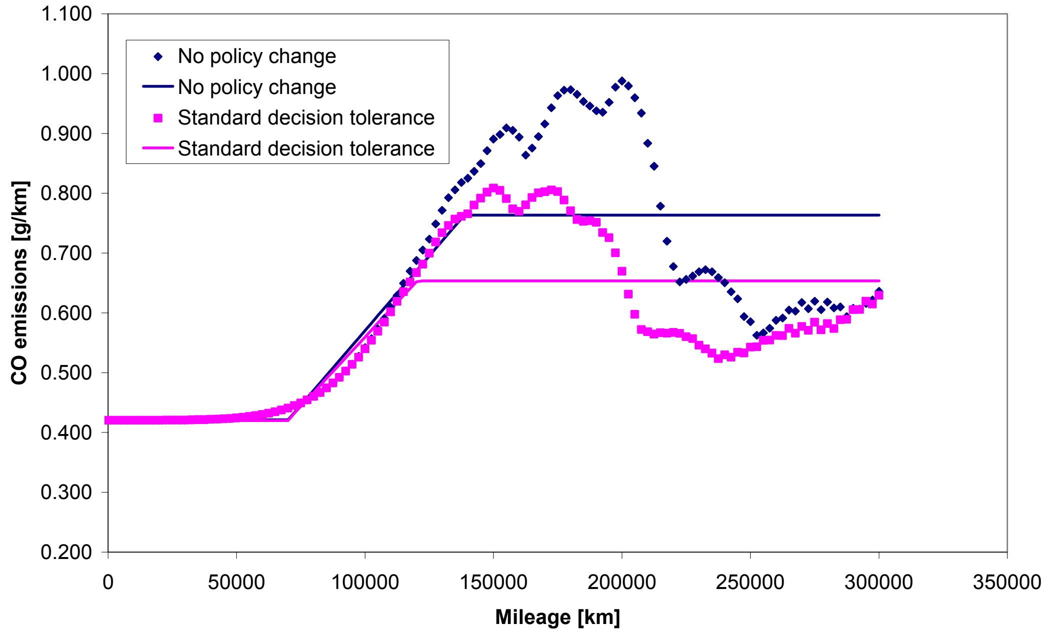


Fig. 4.11: CO emissions over the NEDC for the artificial fleet of vehicles, as a function of mileage. The dots represent the emissions of the representative 250 vehicles fleet. The lines represent the simplified linear trend used in the analysis.

In reality, for much larger fleets, this periodic oscillation is expected to be significantly less pronounced due to the statistical variability. Therefore, it would be sufficient and simpler to assume a three stage function of emissions versus mileage. In the first stage, which lasts approximately 70000 km, vehicle emissions remain constant; in the second phase, vehicle emissions begin to rise due to deterioration of the catalytic converter and lambda sensor; in the third phase, fleet emissions are stabilised to a higher level, which is the mean value of the emissions oscillation due to periodic part replacement. Similar considerations can be made for all pollutants and all threshold levels. In all cases, the linearization is done in such a way as to ensure that the integral emissions in each separate stage are the same in both approaches.

Following the same rationale, we may derive simple linear emission degradation functions for all three pollutants and for each set of OBD threshold levels considered. The resulting degradation functions are shown in Fig. 4.12.

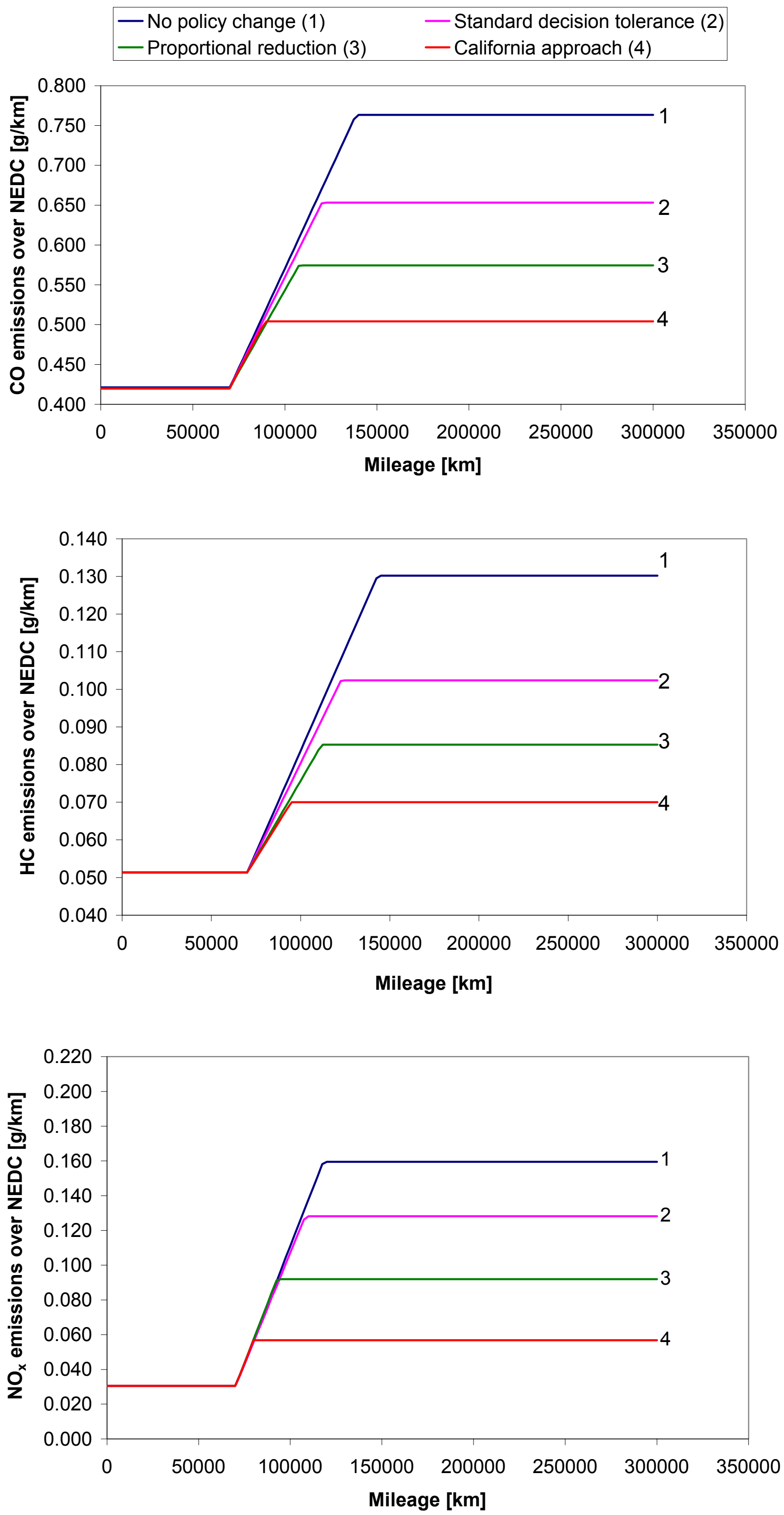


Fig. 4.12: Emissions degradation as a function of mileage for each set of OBD threshold levels considered, for CO (top), HC (middle) and NOx (bottom)

Commenting on these results, we may observe significant improvements in pollutant emissions by moving from the "no policy change" thresholds (1) towards approaches involving more stringent OBD thresholds. The lowest pollutant emissions are observed with the California approach, which involves the most stringent thresholds, hence most frequent part replacements. These emission degradation functions will be used to calculate the total mass of pollutants emitted, according to the mileage of the European vehicle fleet at each year of interest. This will be presented in detail in the section 4.3.

Assuming a vehicle life of 300000 km, it is possible to calculate with the above methodology the average fleet emissions during its life for different OBD threshold levels. The results are summarized in Fig. 4.13. However, this result alone is not representative of the expected effect on emissions in reality, since one has to additionally consider the forecast evolution of the fleet in the coming years in terms of age and mileage. This is precisely the subject of the following section.

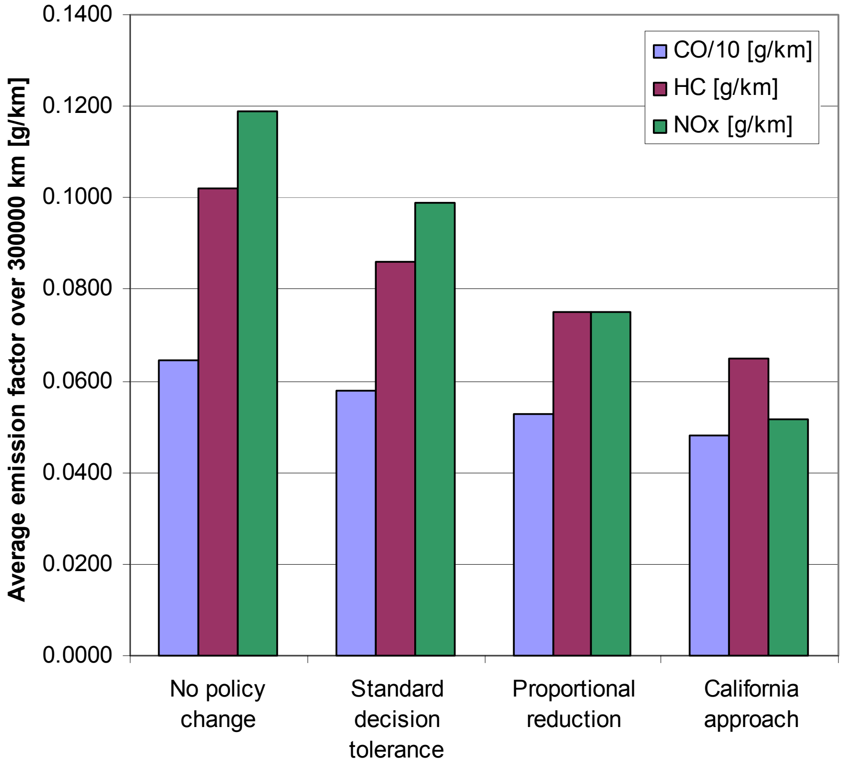


Fig. 4.13: Average vehicle life emissions (vehicle life = 300000 km), for a fleet of vehicles, assuming different OBD threshold levels

4.3 Emissions inventorying calculations

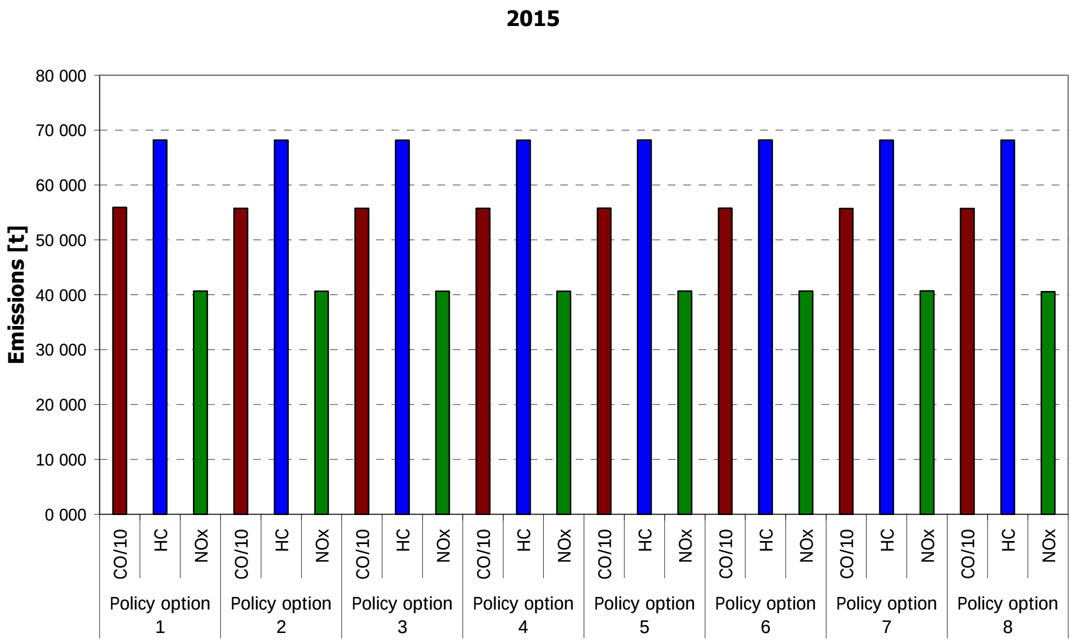
The impact assessment of the various policy options from the environmental effects perspective has been based on emission projections using forecasts for the evolution of the European vehicle fleet and the emissions degradation functions derived above. At a first step the vehicle fleet of petrol-fuelled Euro 4 passenger cars and their annual mileage was derived from the TREMOVE draft baseline results [4] for the years 2015 and 2023 and for each EU-15 member state. Using the TRENDS methodology [14], i.e. calculating the lifetime functions of the fleet for each country, the age distribution of the passenger car fleet was calculated. The resulting fleets were thus distributed into age bins and the accumulated mileage of each age bin was determined. Table 4.4 summarises the results for the two reference years.

From the emissions degradation functions derived in 4.2.2, an emission factor may be attributed to each age bin for the various policy options, pollutants and reference years considered, based on its value for the accumulated mileage. Cumulative emissions for each age bin may be calculated by multiplying these emission factors by the number of vehicles and the accumulated mileage of the respective age bin, which are then summed to give the total cumulative emissions of the entire fleet. Fig. 4.14 illustrates the results of the above procedure. From the following graphs it is evident that only limited (if any) benefits in terms of emissions reductions may be expected in the short-term period up to 2015, while more significant gains may be observed in 2023.

Table 4.4: Activity data for each age bin for 2015 and 2023, for Euro 4, lambda-1 gasoline passenger cars (EU-15). Only vehicles registered after year 2008 are examined.

Age	Number of vehicles (2015)	Average accumulated mileage per vehicle	Number of vehicles (2023)	Average accumulated mileage per vehicle
0	4817336	10754	1553435	10845
1	4756998	21508	2118277	21691
2	4676453	32250	614545	32545
3	4572137	42972	4286258	43405
4	4439065	53658	1535576	54271
5	4323869	64235	2092703	65051
6	4130785	74826	607107	75875
7			4235386	86649
8			1513341	97345
9			2060278	107917
10			597457	118193
11			4171075	128320
12			1485047	138087
13			2018906	147311
14			584917	155884

The maximum reduction that can be obtained, if the strictest thresholds (California approach) was to be applied from 2008 (Policy option 8), is in the order of 7% for CO, 11% for HC and 26% for NOx. If these thresholds are introduced in 2010 (Policy option 6), the pollutant reduction in 2023 will be in the order of 4% for CO, 6% for HC and 20% for NOx, compared to the baseline policy. In the case of the least strict modification in the OBD legislation that can be adopted, which is to adopt the standard decision tolerance thresholds in 2008 (Policy option 2), a reduction in the mass of emitted CO by 3%, HC by 5% and NOx by 9% is expected to be achieved compared to the "no policy change" option.



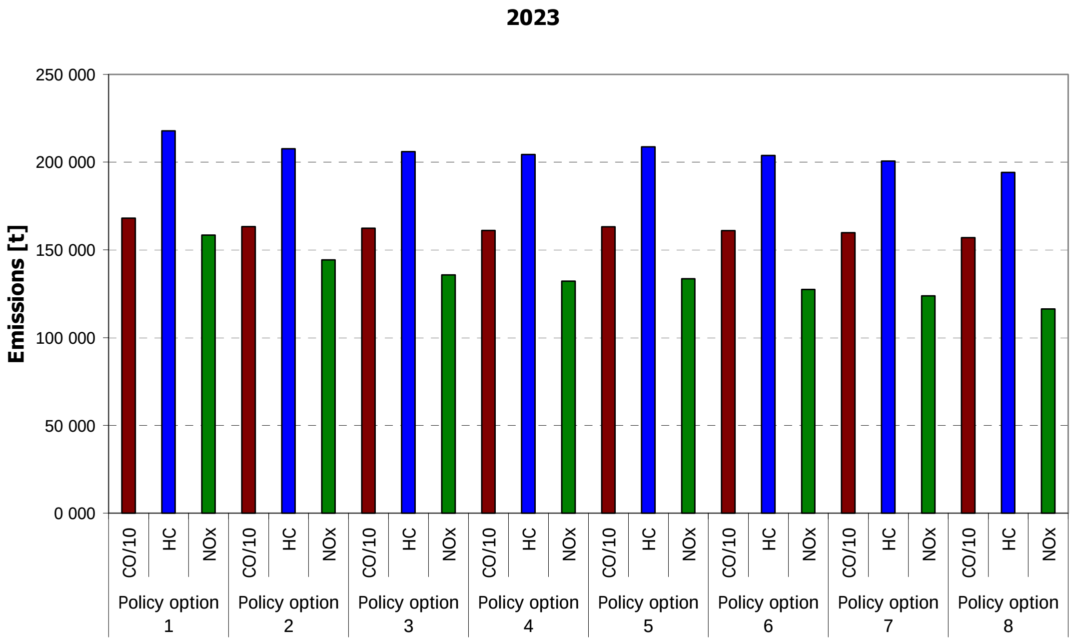


Fig. 4.14: Cumulative emissions of Euro 4, lambda 1 passenger cars, calculated for 2015 (top) and 2023 (bottom), for each pollutant and policy option considered (EU-15). Only vehicles registered after 2008 are included in the calculation. Policy options are described in Table 4.2

Fig. 4.15 shows the achieved emissions reduction for each policy option, compared to Policy 1 (*Baseline Policy*). We must note that the emissions reduction for the year 2015 is negligible, because the fleet is so young that the OBD system has practically not started to affect emissions.

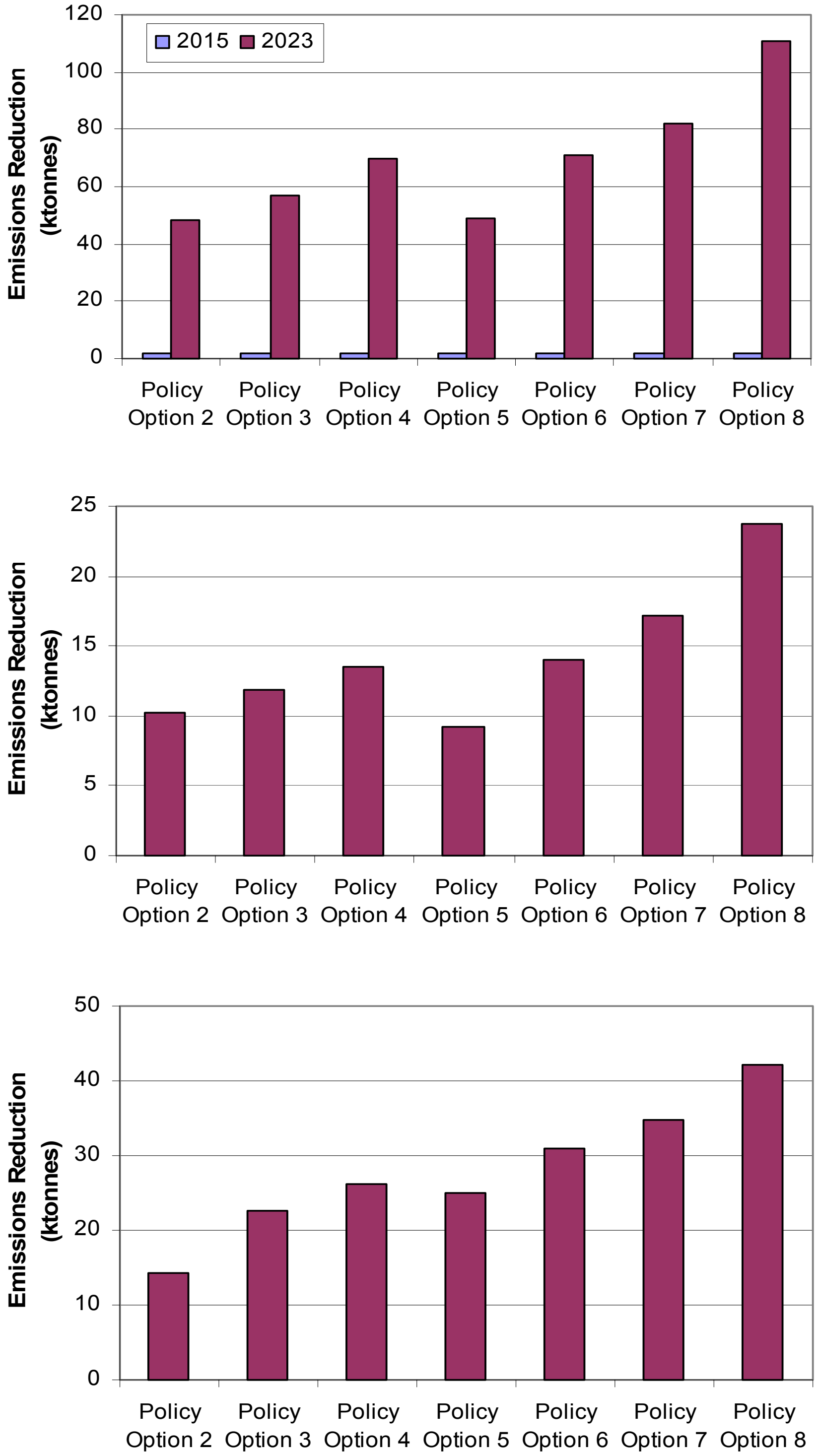


Fig. 4.15: Emissions reduction compared to the Policy Option 1 (*Baseline Policy*). Top: CO (2015 & 2023) Middle: HC (2023) Bottom: NOx (2023)

4.4 Cost effectiveness analysis

4.4.1 Basic assumptions

Generally, our cost–effectiveness analysis is based on the following assumptions that affect all policy options, as described in section 4.1.

1. The costs involved include technology costs (Research & Development, Hardware), user's costs and inspection and maintenance costs.

2. All costs are marked-up at a rate of 29 percent to account for the manufacturers' overhead and profit [15].

3. All costs are in EUROs (2004 monetary terms).

4. We consider that in the long run the sales end up being equal to the vehicles' production.

5. We assume that the proposed threshold limits of every policy option aim equivalently to reduce CO, HC and NOx emissions. So, we make use of the following shares of abatement costs: CO: 1/3, HC: 1/3, NOx: 1/3, to further distribute the abatement cost to each pollutant.

6. We use a discount rate of 4%. This discount rate is expressed in real terms, taking into account inflation and we apply it to costs expressed in constant prices. This discount rate broadly corresponds to the average real yield on longer-term government debt in the EU over a period since the early 1980s [6].

7. The implementation period of each policy option is considered to last from 2008 until 2023. However, we split our analysis into 2 timeframes; namely, 2008 to 2015 and 2008 to 2023, in order to assess the effectiveness of each policy in two time points (2015 and 2023).

4.4.2 Cost analysis

The cost elements considered in this study to be affected from the level of the OBD limit thresholds can be divided in two categories:

- **Development and production cost for the manufacturers**: this cost element includes all the necessary investments in R&D, hardware (sensors etc), software, calibration and testing that is required by the manufacturers. It is expected that the manufacturers will generally comply with the regulations under investigation with limited research and development investments, software upgrades and minor, if any, hardware modifications. Some of these modifications (e.g. linear oxygen sensors) could be already part of their strategy for meeting Euro 4 type approval limits.

The development and production cost for each level of OBD thresholds is presented in Table 4.5. For the "standard decision tolerance" scenario, the involved software and research & development cost amounts to €30 – €50 per vehicle, based on the ACEA answers to the questionnaire (Appendix 2). A large part of this cost is expected to be calibration and test fleet cost, which is not significantly affected by the level of OBD thresholds. Regarding the rest of the policies, the manufacturers are expected to meet the new OBD threshold limits with improved diagnostic technologies. Therefore, we assume an increased cost for software and hardware, compared to the "standard decision tolerance" policy. It is believed that the proportional thresholds can be obtained by introducing simple new sensors (e.g. linear oxygen sensors), hence an extra cost of 10 €/vehicle is assumed, while in the case of the California approach, more extensive changes in the diagnostic system configuration may be required (e.g. use of NOx sensors or other advanced sensors), therefore an extra cost of 40 €/vehicle is assumed compared to the "standard decision tolerance" threshold levels.

Table 4.5: Development and production cost per vehicle, for the different OBD threshold levels, used in the present study.

OBD threshold levels	Development and production cost per vehicle [€]
No policy change	0
Standard decision tolerance	30-50
Proportional reduction	40-60
California approach	70-90

- **Inspection and maintenance cost**: This cost element includes the cost for replacement of deteriorating components (lambda sensor and catalytic converter) as well as the cost of time losses for the motorist, in order to visit the workshop for the necessary repairs. In order to calculate the inspection cost we estimate that the cost per inspection per consumer (per vehicle) is €5 to €10 [16]. Added to this, the cost of the time lost by the driver for scanning the OBD system (5 minutes) and for commuting to the service station is estimated by valuing a time loss of 60 - 120 minutes. Using the default value supplied by the World Bank - 30% of household income per hour is used for the valuation of non-work time; that results to €0.05 per minute - this cost amounts to €3 – €6 per vehicle inspected [16].

  The maintenance cost is the cost involved for the replacement of the catalyst or the lambda sensor or both. Given the distribution of the MIL signal over the years, which is calculated by the methodology presented in the previous section, we calculate the frequency of the necessary replacement of the above emission control systems. The cost for the catalyst's replacement is estimated to be €450 – €550 and the cost for the lambda sensor's replacement is estimated to be €135 – 165 [16]. Following the same rationale as the one used to calculate the average fleet emission functions, we can calculate the average fleet maintenance cost, as a function of vehicle mileage. This is presented in Fig. 4.16, where it appears that the "No policy change" approach has a significantly lower cost than the other OBD threshold levels, and the "California approach" has the highest cost of all. It is important to mention, that between 130000 and 190000 km, the cost for the "No policy change" approach is 1.5-3 times lower than the cost for other threshold levels.

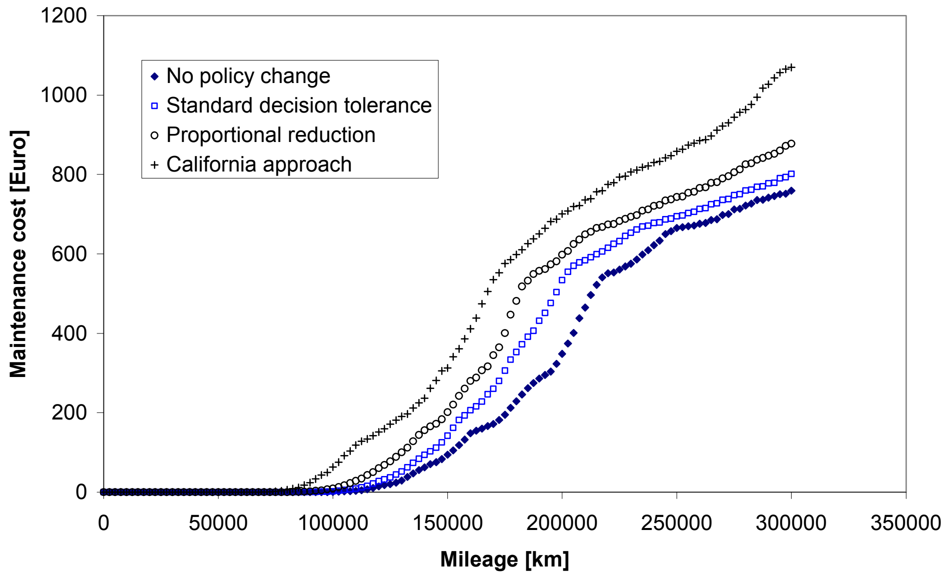


Fig. 4.16: Cumulative cost for maintenance per vehicle (fleet average) as a function of vehicle mileage.

The cumulative Inspection & Maintenance cost, until years 2015 and 2023 is presented in Fig. 4.17.

Based on the calculation of parts replacement presented in sections 4.2.1 and 4.2.2, and the calculation of fleet composition in the years 2015 and 2023 presented in 4.3, we may produce an estimate of the cumulative number of catalytic converters that will be replaced due to normal deactivation, until each of these years. The results are presented in Fig. 4.18, and show that practically no post-2008 Euro 4 catalytic converters will be replaced due to normal deactivation until 2015. It should be recalled that in these figures the calculation starts from the new registrations of 2008, i.e. not taking into account Euro 4 vehicles registered in previous years.

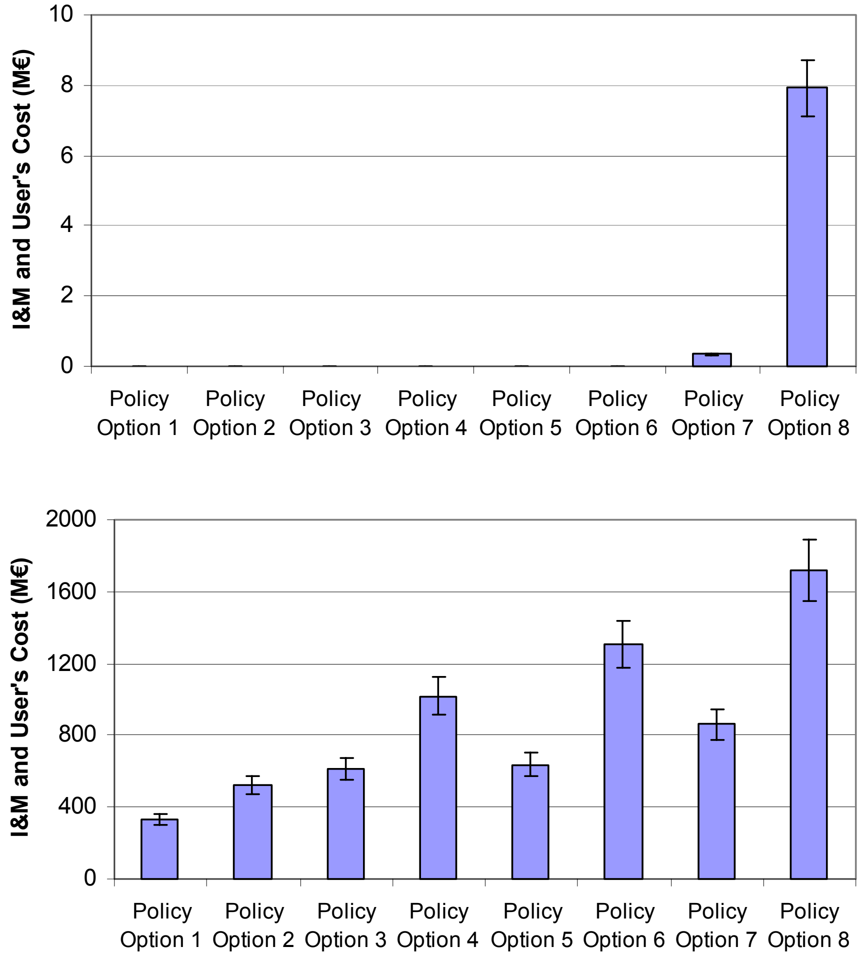


Fig. 4.17: I&M and User's cost until 2015 (top) and 2023 (bottom) for Euro 4 cars

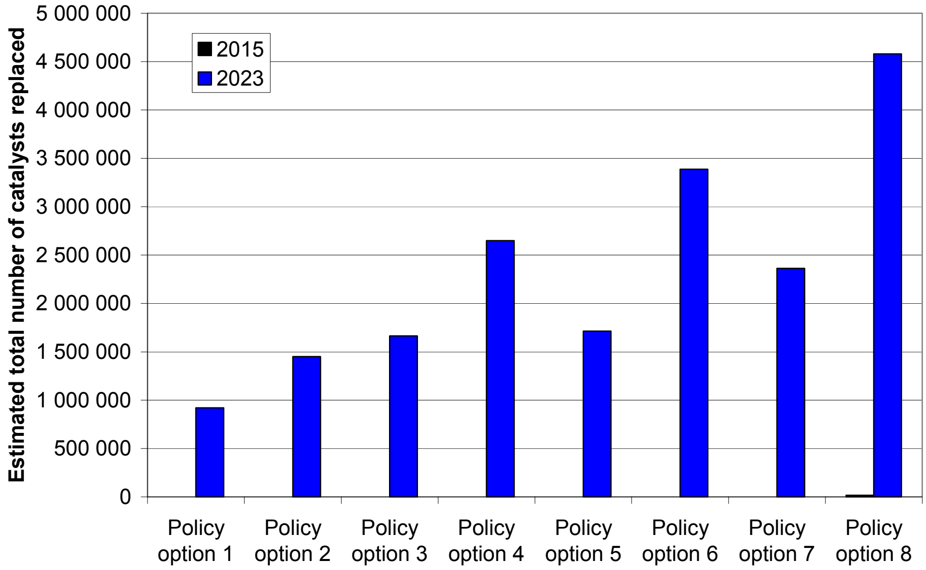


Fig. 4.18: Calculated cumulative number of catalytic converters of post 2008 Euro 4 compliant passenger cars replaced until years 2015 and 2023

Furthermore, the total implementation cost per policy option is shown in Table 4.6.

Table 4.6: Total cost per policy option up to each of the selected years (Net Present Value – M€)

	Total Cost 2015*		I&M and Users's Cost 2023		Manufacturers's Cost 2023		Total Cost 2023	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Policy Option 1	**	**	298	364	**	**	331	331
Policy Option 2	998	1664	471	576	1765	2942	2289	3466
Policy Option 3	1126	1791	549	672	2149	3326	2759	3936
Policy Option 4	1509	2175	917	1121	3299	4476	4318	5495
Policy Option 5	1110	1664	574	701	2132	3198	2770	3836
Policy Option 6	1942	2497	1173	1433	3732	4798	5035	6101
Policy Option 7	1331	1997	776	948	2354	3531	3216	4393
Policy Option 8	2337	3002	1545	1888	4119	5295	5836	7012

* Total cost until 2015 is almost equal to Manufacturers' cost, because I&M and Users' cost are negligible (or zero)

** Policy option 1 has only I&M and User's cost, but not until 2015

4.4.3 Cost-effectiveness results

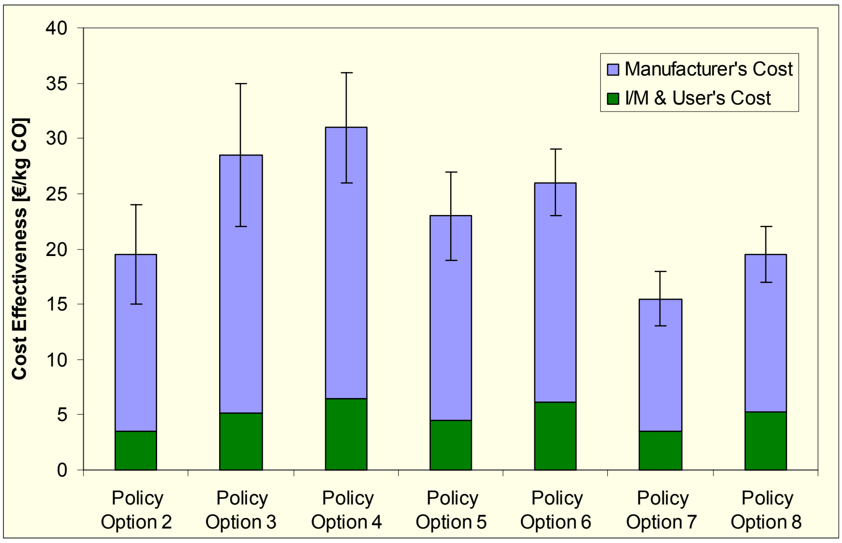
The outcome of the cost-effectiveness analysis for each of the above policy options and up to years 2015 and 2023 is presented in Table 4.7.

Table 4.7: Cost-effectiveness analysis results per pollutant per policy option (€/kg ≡ M€/ktonne)

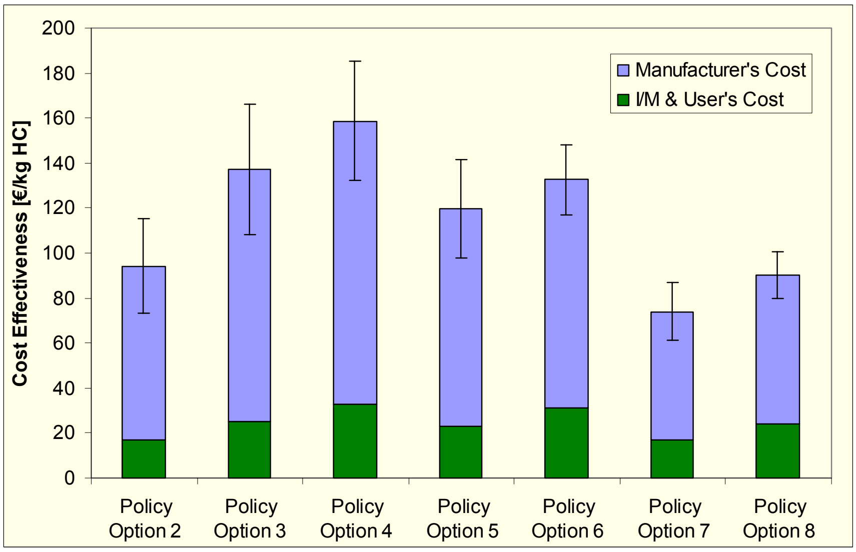
Discount Rate 4%	2015		2023	
	Low Estimate	High Estimate	Low Estimate	High Estimate
CO				
Policy Option 1	*	*	*	*
Policy Option 2	500	833	15	24
Policy Option 3	756	1217	22	35
Policy Option 4	948	1409	26	36
Policy Option 5	699	1049	19	27
Policy Option 6	1224	1573	23	29
Policy Option 7	655	983	13	18
Policy Option 8	1159	1490	17	22
HC				
Policy Option 1	*	*	*	*
Policy Option 2	**	**	73	115.1
Policy Option 3	**	**	108	166.2
Policy Option 4	**	**	132	185.0
Policy Option 5	**	**	98	141.4
Policy Option 6	**	**	117	148.2
Policy Option 7	**	**	61	86.7
Policy Option 8	**	**	80	100.8
NOx				
Policy Option 1	*	*	*	*
Policy Option 2	**	**	53	83
Policy Option 3	**	**	57	87
Policy Option 4	**	**	68	96
Policy Option 5	**	**	36	52
Policy Option 6	**	**	53	67
Policy Option 7	**	**	30	43
Policy Option 8	**	**	45	57

* Policy option 1 is considered to be the *Baseline Policy*
** There is no emissions reduction over the *Baseline Policy*

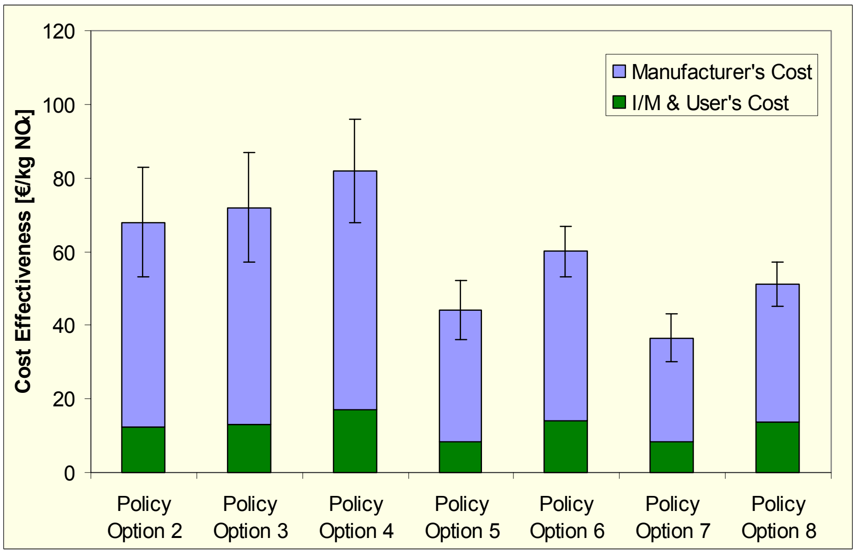
The above cost-effectiveness analysis results for each pollutant for the year 2023 are also depicted in Fig. 4.19. It is interesting to note that manufacturer costs (development, hardware, software testing, calibration) are main contributor to the total cost.



CO



HC



NOx

Fig. 4.19: Cost-effectiveness analysis results for the year 2023 showing the manufacturers' and users' costs

Based on this analysis, policy option 7 seems to be the most cost-effective scenario. According to this policy option a proportional reduction in OBD thresholds is applied already in 2008. However, it has to be considered that probably no manufacturer is currently prepared to apply such "proportionally reduced" thresholds. Taking into account that they will need at east 1-2 years time for developments and calibrations, the target of 2008 would be challenging to achieve. The same applies for the even more demanding thresholds of policy option 8 (California approach from 2008), which ranks 2nd in cost-effectiveness. Interestingly, policy option 2 (draft Commission's proposal implemented from 2008) is almost equally cost-effective to policy option 8 with the exception of NOx emissions. Policy options 3 and 4 are clearly the least cost effective, mainly because they involve an intermediate change in thresholds and therefore increased calibration costs for the manufacturers. In this context, policy option 5 seems to be the most interesting especially as regards the cost-effectiveness related to NOx emissions.

4.4.4 Sensitivity Analysis

Sensitivity analysis explores the impact of uncertainty in particular assumptions or parameters, in terms of their relative importance in influencing the results. It shows how changes in particular values affect the outcome of the various options being considered. More particularly, keeping in mind that we are dealing with very long time horizons, a useful form of sensitivity analysis is to identify how much the value of the discount rate affects the above presented results. In Table 4.8 and Table 4.9 we present the cost-effectiveness analysis results for discount rates 3% and 5%, respectively.

Table 4.8: Cost-effectiveness analysis results per pollutant per policy option (€/kg ≡ M€/ktonne), with 3% discount rate

Discount Rate 3%	2015		2023	
	Low Estimate	High Estimate	Low Estimate	High Estimate
CO				
Policy Option 1	*	*	*	*
Policy Option 2	539	898	17	27
Policy Option 3	821	1321	25	39
Policy Option 4	1032	1532	29	41
Policy Option 5	758	1137	21	30
Policy Option 6	1327	1706	26	33
Policy Option 7	707	1060	14	21
Policy Option 8	1250	1607	19	24
HC				
Policy Option 1	*	*	*	*
Policy Option 2	**	**	83	129
Policy Option 3	**	**	123	188
Policy Option 4	**	**	150	210
Policy Option 5	**	**	111	160
Policy Option 6	**	**	132	168
Policy Option 7	**	**	68	98
Policy Option 8	**	**	90	114
NOx				
Policy Option 1	*	*	*	*
Policy Option 2	**	**	59	93
Policy Option 3	**	**	64	98
Policy Option 4	**	**	78	108
Policy Option 5	**	**	41	59
Policy Option 6	**	**	60	76
Policy Option 7	**	**	34	49
Policy Option 8	**	**	51	64

* Policy option 1 is considered to be the *Baseline Policy*

** There is no emissions reduction over the *Baseline Policy*

Table 4.9: Cost–effectiveness analysis results per pollutant per policy option (€/kg ≡ M€/ktonne), with 5% discount rate

Discount Rate 5%	2015		2023	
	Low Estimate	High Estimate	Low Estimate	High Estimate
CO				
Policy Option 1	*	*	*	*
Policy Option 2	464	773	14	22
Policy Option 3	697	1122	20	31
Policy Option 4	871	1297	23	32
Policy Option 5	646	968	16	24
Policy Option 6	1130	1453	20	26
Policy Option 7	608	912	11	16
Policy Option 8	1076	1383	15	19
HC				
Policy Option 1	*	*	*	*
Policy Option 2	**	**	65	103
Policy Option 3	**	**	96	147
Policy Option 4	**	**	117	164
Policy Option 5	**	**	87	125
Policy Option 6	**	**	103	131
Policy Option 7	**	**	54	77
Policy Option 8	**	**	71	90
NOx				
Policy Option 1	*	*	*	*
Policy Option 2	**	**	47	74
Policy Option 3	**	**	50	77
Policy Option 4	**	**	60	85
Policy Option 5	**	**	32	46
Policy Option 6	**	**	47	60
Policy Option 7	**	**	27	38
Policy Option 8	**	**	40	51

* Policy option 1 is considered to be the *Baseline Policy*
** There is no emissions reduction over the *Baseline Policy*

The results of the sensitivity of the cost-effectiveness on the discount rate are depicted in Fig. 4.20 for the year 2023. Clearly the discount rate does not influence the final ranking of the policy options.

Another interesting parameter which needs to be considered in the sensitivity analysis is the annual vehicle mileage. Currently, the values used for the annual mileage is derived from the TREMOVE draft baseline, and its average value for EU-15 is approximately 15000 km/y. However, since there is an overall trend towards higher annual mileage (e.g. [2]), it is reasonable to examine the sensitivity of the cost effectiveness figures to a 25% increase in the annual mileage per vehicle. These figures, for the year 2023 are presented in Table 4.10.

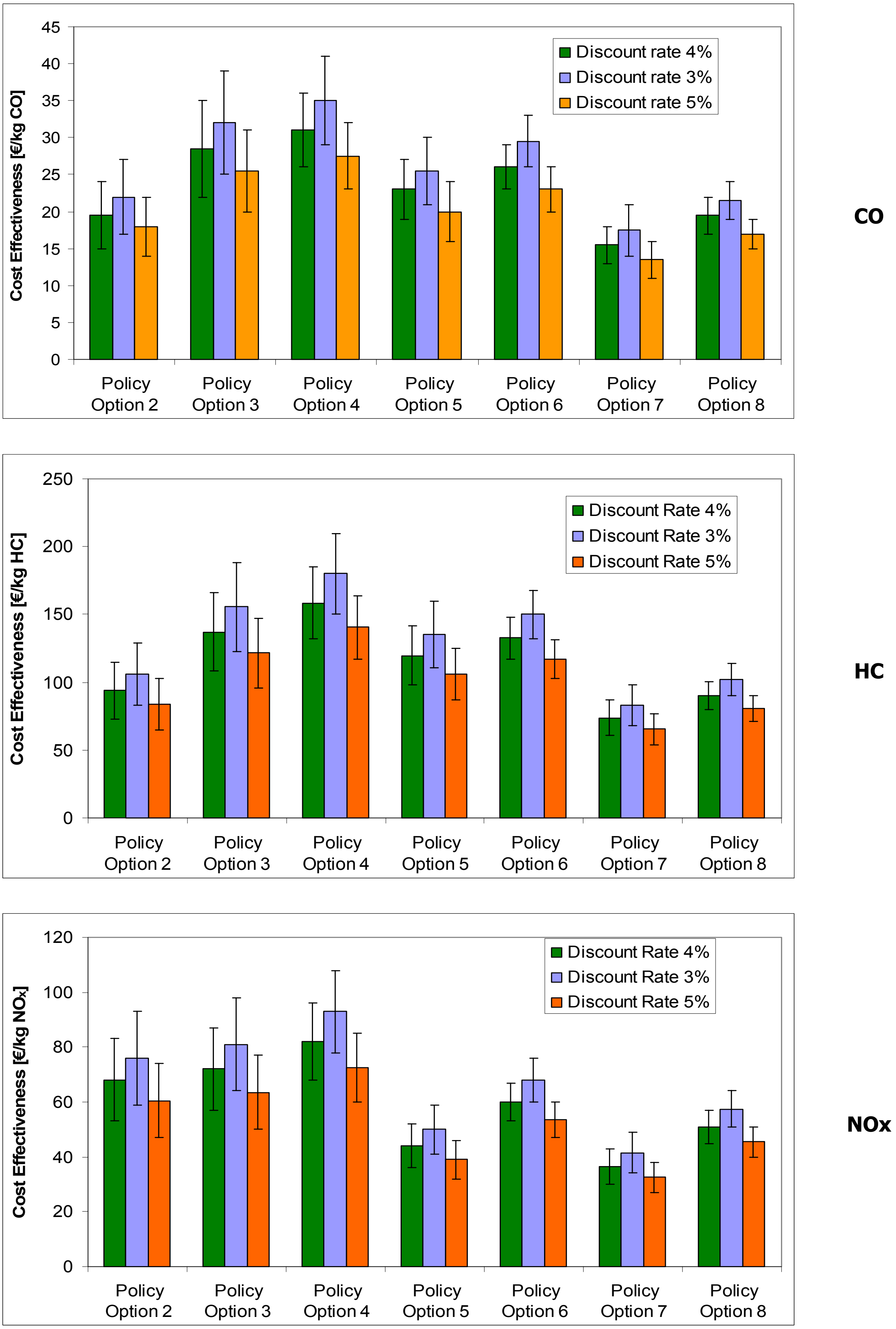


Fig. 4.20: Sensitivity of the cost-effectiveness analysis results for the year 2023 on the discount rate used in the calculations

Table 4.10: **Cost–effectiveness analysis results per pollutant, assuming a 25% increase in the annual mileage (€/kg ≡ M€/ktonne)**

Discount Rate 4% & 25% increase of annual mileage	2023	
	Low Estimate	High Estimate
CO		
Policy Option 1	*	*
Policy Option 2	12	18
Policy Option 3	14	21
Policy Option 4	16	22
Policy Option 5	12	16
Policy Option 6	15	19
Policy Option 7	11	14
Policy Option 8	14	17
HC		
Policy Option 1	*	*
Policy Option 2	52	76
Policy Option 3	63	91
Policy Option 4	75	102
Policy Option 5	54	74
Policy Option 6	68	86
Policy Option 7	47	64
Policy Option 8	60	75
NOx		
Policy Option 1	*	*
Policy Option 2	50	72
Policy Option 3	43	62
Policy Option 4	52	70
Policy Option 5	31	43
Policy Option 6	44	55
Policy Option 7	29	40
Policy Option 8	41	52

* Policy option 1 is considered to be the *Baseline Policy*

The results are also plotted in Fig. 4.21. It is interesting to note that, in this case, the cost effectiveness figures are reduced by 10-40%. This is attributed to the fact that most of the vehicles affected by the OBD have a mileage between 120000 and 190000 km. In this mileage area, the baseline policy has a significantly lower maintenance cost than the other policies (1.5-3 times lower), as can be seen in Fig. 4.16. By increasing the average mileage, more vehicles present mileage above 200000 km, where the difference in the maintenance cost between the various policy options is less pronounced.

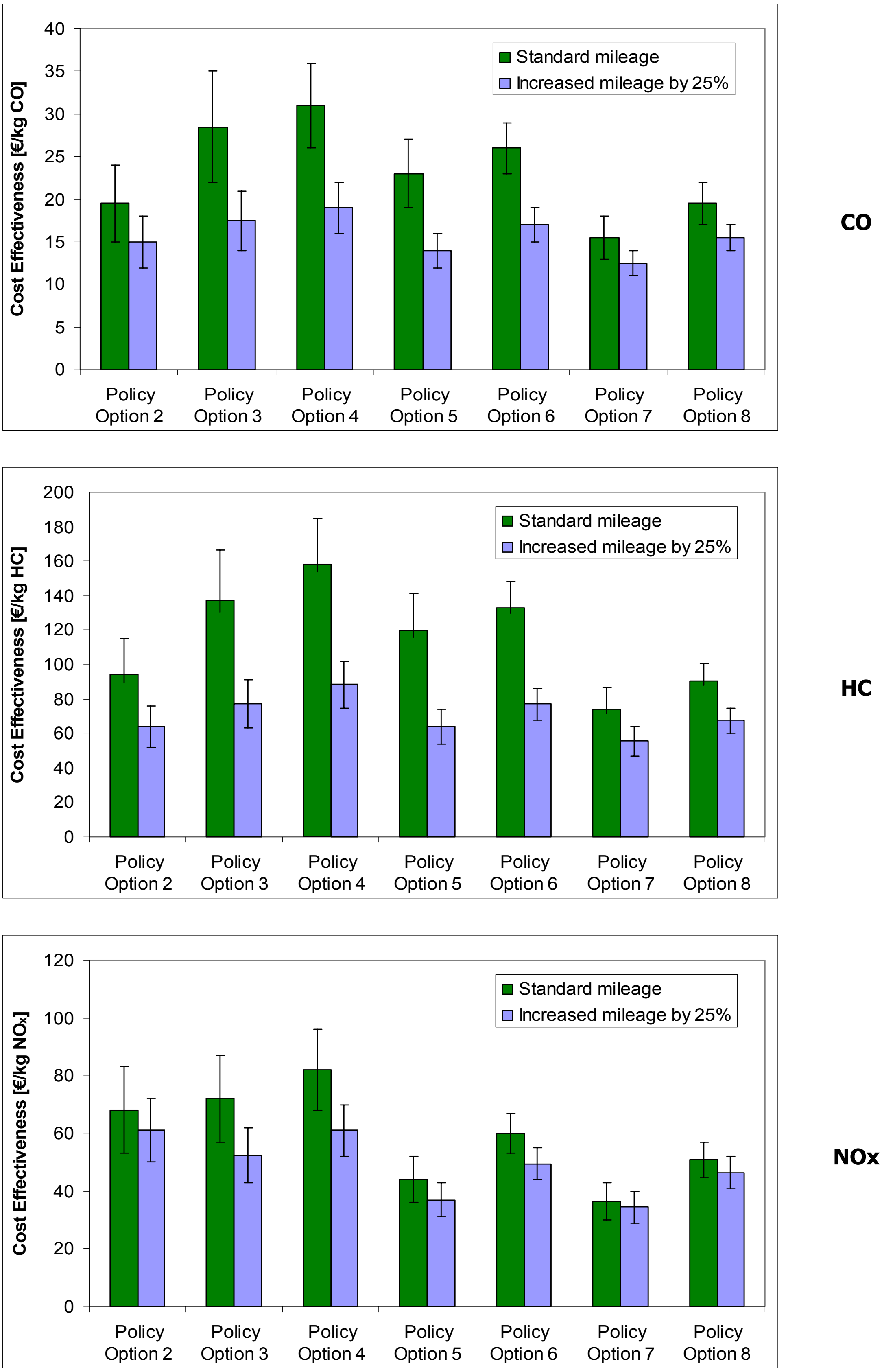


Fig. 4.21: Sensitivity of the cost-effectiveness analysis results for the year 2023 on the annual vehicle mileage per vehicle

Moreover, the ranking of the cost-effectiveness of the different policy options is affected compared to the baseline calculation. Despite the fact that policy option 7 (proportional reduction from 2008) seems to be again the most cost-effective for all pollutants, policy option 5 (proportional reduction from 2010) is now ranking second. It should be stressed that from the practical point of view, policy option 5 is also more realistic taking into account the time restrictions associated with the enforcement of the regulation and the development times from the manufacturers point of view. Application of the stricter "California approach" in policy options 4, 6 and 8 is less cost-effective. Moreover, with the assumption of increased mileage, policy option 2 (draft Commission's proposal) has still an acceptable cost-effectiveness with the exception of NOx.

4.4.5 Analysis of Results - Conclusions

In order to interpret the above results we should take into account, for each of the eight different policy options, the achieved pollutant reduction, the cost-effectiveness analysis results, and the total implementation cost. We should mention that the longer the implementation period of the policies, the more cost-effective all policies turn out to be. Following the same rationale, policy options which require new OBD thresholds to be established twice in the evaluation period (policy options 3 and 4) are the least cost-effective, due to the increased cost for research, development and calibration. Among all options, policy option 7 (proportional reduction from 2008) is the most cost-effective, and it achieves a proportionally greater pollutant reduction than the other options. In addition to that, policy options 2 and 5 are also well-accepted choices. Finally, the sensitivity analysis revealed that the discount rate has a moderate role in the determination of the exact value of the cost-effectiveness, but a possible change in its value does not affect the choice of the preferable policy option. The annual vehicle mileage has a far more important role, as it increases the cost-effectiveness of all policy options, and especially of the least cost-effective ones.

4.5 Social impacts

The implementation of each of the proposed policy options inevitably triggers some changes that may affect the market as a whole, due to the interactive relation between manufacturers and consumers. The estimated 'social' impacts are presented below.

4.5.1 Affected businesses and potential impacts

Any business involved in manufacturing, purchasing or servicing passenger cars, light-duty trucks and medium-duty vehicles could be affected by the proposed amendments. Also affected are businesses that supply parts for these vehicles.

Another aspect of the social impacts of the introduction of stricter limits may affect all Small and Medium Enterprises (SMEs). If the costs for implementing new technologies in order to meet the new limits are too excessive, then all SMEs will probably have to undertake a large financial burden to keep up with the forthcoming changes. Therefore, large manufacturers will be able to eliminate the 'smaller competition' and further increase their share in the market. However, the implementation cost will be negligible in the case of adopting the current Commission proposal, which does not enforce advanced OBD technologies and new hardware. So, it seems that the proposed regulations (policy option 2) are not expected to affect business creation, elimination or expansion.

In the case of advanced monitoring equipment requirements ("proportional" or "California" approaches) the market of exhaust gas sensors (linear oxygen, temperature, NOx etc) will be positively affected since the demand will rise strongly.

Moreover, no major impact on manufacturers' competitiveness is expected since according to ACEA, the OBD system is considered as being not competition-related and regulation stands the same for all manufacturers.

4.5.2 Impacts on customers

Adopting more stringent OBD limits is expected to affect the vehicle price moderately. The effect could be proportionally higher in small and medium size vehicles. Estimates of the costs associated with each of the examined policy options were presented in section 4.4. At the same time, stricter limits would probably encourage manufacturers to develop more durable vehicles, which could result in the need for fewer vehicle repairs and therefore savings for customers. On the other hand, lacking reliable OBD technologies, the manufacturers' calibration to low OBD thresholds could result in more frequent replacements of emission control components. This cost will directly affect the customers.

4.5.3 Public acceptance of technology and legislation

One argument against the introduction of stricter threshold limit values is that they may produce external impacts from a societal point of view. More specifically, stricter OBD thresholds could probably lead to increased probabilities of “false alarms”, which will have a negative social impact, since the drivers will be annoyed by the unnecessary disturbance and will end up losing their confidence in the new technology and legislation. Moreover, this will have a negative impact on the acceptance of OBD technology as a critical part of vehicle maintenance procedure.

At the present stage, it is almost impossible to quantify this effect and provide a comparative assessment between different policy options. Until more experience is accumulated and analyzed, one could simply refer to the responses of ACEA members to the questionnaire. More specifically, ACEA provided Table 4.11 and Table 4.12, which illustrate the correlation between emissions in driving cycle and MIL status, and the average estimated percentage of errors of omission (high emitting vehicles not identified by OBD) and errors of commission (low emitting vehicles falsely identified by OBD), based on Euro 3 OBD thresholds.

Table 4.11: **Correlation between emissions in driving cycle and MIL status for Euro 3**

		Percentage of vehicles [%]
Measured vehicles with **MIL ON**	Below type approval limit	0% to 42%
	Between type approval limit and MIL activation threshold	30% to 38%
	Greater than the MIL activation threshold	20% to 70%
Measured vehicles with **MIL OFF**	Below type approval limit	95% to 98%
	Between type approval limit and MIL activation threshold	2 % to 5%
	Greater than the MIL activation threshold	0%
	Pollutant with most serious deterioration	Not possible to assess
Comments: High proportion of MIL on below type approval limits due to the legal requirements to illuminate the MI when the OBD is no longer able to monitor due to the occurence of a failure on an other monitor system.		

(Appendix 2 – Questionnaire)

According to these data, it seems that the manufacturers calibrate their diagnostics in such a way so that the possibility of a false failure is practically zero. For some manufacturers, a MIL ON could still appear in case of a component failure which does not lead to exceedance of OBD thresholds. This case can not be classified as a “false failure”.

It is reasonable to assume that this small possibility of false failures is related to the “safety margin” between the type approval limit and the OBD threshold (more specifically, the lower OBD threshold, as defined in this report). In the analysis presented here, this safety margin is assumed to remain practically constant for the case of conventional OBD hardware. Therefore, the possibility of false failures will still be very close to zero. In the case of stricter limits, adoption of advanced hardware is assumed to facilitate tightening of this safety margin, still keeping the possibility of false failures negligible. The above assumptions are probably quite realistic especially in the case of slowly developing malfunctions (OBD related), which were studied in detail here.

Based on the above, the results of this report refer to the case of negligible false failure indications for all policy options. This was made possible by careful adjustment of the OBD detection area as a function of OBD threshold and the required diagnostic technology (sensors).

Table 4.12: Errors of commission and omission for Euro 3 OBD

Errors of commission	**% of MIL activations**	**Stoichiometric**	**Lean burn**
	<1%	✓	✓
	1-10%		
	>10%		
Errors of omission	**% of high emitters**	**Stoichiometric**	**Lean burn**
	<1%	✓	✓
	1-10%		
	>10%		

(Appendix 2 – Questionnaire)

4.5.4 Potential impacts on employment

No major impact on employment and business creation is expected by the introduction of stricter threshold limit values. The proposed requirements will be addressed primarily with the existing vehicle manufacturers' workforce. In the cases of more aggressive policy options additional employees and/or outsourcing may be required to comply with the larger amount of R&D and calibration work.

4.5.5 Impact and Results Matrix

In Table 4.13, we present the impact matrix, which captures the main impacts for every policy option.

Table 4.13: **Impact Matrix - Assessment of each impact for each policy option**

Policy Options		**IMPACTS**				
		Potential Impacts on businesses related to the Automotive industry	Impact on consumers	Impact of public acceptance of the technology and legislation	Impact on employment	Impact on competitiveness
Policy Option 1	Likelihood	Unlikely	Unlikely	Certain	Unlikely	Unlikely
	Characterization	Positive	Positive	Positive	Positive	Positive
Policy Option 2	Likelihood	Probable	Probable	Probable	Unlikely	Unlikely
	Characterization	Uncertain	Uncertain	Uncertain	Positive	Positive
Policy Option 3	Likelihood	Probable	Probable	Probable	Unlikely	Unlikely
	Characterization	Negative	Negative	Uncertain	Positive	Uncertain
Policy Option 4	Likelihood	Probable	Probable	Probable	Unlikely	Unlikely
	Characterization	Negative	Negative	Uncertain	Positive	Uncertain
Policy Option 5	Likelihood	Probable	Probable	Probable	Probable	Unlikely
	Characterization	Negative	Negative	Uncertain	Positive	Uncertain
Policy Option 6	Likelihood	Probable	Probable	Probable	Probable	Unlikely
	Characterization	Negative	Negative	Uncertain	Positive	Uncertain
Policy Option 7	Likelihood	Certain	Probable	Probable	Probable	Unlikely
	Characterization	Negative	Negative	Uncertain	Positive	Uncertain
Policy Option 8	Likelihood	Certain	Probable	Probable	Probable	Unlikely
	Characterization	Negative	Negative	Uncertain	Positive	Uncertain

Furthermore, Table 4.14 shows the main results for each policy option.

Table 4.14: **Qualitative & quantitative description and monetized value of each impact over policy option 1**

IMPACTS	Policy Option	Qualitative Description	Quantitative Description	Monetized Value
Financial Impact on manufacturers	**2**	Increase of development and production cost*	0.6% - 1.0% increase	€30 - €50
	3		1.4% - 2.2% increase	€70 - €110
	4		2.0% - 2.8% increase	€100 - €140
	5		0.8% - 1.2% increase	€40- €60
	6		1.4% - 1.8% increase	€70 - €90
	7		0.8% - 1.2% increase	€40 - €60
	8		1.4% - 1.8% increase	€70 - €90
Potential Impacts on businesses related to the Automotive industry	**2**	Car sales decrease **	0.18% - 0.3% decrease	Not Monetized
	3		0.18% - 0.36% decrease	
	4		0.18% - 0.54% decrease	
	5		0.24% - 0.36% decrease	
	6		0.42% - 0.54% decrease	
	7		0.24% - 0.36% decrease	
	8		0.42% - 0.54% decrease	
Impact on consumers	**2**	More frequent replacements of emission control components ***	3	Not Monetized
	3		1	
	4		1	
	5		1	
	6		1	
	7		1	
	8		1	
Impact of public acceptance of the technology and legislation	**2**	Frequent false “MIL ON”. Unreliable System ***	5	Not Monetized
	3		4	
	4		4	
	5		4	
	6		4	
	7		4	
	8		4	
Impact on employment	**2**	Job creation ***	5	Not Monetized
	3		2	
	4		2	
	5		2	
	6		2	
	7		2	
	8		2	

* We take as example, that the development and production cost for a mean sized car equals to 5000€.

** According to [17] an 1% increase in price of a small or medium car leads to a mean decrease of car sales by 0.3%. This percentage is the price elasticity for cars.

*** Classification as follows: 1 (more likely) to 5 (unlikely)

5 Direct-injection gasoline engines

In order to increase the fuel efficiency and decrease CO_2 emissions, the automotive industry recently introduced the direct-injection gasoline engine technology. These engines are referred to as direct injection spark-ignition engines (DISI), commonly or also known as "GDi" for short. This direct-injection technology is an enabling technology to achieve acceptable engine operation when the engine is running lean of stoichiometry.

This technology is still not fully mature, and the penetration of these engines in the European market is extremely small. To prove their mechanical durability. some first-generation GDi engines were made to operate, for the majority of the time, at the conventional stoichiometric ratio. Later ones are using more aggressive calibrations, where a greater proportion of their operation is at lean air-fuel ratios (significantly greater than 14.7:1), but the sales volumes remain extremely small, compared with conventional gasoline engines.

It has to be considered that some direct injection gasoline engines operate at stoichiometric conditions only. In this case, the emission control and OBD technology is exactly the same with conventional gasoline engines.

In the case of direct injection engines operating partly on lean conditions, the control of NOx emissions is accomplished by a NOx storage catalyst (NOx trap). Typically, the manufacturer employs a combination of a close-coupled 3-way catalyst and an underfloor NOx storage catalyst. The function of the latter is mainly to adsorb nitrogen oxides under lean operating conditions, which are desorbed and reduced in a controlled way by running the engine rich at specified short intervals.

During lean burn operation, no oxygen storage/release phenomena take place, and therefore the classical dual lambda sensor OSC technique for catalyst diagnosis is not applicable. On the other hand, one could imagine alternative OBD technologies for these engines. For example, these engines are normally equipped with a NOx sensor downstream the NOx trap for control purposes. This sensor could potentially be used for OBD purposes also, at least as regards the NOx efficiency of the catalyst. Moreover, the manufacturer could choose to diagnose the catalyst system during stoichiometric operation of this engine, when the traditional Oxygen Storage method is still applicable.

Nevertheless, it has to be recognized that there are indeed technological challenges with the diagnosis of emission control systems of lean-burn engines. These challenges support the argument of not proposing stricter thresholds for these engines at this stage and wait until more experience is accumulated in-use with these vehicles.

6 Diesel engines

6.1.1 Technological feasibility

Unlike gasoline vehicles, current diesels do not have sensors in the exhaust stream that are sufficient for monitoring the catalyst system. Additionally, current diesel vehicles do not require extensive aftertreatment to meet the applicable standards. In order to comply with future emission standards, diesel engine manufacturers are expected to utilize mainly oxidation catalysts, and particulate filters. NOx adsorbers and lean NOx catalysts could also be an alternative for reducing NOx emissions, although their application does not seem necessary in the 2005 stage.

Oxidation catalysts are nowadays universally applied for CO and HC reduction in diesel exhaust. The diagnosis of this type of catalysts at lean exhaust conditions is not possible by the traditional oxygen storage technique, as explained above for the case of lean burn gasoline engines. Alternative diagnostic techniques, utilizing temperature measurements before and after the catalyst could possibly be used for catalyst function diagnostics. This, of course, would require additional hardware, software and calibrations by the manufacturers.

As regards the diesel particulate filter (DPF) technology, manufacturers (with only one exception) started to introduce DPF equipped vehicles only a few months ago. Most of these systems are equipped with various sensors to monitor the temperature, pressure and air-to-fuel ratio, in order to optimize the regeneration strategies. It could be possible to employ some of these sensors for on-board diagnostic purposes. In fact, the pressure drop measurement across the filter could provide useful information on the functionality of the filter. However, it is not likely that such an on-board measurement can be calibrated to detect particulate emissions through the filter at a specified threshold. Therefore, it is more realistic to expect that currently used sensors will only be able to detect total failure of a DPF.

With NOx adsorbers, the frequency of fuel addition to the exhaust, intended to reduce NOx emissions, should be minimized to optimize fuel economy. This would suggest the use of a NOx sensor to determine when fueling should occur (manufacturers could rely on engine mapping to achieve the same result, but this might result in excess fueling strategies to provide a safety factor for meeting emission standards). This sensor could potentially be used to monitor the NOx conversion efficiency of the adsorber.

6.1.2 CARB regulation

In California, for 2005 and 2006 model year medium-duty vehicles and engines, the proposed requirements are identical to the U.S. EPA's requirements and are adequate for the level of technology expected to be used on those vehicles. For the 2004 and subsequent model year light-duty vehicles and 2007 and subsequent model year medium-duty vehicles and engines, however, the proposed requirements reflect more stringent monitoring requirements, consistent with both the expected technology to be used and with the current requirements for gasoline vehicles.

6.1.2.1 Catalyst diagnosis

The CARB believes it is feasible to conduct catalyst monitoring on diesel passenger car and light-duty trucks beginning in the 2004 model year. Several manufacturers and suppliers have been developing monitoring strategies primarily utilizing wide-range air/fuel sensors or temperature sensors. In some cases, however, monitoring of the catalyst may indeed require “intrusive” fuel control strategies like those often used on gasoline engines. That is, to perform the catalyst monitor, the fuel control system may be required to actively change the fueling characteristics to achieve an optimal condition for catalyst monitoring. This may include the use of post-injection strategies or even an auxiliary fuel injector in the exhaust.

Regarding the strategy of a “presence” type monitor, there is a possibility that such an indirect strategy could meet the requirements of the regulation. Specifically, in cases where the performance of the catalyst is such that only a functional monitor is required (e.g., the monitor need only verify that some detectable level of catalyst efficiency is still present), an indirect monitor that verifies a pressure drop across the catalyst could meet the requirements.

For 2005 and 2006 model year medium-duty vehicles, the proposed catalyst requirements would require monitoring of reduction catalysts (i.e., catalysts primarily involved in reducing NOx emissions via reduction processes) for proper conversion capability. Monitoring of oxidation catalysts, which generally have a relatively small emission impact on diesel vehicles, would not be required. Manufacturers would be required to indicate a reduction catalyst malfunction when the conversion capability of the catalyst system decreases to the point that emissions exceed 1.75 times the applicable NOx or PM standard. If a malfunctioning reduction catalyst cannot cause emissions to exceed the emission threshold of 1.75 times the applicable standards, a manufacturer may request an exemption from the requirements for diesel reduction catalyst monitoring.

For 2004 and subsequent model year light-duty vehicles and 2007 and subsequent model year medium-duty vehicles, the proposed catalyst monitoring requirements would require monitoring for both HC and NOx conversion capability. Manufacturers would be required to indicate a catalyst malfunction when the conversion capability of the catalyst system decreases to the point that emissions exceed 1.75 times the applicable HC, NOx, or PM standard. Consistent with all other OBD II monitoring requirements, if a malfunctioning catalyst cannot cause emissions to exceed the emission threshold of 1.75 times the applicable standards, a manufacturer would only be required to functionally monitor the system and indicate a malfunction when no HC or NOx conversion efficiency could be detected. Additionally, through the 2009 model year, no monitoring would be required if the conversion efficiency of the catalyst system was less than 30 percent.

6.1.2.2 PM trap diagnosis

CARB believes it is feasible to conduct PM trap monitoring on diesel passenger car and light-duty trucks beginning in the 2004 model year. OBD strategies primarily utilize pressure sensors to measure the pressure drop across the PM trap in specific operating conditions to verify that the trap is still performing acceptably, taking into account that many of the PM trap systems are actually using the same pressure sensors as part of the regeneration control strategy. A natural fall-out from such a control strategy is the ability to know when the control system can no longer perform as it should, such as the inability to burn off sufficient PM during a regeneration event (the pressure sensors do not indicate a substantial change in pressure from before and after the regeneration event) or even when the time between requested regeneration events becomes too short (indicating the trap no longer has sufficient PM storage capability).

For 2005 and 2006 model year medium-duty vehicles, the proposed requirements for PM traps would require monitoring for proper performance. The malfunction threshold for a PM trap, however, would not be based on a specific emission level. Rather, manufacturers would be required to indicate a PM trap malfunction when catastrophic failure occurs (e.g., a cracked trap substrate). Similar to catalyst monitoring, a manufacturer could be exempted from PM trap monitoring if catastrophic failure would not cause emissions to exceed 1.5 times the applicable standards.

For 2004 and subsequent model year light-duty vehicles and 2007 and subsequent model year medium-duty vehicles, the proposed requirements for PM traps would require monitoring for proper performance. Manufacturers would be required to indicate a PM trap malfunction when the capability decreases to the point that emissions exceed 1.5 times any of the applicable standards. If a malfunctioning PM trap cannot cause emissions to exceed the emission threshold of 1.5 times the applicable standards, a manufacturer would only be required to perform functional monitoring of the system and indicate a malfunction when no PM trap capability could be detected.

6.1.3 Conclusion

Since the mandatory application of OBD on diesel vehicles begins in 2003/04, the experience in real-use of OBD is negligible. No such experience exists anywhere outside Europe as well. From the technological point of view, the OBD problem is challenging and further research is needed to develop reliable sensors and calibrate them to specific thresholds. Therefore, it can be concluded that there are valid reasons for not modifying the OBD requirements for diesel vehicles at this stage. It is estimated that at least 3 years of in-use experience with first generation OBD systems in diesel engines are needed, in order to proceed with amendments in OBD thresholds. Moreover, at least 2-3 years of real-world operation of modern Euro 4 compliant diesel engines with advanced after-treatment is necessary to acquire experience on the performance of state-of-the-art emission control including oxidation catalysts and especially particulate filters.

7 Gas-fuelled engines

Although the main principles of combustion and after-treatment in gas-fueled engines (LPG, CNG, bi-fuelled engines) are similar to the gasoline engine, there are still some peculiarities which differentiate these engines and complicate the implementation of OBD.

The engine calibration and the raw emissions of these engines are not identical to the respective gasoline ones. As a marked example, the CNG engine emits mainly methane, which is a very slowly oxidizing hydrocarbon compared to other HC species of the gasoline engine. Due to differences in the exhaust environment (composition, temperature) the deterioration rate of emission control components could also be different in these engines. The above support the argument that OBD systems for gas-fuelled engines will have to be calibrated specifically for the respective fuel. Since the cost of calibration is more or less fixed for a given engine, the cost per unit could be unacceptably high if small volume production gas engines were to be re-calibrated every few years.

Since the mandatory application of OBD on these vehicles begun in 2003/04, a change at 2005/06 would be apparently neither cost-effective nor would it have any measurable impact on air quality. A revision of OBD thresholds for gas-fuelled engines would not be meaningful until 2010, taking additionally into account the necessity of accumulating in-use experience.

8 Summary of conclusions

8.1 Current experience with EOBD

Although the introduction of EOBD has posed significant technical challenges to the manufacturers, they regard it as a useful tool which could facilitate the proper maintenance of the vehicles and improve air quality. Many of the emissions related components are anyway monitored for proper operation by the engine ECU irrespective of the OBD thresholds (they either work correctly or have completely failed). In this case the OBD diagnostic needs not be calibrated against a specific threshold. The manufacturers make sure that such total failures are immediately diagnosed and the driver is alerted. It has to be mentioned that many manufacturers alert the drivers of such total failures even if the emissions of the vehicle are still below the OBD thresholds. On the other hand, OBD needs to be calibrated based on extensive on-road testing and sophisticated software algorithms, in order to cope with slowly developing failures (the most important of them being related to oxygen sensors and catalysts). Frequent re-calibration of the emission control systems for lower OBD thresholds is something to be avoided since the associated cost is high.

The acceptance of OBD as a tool to facilitate the maintenance of vehicles is well appreciated in the repair workshops. Moreover, although the customers seem to be still reserved about this new feature of their vehicle, the occurrences of real “false failures” is so rare that does not seem to present a problem for the time being. Of course, if such a problem with false failures exists or not, will be visible in appr. 5 years from now, after the accumulation of mileage allows for statistically valid conclusions.

8.2 Assessment of different policy options

Four different sets of OBD thresholds were studied in terms of the effect they would have on vehicle emissions as function of mileage. The calculations were based on a number of assumptions regarding the deterioration rates expected in real-world and the expected statistical variability regarding the initial emissions and the durability of the emission control components. Based on four different sets of OBD thresholds, 8 policy options reflecting various realistic implementation periods were studied taking into account the vehicle fleet data for a 15-year period starting at 2008.

For each of the eight different policy options, we estimated the achieved pollutant reduction and the total implementation cost and then we calculated the expected cost-effectiveness. The analysis makes it quite clear that, for the evaluation period 2008-2023, policy option 7 (“Proportional Reduction” starting from 2008) is the most cost-effective one. However, if we consider the timeframe required for the enforcement of the regulation and the time needed by the manufacturers for adaptation, 2008 could be too early for the introduction of such thresholds. The draft Commission’s proposal (Policy option 2) is generally interesting regarding its cost-effectiveness with the exception of

NOx. The delayed application of the proportional thresholds at 2010 (Policy option 5) seems to be also a cost-effective solution, especially if we assume a 25% increase in the annual mileage driven by the vehicles. Although the application of the strictest "California approach" thresholds in 2008 (policy option 8) also appears to be cost effective, the application of this policy option is not considered to be technically feasible by the manufacturers at this timeframe. Moreover the cost-effectiveness of this approach is less interesting in the case of higher mileage assumption. Finally, adoption of a "two-step" policy by revising the 2008 thresholds in 2012, proved to be the least cost-effective approach due to the high costs associated with the need for multiple OBD calibrations.

8.3 Non-lambda 1 engines

8.3.1 Positive ignition

A few years ago, lean burn direct injection positive ignition engines were considered as a promising future technology. However, more recent developments tend to limit the operation of direct injection engines to stoichiometric conditions. Therefore, it is expected that the market share of lean-burn direct injection engines will be very limited at least for the near future. For these engines, the technology for OBD is basically present, although not extensively tested in real world. Due to the high calibration costs and the low production volumes, it will obviously be not cost-effective to modify the OBD thresholds for these vehicles before 2010.

8.3.2 Compression ignition

Since the mandatory application of OBD on diesel vehicles begins in 2003/04, the experience in real-use of OBD is negligible. From the technological point of view, the OBD problem is challenging and further research is needed to develop reliable sensors and calibrate them to specific thresholds. Therefore, there are valid reasons for not modifying the OBD requirements for diesel vehicles at this stage. It is estimated that at least 3 years of in-use experience with first generation OBD systems in diesel engines are needed, prior to proceeding with amendments in OBD thresholds. Moreover, at least 2-3 years of experience with modern Euro 4 compliant diesel engines with advanced after-treatment is necessary to acquire experience on the performance of state-of-the-art emission control including oxidation catalysts and especially particulate filters.

8.4 Gas-fuelled engines

The engine calibration and the raw emissions of these engines are not identical to the respective gasoline ones. Due to differences in the exhaust environment (composition, temperature) the deterioration rate of emission control components could also be different in these engines. The above support the argument that OBD systems for gas-fuelled engines will have to be calibrated specifically for the respective fuel. Since the cost of calibration is more or less fixed for a given engine, the cost per unit could be unacceptably high if small volume production gas engines were to be re-calibrated every few years.

Since the mandatory application of OBD on these vehicles begun in 2003/04, a change at 2005/06 would be apparently neither cost-effective nor would it have any measurable impact on air quality. A revision of OBD thresholds for gas-fuelled engines would not be meaningful until 2010, taking additionally into account the necessity of accumulating in-use experience.

8.5 Concluding remark

This study was faced with a lack of real-world data which could be used for an in-depth evaluation of the current status of OBD in Europe. With the exception of some scarce data from recent European studies (only marginally addressing the issues this study was raising) the Commission (and the Community as whole including the Member States) failed to launch the necessary activities in order to

- Evaluate the actual performance of the Euro 3 OBD systems from the societal viewpoint
- Closely collaborate and follow the activities of the OEMs in the field, in order to asses the OBD performance from the point of view of the OEMs including the improvements that the OEMs have brought into the systems, irrespective of enforcement procedures.

The above are in direct contrast with what happens in the US and California in particular. Since the introduction of OBD II in 1996 in United States, OBD has been widely supported by the enforcement federal and state authorities, has attracted a lot of attention from the general public and has been included in the research and application programmes of several academic and research institutions. These activities underline the fact that the US has fully understood the potential that OBD has not only to keep the emissions at near type approval levels throughout the useful life of each vehicle, but also to substantially facilitate the quick and effective repair of the cars at the lowest possible cost for the consumer. In addition, it needs to be particularly stressed that the potential of OBD to provide accurate and statistically detailed information with respect to the usage of vehicles and their actual emission performance is also understood and started to be phased in. One can also speculate here that actually OBD can serve as the basic “vehicle” for the development of real time emission (and not only) inventories, which can then be used for effective traffic management to address almost real-time air quality and CO_2 emission issues (not to mention congestion).

In this context the study team is of the strong opinion that there is the immediate need of a number of initiatives at European level, in order to support on one hand the necessity of full evaluation of OBD performance and on the other to further evaluate and explore the new capabilities that OBD together with the concurrent development of intelligent sensors may offer for the future.

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APPENDIX 1

CARB PROPOSED REVISIONS TO OBDII

Requirement	Situation so far in OBD II	Proposal / Technical Feasibility / Comments
Catalyst Monitoring		
NOx Catalyst Monitoring 2007 and subsequent model years 1.75 x HC <u>or</u> NOx standard (2.5x for SULEVs) 2005 and 2006 model years 3.5 x NOx standard	Only HC conversion efficiency monitored	• Usage of enhanced relationship between O2 storage capacity and NOx combined with • Monitoring of a smaller portion of the total catalyst system • Modification of precious metal loading and washcoat formulations • Usage of a NOx sensor, • Usage of a catalyst temperature sensor
Catalyst Aging 2005 and subsequent model year vehicles certified to the Low Emission Vehicle II standards	Manufacturers deteriorate catalysts to the point where emissions exceed 1.75 times the standard. The most common methods of catalyst aging are oven aging and misfire aging. The manufacturers infer catalyst system performance from monitoring only a portion of the catalyst volume. When manufacturers age a catalyst system with a partial volume monitor, the monitored portion of the catalyst is aged to the OBD II threshold level and the unmonitored portion is aged to the equivalent of the end of the vehicle's useful life.	Usage of deterioration methods that more closely represent real world deterioration, ensuring that the MIL would illuminate at the appropriate emission level during real world operation. It is required that the catalyst system be aged as a whole. Manufacturers that use fuel shutoff to misfiring cylinders in order to minimize catalyst temperatures may continue to use the current process of aging the monitored catalyst to the malfunction criteria and the unmonitored catalysts to the end of the useful life
Misfire monitoring: Restriction of the number of possible disablements by limiting disablements to specific conditions. 2005 and newer vehicles	The misfire monitor is disabled if necessary to assure that the systems reliably identified misfire	• Misfire monitoring disablement is no longer permitted during throttle movements less rapid than occur over the US06 (or "off cycle") driving cycle, automatic transmission shift changes except under wide open throttle conditions, air conditioning compressor on and off cycling, or other conditions that have been shown to be unnecessary. • Because of the availability of better computers, manufacturers should no longer disable misfire

		detection during engine speed changes that had taxed their engine computer's ability to keep up with the calculation requirements. • Better definition of when a single cylinder or multiple cylinder misfire code is set, and establishing a more specific means of determining the temperature at which catalyst damage occurs • 1% (for a 1000-revolution monitoring interval) and 5% (for a 200-revolution monitoring interval) for detecting emission-related and catalyst damage misfires.
Secondary Air System Monitoring 2006-2008 phase-in	Manufacturers perform a functional check in lieu of correlating secondary air system airflow to emissions (i.e., 1.5 times the applicable FTP standards) if the design of the system is unlikely to deteriorate. The regulation also allows manufacturers to define the appropriate conditions for operating the monitor with the limitation that the defined conditions are encountered during the first engine start portion of the FTP.	• All vehicles should indicate a secondary air system malfunction that causes airflow to diminish such that the vehicle would exceed 1.5 times any of the applicable FTP emission standards. • This diagnostic is required to monitor the secondary air system while the system is normally active (e.g., during vehicle warm-up following engine start) and not when the system is intrusively turned on solely for monitoring purposes. • Usage of linear oxygen sensors (wide-range oxygen sensors or air-fuel ratio sensors) would most likely be required. • Usage of "quick light-off" sensors (active within about 10 seconds).
Oxygen Sensor Monitoring 2006 and subsequent model year vehicles certified to Low Emission Vehicle II standards.	OBD is required to monitor the output voltage, response rate, and any other parameter that can affect emissions and/or other diagnostics of the primary and secondary oxygen sensors. For heated oxygen sensors, the heater circuit is monitored to detect when the current or voltage drop within the circuit deteriorates below the manufacturer's specified limits for proper operation. Manufacturers have been able to execute all of the oxygen sensor diagnostics, including basic	• Virtually continuous monitoring of the primary oxygen sensor's circuit continuity and out-of-range values and the secondary oxygen sensor's out-of-range values for malfunctions. • For heated oxygen sensors, continuous monitoring will also be required for all circuit continuity faults of the heater circuit that conflict with the commanded state of the heater. • These changes would help to pinpoint the oxygen sensor as the malfunctioning component in fuel system faults

	electrical diagnostics for open and shorted circuits, once per trip rather than continuously.	
Engine Cooling System Monitoring 2006 and subsequent model year vehicles certified to Low Emission Vehicle II standards	Monitoring of the thermostat and engine coolant temperature sensor is required Also the coolant temperature sensor must be monitored for rationality, electrical, and out-of-range failures. Maximum warm-up time of two minutes for engine starts at or above 10^{o}C and five minutes for engine starts between -7 and 10^{o}C. For the thermostat monitor, it is required to detect malfunctions when the engine coolant temperature does not achieve the highest temperature required to enable other diagnostics or warm up to within 11^{o}C of the manufacturer's thermostat regulating temperature.	• For engine starts that are up to 8^{o}C below the closed-loop enable temperature, the diagnostic would be required to indicate a malfunction if the enable temperature is not achieved within two minutes of engine start. • For engine starts that are between 8 and 19^{o}C below the closed-loop enable temperature, a malfunction would be required to be indicated when the enable temperature is not achieved within five minutes of engine start. • Vehicles that do not utilize engine coolant temperature to enable closed-loop fuel control would continue to be exempted from time-to-closed-loop monitoring. • Rationality monitoring for engine coolant temperature sensors must identify sensors that read inappropriately low (and thus, disable or delay operation of other monitors) or sensors that read inappropriately high (again, disabling or delaying operation of other monitors)
Cold Start Strategy Monitoring 2006-2008 phase-in	Monitoring is required of the idle control system and monitoring of the ignition system by the misfire monitor after the engine has warmed up.	• Monitor the key parameters used to implement cold start emission reduction strategies, while the strategy is active. • Cold start monitoring strategies mainly involve software modifications
Variable Valve Timing Monitoring 2005 and newer vehicles	Monitoring of the individual electronic components used in the variable valve timing system is required. No specific monitoring requirements for the detection of variable valve timing system malfunctions.	Manufacturers are responsible for detecting target errors and slow response malfunctions of these systems. For target error and slow response malfunctions, the diagnostic system would be required to detect malfunctions when the actual valve timing and/or lift deviates from the commanded valve timing and/or lift such that 1.5 times the applicable FTP emission standard would be exceeded. Manufacturers utilizing variable valve timing are often able to remove external exhaust gas recirculation

		(EGR) valves and controls from their vehicles, offsetting the cost increase for the system.
Input components (typically: the mass air flow sensor, manifold absolute pressure sensor, intake air temperature sensor, vehicle speed sensor, and throttle position sensor) 2005 and subsequent model year vehicles	Monitored continuously for out-of-range and circuit continuity faults (e.g., shorts, opens, etc.) and "once-per-driving cycle" for rationality faults (e.g., where a sensor reads inappropriately high or low but still within the valid operating range of the sensor).	Rationality monitoring of input components would be required each time all manufacturer-defined enable conditions are met instead of once per driving cycle.
Output components/systems (typically idle speed control valves and automatic transmission solenoids) 2005 and subsequent model year vehicles	Monitored once per driving cycle for proper functional response (e.g., when the component is commanded to do something by the on-board computer, the OBD II system verifies that the action has occurred). If functional monitoring is not feasible, circuit continuity monitoring is required.	Functional monitoring of the idle speed control system each time the vehicle is operated at idle and meets the manufacturer-defined monitoring conditions.
Other Emission Control or Source Device Monitoring (Typical devices under this category include hydrocarbon traps, NOx storage devices, and thermal storage devices)	Required manufacturers to submit a monitoring plan for ARB's review and approval for any new emission control technology prior to introduction on any future model year vehicles.	The proposed regulation would continue this provision. However, modifications would be made to provide further guidance as to what type of components would fall under the requirements of this section instead of under the comprehensive component section.

APPENDIX 2

1. Questionnaire

1.1. Contact information

Company name	ACEA
Contact person	Carlo Cucchi
Position	Director
Department	Emissions and Fuels
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This answer is a consolidation of the answers of the manufacturers BMW Group, DC, Fiat, Ford Group, GME, Porsche, PSA, Renault and Volkswagen Group.

1.2. Current experience with EOBD

1. Do you have any data regarding the OBD system performance in current generation vehicles? If yes, please indicate type of data, otherwise skip questions 1-4.

Manufacturer		A	B	C	D
Models		Passenger cars across the model range	Passenger cars across the model range	Passenger cars across the model range	Passenger cars across the model range
No of Vehicles		50 to 100 per model	60	70.000	
Accumulated mileage			1,3 10^6 km		
Data gathering period		99 to 2004	2002 to 2004	Sept. 2003 to February 2004	2000 to 2004
Type of tests performed	OBD system check	X	X	X	X
	Idle emission measurements	Not Applicable	N A	N A	N A
	Driving cycles emission measurement	X	No	No	X
Number of vehicles with MIL on		No data available	4	52 (less than 0,1%)	No data available
False MIL activations		Not relevant on customer vehicle	0		0
Other/data description:		Customer vehicles Aged. Not more than 3 years	None Internal fleet	Customer vehicles	None Internal fleet

The table above represents manufacturer knowledge accumulated on production vehicles with the final version of the OBD system.

Answers to the questionnaire were based on the above knowledge and experiences gained during the OBD development phase on several (typically 20 vehicles per model/engine type and 100.000 km per vehicle) vehicles.

2. Which are the most common malfunctions, which induce MIL activation? Please rank the following groups of malfunctions according to the order of appearance (1=most common). If available, provide respective percentages.

	Rank	**Percentage [%]**
Lambda Sensor front	for most 3 but also 1 and 4	Confidential
Lambda Sensor rear	for most 5 but also2 and 4	Confidential
Misfire	for most 1 but also 3	Confidential
Air flow sensor	7	Confidential
Coolant temperature sensor	for most 4 but also 5 and 6	Confidential
Fuel system components	6 (4) Not applicable	Confidential
EGR	N A for most manufacturer but 7 for one	Confidential
Catalytic converter	for most 2 but also 6	Confidential
Other/comments:		

3. What is the percentage of vehicles with readiness status indicated "not ready"? How is this percentage affected by vehicle mileage? Please fill in the most typical mileage bins and the respective percentage of vehicles. *Alternatively*, indicate the average expected mileage required for all DTC's to execute, based on average daily driving.

Mileage	**Percentage [%]**

Comments:

Typically 10 to 50 km for mixed driving conditions.

Dependant on supplier of OBD system and difficult to gather data without including problems that have been fixed (e.g. readiness codes reset with key-off). Clarifications needed as part of the Commission proposal.

4. Correlation between emissions in driving cycle and MIL status.

		Percentage of vehicles [%]
Measured vehicles with **MIL ON**	Below type approval limit	0% to 42%
	Between type approval limit and MIL activation threshold	30% to 38%
	Greater than the MIL activation threshold	20% to 70%
Measured vehicles with **MIL OFF**	Below type approval limit	95% to 98%
	Between type approval limit and MIL activation threshold	2 % to 5%
	Greater than the MIL activation threshold	0%
	Pollutant with most serious deterioration	Not possible to assess

Comments: High proportion of MIL on below type approval limits due to the legal requirements to illuminate the MI when the OBD is no longer able to monitor due to the occurence of a failure on an other monitor.

5. Based on your experience with the OBD system performance so far, please judge each of the following statements by assigning a number from -2 (disagree) to +2 (agree) in the "Agreement level" field.

Statement	Agreement level	Comments
EOBD is an efficient and reliable tool for diagnosing emissions related faults.	+2	
EOBD has an improved ability to diagnose faults compared to idle emissions measurements.	+2	
EOBD helps the dealer/workshop diagnose faults correctly from the first time.	for most +2 but also +1	Repairer training and expertise with OBD
EOBD system operation is affected by the driver's driving style	0 to +1	e.g. driving in congested city traffic
EOBD system operation is affected by the country where the vehicle is used	-2 0	EU fuel quality Non-EU fuel quality
Diagnostic algorithms should be calibrated to execute under a wider range of operating conditions than they are now.	-2	OBD calibration covers a wide range of conditions within and outside the NEDC. However, OBD operating ranges depend on the OBD thresholds. Too low thresholds would make restriction of the ranges necessary.
Comments:		

1.3. Advances in emissions control technology since Euro 3

6. What is the average reduction of **engine-out (raw)** emissions between Euro 3 and Euro 4 level vehicles? In which modes of engine operation is this reduction primarily observed? Please fill in *indicative reduction percentages* in the following table:

	Stoichiometric Engines			**Lean burn positive ignition engines**		
	UDC	EUDC	NEDC	UDC	EUDC	NEDC
CO						
HC						
NO_x						
Comments: For many manufacturers there are essentially no changes between Euro 3 and Euro 4 engines.						

7. What is the average reduction of **tailpipe** emissions between Euro 3 and Euro 4 level vehicles? In which modes of engine operation is this reduction primarily observed? Please fill in *indicative reduction percentages* in the following table:

	Stoichiometric Engines			**Lean burn positive ignition engines**		
	UDC	EUDC	NEDC	UDC	EUDC	NEDC
CO	55% to 60%	5% to 15%	55% to 60%	55% to 60%	5% to 15%	55% to 60%
HC	55% to 60%	5% to 15%	50% to 55%	55% to 60%	5% to 15%	50% to 55%
NO_x	50% to 60%	5% to 15%	45% to 50%	50% to 60%	5% to 15%	45% to 50%
Comments:						

8. Which are the main technological changes adopted in Euro 4 vehicles towards the reduction of pollutant emissions, compared to previous Euro 3 models? Place a cross (+) for each technological solution that is applied, and a dash (-) when the listed technological solution is not applied.

	Stoichiometric <1.8 ℓ		**Stoichiometric >1.8 ℓ**		**Lean burn**	
	EU-3	EU-4	EU-3	EU-4	EU-3	EU-4
Close coupled catalytic converter	+, -	+, -	+, -	+, -	+, -	+, -
Cascade catalytic converter system	+, -	+, -	+, -	+, -	+, -	+, -
Advanced catalytic converter substrates	-, +	-, +	-, +	-, +	-	-, -
Exhaust gas recirculation	**-**	**-**	**-, +**	**-**	**-, +**	**-, +**
NO_x traps	-	-	-	-	+	+
Heated/planar oxygen sensors	+	+	+	+	+	+
Linear oxygen sensor up-stream and normal oxygen sensor down-stream	-, +	-, +	-, +	-, +	+	+
Advanced engine control at cold start	+	+	+	+	+	+
Other measures (please describe)	-	-	-	-	-	-
Comments						

1.4. Current and future technologies for on board diagnosis

9. Which are the currently most commonly applied technologies for 3-way catalytic converter diagnosis, according to the Euro 3 OBD thresholds? Please indicate on a scale from 1 (not applied) to 5 (very widely applied)

	Stoichiometric <1.8 ℓ	**Stoichiometric >1.8 ℓ**	**Lean burn**
Dual lambda sensors: down-stream sensor conventional	5	5	1
Dual lambda sensors: down-stream sensors linear	1	1	1
Dual lambda sensors: partial catalyst volume monitoring	1 to **3**	1 to 3	3
Dual lambda sensors: full catalyst volume monitoring	3 to 5	3 to 5	3
Thermal methods	1	1	2
on-off signal of NOx sensor	1	1	5
Comments: Answers apply to the rear sensor (sensor for catalyst monitoring)			

10. Which are the currently most commonly applied technologies for misfire diagnosis, according to the Euro 3 OBD thresholds? Please indicate on a scale from 1 (not applied) to 5 (very widely applied)

	Stoichiometric <1.8 ℓ	**Stoichiometric >1.8 ℓ**	**Lean burn**
Crankshaft Velocity Fluctuation	5	5	5
Ionization Current Monitoring	1	1 to 2	1
Cylinder Pressure Sensing	1	1	1
Exhaust Pressure Analysis	1	1	1
Other measures (please describe)	1	1	1
Comments:			

11. Which are the currently most commonly applied technologies for EGR diagnosis, according to the Euro 3 OBD thresholds? Please briefly describe technologies and indicate on a scale from 1 (not applied) to 5 (very widely applied)

Technologies	**Stoichiometric <1.8 ℓ**	**Stoichiometric >1.8 ℓ**	**Lean burn**
EGR Stepper Motor – Change in MAP	3, non applicable for most	3 to 5 non applicable for most	5, non applicabl e for most

12. Which are the currently most commonly applied technologies for oxygen sensor diagnosis, according to the Euro 3 OBD thresholds? Please briefly describe technologies and indicate on a scale from 1 (not applied) to 5 (very widely applied)

Technologies	**Stoichiometric <1.8 ℓ**	**Stoichiometric >1.8 ℓ**	**Lean burn**
Circuit continuity Signal amplitude Delay time	5 5, but also 3 5	5 5, but also 3 5	5 5 5

13. Among the monitored components, which seem to present the highest technical difficulties in diagnosis? Please indicate on a scale from 1 (most difficult diagnosis) to 5 (easiest diagnosis)

Components	**Stoichiometric <1.8 ℓ**	**Stoichiometric >1.8 ℓ**	**Lean burn**
Catalytic converter	1 to 2	1 to 2	1
Misfire	1 to 3	1 to 3	1 to 3
Oxygen sensor	1 to 3	1 to 3	1
EGR	2 to 3, but for most n. a.	2 to 3, but for most n. a.	2 to 3
Other systems *(please list)* Secondary air	1 to 3 but for some n. a.	1 to 3 but for some n. a.	1 but for most n.a.
Comments			

14. At the vehicle level, what is the average estimated percentage of errors of omission (high emitting vehicles not identified by OBD) and errors of commission (low emitting vehicles falsely identified by OBD), based on Euro 3 OBD thresholds? (Please tick)

	% of MIL activations	**Stoichiometric**	**Lean burn**
Errors of commission	<1%	✓	✓
	1-10%		
	>10%		
	% of high emitters	**Stoichiometric**	**Lean burn**
Errors of omission	<1%	✓	✓
	1-10%		
	>10%		
Comments	.		

15. In which direction would you expect that the above figures will change, if the same diagnostic technologies are applied for diagnosis according to the proposed Euro 4 level standards? Please indicate on a scale of -2 (significant increase of errors) to +2 (significant decrease of errors).

	Stoichiometric	**Lean burn**
Errors of commission	-1 to 0	-1 to 0
Errors of omission	0	0
Comments	It is assumed that Euro 4 level standards means proposed Euro 4 OBD thresholds	

16. Which ones of the alternative technological solutions would you consider as promising for application in the near future? Please rate each individual feature on a scale of 1 (poor) to 5 (very good).

	Accuracy of diagnosis	**Cost**	**Durability**
Thermal methods for catalyst diagnosis	1	3	3
NO_x sensors for 3WCC diagnosis	2	1	3
NO_x sensors for NO_x storage catalyst diagnosis	3 to 4	1	3
HC sensors for 3WCC diagnosis	Not available		
Cylinder pressure sensing for misfire	4	1	2
Exhaust pressure analysis for misfire	2	1	2
Other measures (please describe)			

1.5. On-Board Diagnosis of SI lean burn engines

17. Which particular difficulties (if any) are encountered in diagnosing exhaust related malfunctions in SI engines operating under lean conditions? Please describe.

Components	**Particular difficulties**
3 way catalyst	same as stoichiometric
NO_x storage catalyst	complex strategies, costs
Misfire	same as stoichiometric
Oxygen sensor	same as stoichiometric, but also accuracy for some manufacturers
EGR	accuracy and durability, but for most manufacturers n.a.

18. In what ways are the currently applied technological solutions for diagnosis of lean burn engines different from the ones applied to stoichiometric engines? Please describe. If you believe this topic has been covered by previous questions please ignore this question.

Components	Current differences from stoichiometric engines
3 way catalyst	see previous questions
Misfire	
Oxygen sensor	
EGR	

1.6. OBD thresholds

19. According to the current EU legislation, type approval of the OBD systems may be performed in other driving conditions outside the NEDC. What kind of driving conditions are mostly used for OBD system type approval? (please tick)

Driving conditions	
NEDC	✓
Steady state operating conditions	
Other legislated driving cycles (please list)	
Custom driving cycles (please describe)	
Comments: Directive 70/220/EEC specifically requires demonstration using the NEDC.	

20. Which are the most commonly applied methods to generate or simulate malfunctions during type approval testing of the OBD system?

Catalytic converter ageing	thermal ageing + poisoning
Misfire	electronic simulation
Lambda sensor deterioration	electronic simulation, modification of housing
Other components NOx sensor	electronic simulation
Comments: We also install faulty components.	

21. Are there any particular technological constraints, which apply to the diagnosis of increased NOx emissions from stoichiometric engines? If yes, please describe the difficulties and the proposed technical solutions to improve diagnosis accuracy.

> Depends on the cause of the NOx increase. If confined to catalyst diagnosis, no insurmountable technical problems providing OBD threshold is correctly set as defined in the November 2002 proposal.
>
> Further reduction of the NOx thresholds would make the catalyst NOx diagnosis difficult and, probably, unreliable.

22. Please describe the particular technological requirements and main differences between an OBD system certified according to the EU legislation (EOBD) and one certified according to the US legislation (OBD-II).

> Not relevant

23. In the US legislation, the OBD threshold is expressed as a fraction of the type approval limit, while in the EU legislation, the OBD threshold tends to be expressed as a standard "decision tolerance" from the type approval limit. From the technological point of view (ability to diagnose high emitting vehicles), which approach seems to make more sense? Please comment.

> Both approaches are able to detect high emitting vehicles but the “decision tolerance” approach is the most cost effective.
>
> The ability to diagnose a failure is based on a system that is able to differentiate a good component from a deteriorated one. To be as accurate as possible and in order to have a good compromise between false detection and no detection, the gap between type approval limit values (good component) and OBD thresholds (bad component) is a key point. If this gap becomes too narrow, then the OBD system becomes less efficient, because failures will require more time to be detected i.e. the OBD system will need a more clearly defined range of running conditions to detect the occurrence of a failure with the needed confidence. This implies that a vehicle with a failure will be driven for a longer time with a non-detected failure. This situation occurs with the US approach. Indeed, the US system is unnecessarily complex.
>
> On the contrary if this gap between limit value and threshold, instead of decreasing, stays much or less the same (“decision tolerance” approach), the system will keep its capability to diagnose high emitting vehicles.
>
> For further explanation see the attached document.

24. Please state any other comments that you have, regarding the feasibility of complying with the proposed EOBD threshold values for Euro 4 vehicles.

> The HC and NOx thresholds, as proposed by the Commission, are feasible. Further reduction is unnecessary because failures would be detected only insignificantly earlier, or even later if the thresholds are reduced below a critical value.
>
> The CO threshold is unnecessarily low (as already in EU3).
>
> Moreover, too low thresholds would require ageing of parts to "artificial" failures (not observed in the field) for certification, thus generating an unnecessary burden.
>
> HC threshold is an issue for gas engines (methane).
>
> Further reduction of the NOx threshold would make catalyst NOx diagnosis difficult and probably unreliable.
>
> A sufficient lead-time is needed to modify the thresholds against which OBD monitors the occurrence of a failure. This lead-time is estimated in at least one year if the new thresholds are those proposed by the Commission. Any more ambitious thresholds will require a lead-time of 3 years.

1.7. On-Board Diagnosis of diesel engines

25. Which of the emissions control components listed below are most likely to be used in Euro 4 level vehicles? (please tick)

Diesel Oxidation Catalyst (DOC)	✓
Diesel Particulate Filter (DPF) + fuel additive	✓, but not all manufacturers
Catalyzed DPF	✓ but not all manufacturers
Non wall-flow DPF	-
EGR	✓, some cooled EGR
NOx absorber	-
NOx sensor	-
Cylinder pressure sensing	-
Other components/technologies (please describe): some manufacturers Oxygen sensor Temperature sensor Pressure sensor	 ✓ ✓ ✓

26. From the above components, name the ones with the highest expected amount of failures, leading to emissions increase

1	
2	
3	
4	
Comments: question non relevant to the OBD proposal	

27. Which are the currently available/applied OBD technological solutions for diagnosing the following components (please list)

Components	**Technologies**
Diesel Oxidation Catalyst (DOC)	NOT AVAILABLE
Diesel Particulate Filter (DPF)	Differential Pressure, Temperature sensor
EGR	Closed loop control deviation, Valve position
Fuel system	Fuel Pressure Feedback, Rail pressure loop + offset pressure sensor, Solenoid feedback signal
Fuel additive system	Regeneration successful monitoring, monitor of level of fuel additive and circuit continuity-
Other components/technologies (please describe): Air flow meter Turbocharging	 Speed density or mass plausibility check Pressure loop control

28. From the above components, name the most difficult to diagnose, based on current OBD requirements

1	Diesel Oxydation Catalist (diagnostic not available)
2	
3	
4	
Comments:	

29. Which are the most important technical and economic hurdles towards the introduction of stricter OBD thresholds for diesel engines? Please indicate on a scale of 1 (least important) to 3 (most important).

Components	**Obstacles**	**Importance level**
DPF	No soot sensors available	2 for most but also 3
	Inability to diagnose partial failures based on pressure drop	3
	Other (please describe)	
DOC	No oxygen storage capacity of DOC	3
	Limited exothermy of DOC	3 for most but also 2
	Other (please describe)	
EGR	EGR cooler efficiency	1 for most but also 2
	Other (please describe)	
NOx sensor	Increased cost for OBD purposes	3
	Durability	2 to 3
	Other (please describe): reliability	3
Other (please describe)		

1.8. Economic and social impacts of OBD

30. What is the estimated cost per vehicle of necessary investments for developing systems able to comply with future Euro 4 OBD threshold limits as proposed by the Commission (Doc........)?

	Stoichiometric <1.8 ℓ	**Stoichiometric >1.8 ℓ**	**Lean burn**
R&D costs (**present proposal**, calibrations, testing, aged/deteriorated in the laboratory and on th road components)	€30-50/vehicle	€30-50/vehicle	€30-50/vehicle
Hardware costs (sensors, processors)	?	?	?
Estimated effect on vehicle retail price (please comment)	n.a.		

31. How would the above cost figures be affected, if the OBD limit thresholds were reduced proportionally to the type approval limits (instead of adopting a standard "decision tolerance" from the type approval emission standards)?

	Stoichiometric <1.8 ℓ	**Stoichiometric >1.8 ℓ**	**Lean burn**
R&D costs (development of algorithms etc)	**?**	**?**	**?**
Hardware costs (sensors, processors)	**?**	**?**	**?**
Estimated effect on vehicle retail price (please comment)	Lower thresholds will possibly trigger also substantial hardware costs		

32. What is the estimated additional cost per vehicle, in order to develop an OBD-II compliant system, based on an EOBD compliant system (and vice-versa)?

n.a.

33. What is the expected effect of the establishment of new OBD thresholds on the competition between manufacturers a) with the currently proposed limit thresholds, b) with limit thresholds reduced proportionally with the type approval emission standards.

No effect. OBD is not competition-related. The regulation is the same for all manufacturers.

34. What is the expected environmental benefit from the establishment of new OBD thresholds a) with the currently proposed limit thresholds, b) with limit thresholds reduced proportionally with the type approval emission standards.

No environmental benefits for proportionally reduced thresholds. Disadvantages (delayed indication of real-world failures) below a critical limit, as far as it will take a longer time to detect an emission-related failure.

35. What is the observed or expected customer confidence on OBD technology and perception of vehicle reliability? Please comment.

Customer confidence depends strongly on the avoidance of false failure indications. This is achieved best with OBD thresholds that detect all real-world failures, but are not lower than necessary.

APPENDIX 3

	Impact of the use of On-Board Diagnostic systems (OBD) in the diagnosis and maintenance of automobiles	
	Questions	***Your comments***
1	Among your workshop's clients, what is the approximate percentage of the vehicles equipped with OBD systems?	
2	What is the approximate percentage of the vehicles which visit your workshop with the "check engine" light (MIL) on?	
3	Among those vehicles, which are the most common malfunctions, which induce MIL activation?	
4	Do you perform idle emission tests on the vehicles, which arrive at the workshop with MIL on? If yes, what are the emission levels compared to the I/M procedure thresholds?	
5	Have you observed any vehicles with MIL on, but without any actual failure? If yes, how do you handle the situation, and what are the client reactions?	
6	Have you observed any vehicles with severe failures, but with MIL off;	
7	For the vehicles which are not equipped with OBD systems, do you use other electronic diagnostic equipment?	

8	If yes, what are the benefits of OBD system compared to previous diagnostic equipment?	
9	Do the OBD systems influence the **time** necessary for diagnosing a failure? If yes, towards which direction?	
10	Do the OBD systems influence the **cost** for diagnosing and repairing a failure? If yes, towards which direction?	
11	Do your clients become aware of these influences (wherever they exist)?	
12	Other comments, observations and remarks regarding the use of OBD systems in the workshop?	