Limited edition

ESTIMATION OF COSTS AND BENEFITS OF INSPECTING OBD SYSTEMS

Final report

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1 EXECUTIVE SUMMARY

The objective of this report is to estimate the costs and benefits from a potential introduction of examining OBD systems at periodic inspection, with and without the currently used 4gas analysis, as part of the 2nd CITA Programme of Research on Emissions. In the context of the CITA study, several measurement campaigns have been done. In these tests, emissions of CO, NO_x and HC of gasoline vehicles have been measured for a number of vehicles with enforced failures.

In this report, a methodology has been developed for the cost-benefit and cost-effectiveness analysis of scanning OBD at periodic inspection. To this purpose, a model is build by Vito that uses the data from the test, and in addition data and assumptions on failures. The benefits from the reduction of the emissions are valued in economic terms based on data from the European ExternE project. These data are based on a detailed assessment of the impacts of emissions on man and environment. The cost are estimated using data from national partners from CITA and from literature. In order to get an idea of the importance of regional variation within Europe of failures, impacts and the sensitivity of inspection scheme, the calculations are made for Belgium, the UK and Germany.

These case studies have shown that there are important gaps in the data availability related to the additional number of failures identified by OBD compared to 4-gas analysis as well as their impact on emissions. Therefore, the case studies are rather an illustration of the methodology then a full cost-benefit analysis, especially since we can only quantify some parts of the total benefits.

The costs of scanning OBD at periodic inspection will depend on a number of factors, especially the required additional time. The difference between centralised and decentralised systems is less important. For Belgium and the UK the cost for the could be around 3 € per vehicle inspected, but a more simplified procedure would however reduce these costs significantly. The situation is also different in Germany where the net costs may be zero as OBD may replace another test. It is not clear whether OBD may lead to benefits for motorist in terms of avoided repair costs or fuel savings, as claimed in leaflets. Overall, there will be no big increase of costs for the introduction of an OBD test (zero or even negative in Germany).

Scanning OBD at periodic inspection leads no doubt to benefits as it identifies additional vehicles with failures, so that inspection is improved. In addition are benefits related to an earlier repair of vehicles following the MIL lamp indicating a failure.

There are not enough data to make a good estimate on how many additional failures and vehicles will be identified, neither what the impact on all relevant emissions will be. In the case studies, we can only quantify impacts from a limited number of pollutants (HC, NOx and CO), based on information on some failures. This subtotal of the total benefits is not big enough to outweigh our estimate of the costs. The numbers show that the variation in the benefits between the three countries studied is limited but that the impact of early repair may be important.

This study however does not exclude that the benefits may be larger then the costs, because we don't have data to estimate the impacts on emissions of PM and CO2, which are the two most important pollutants from recent gasoline vehicles. In addition, as OBD becomes more performing, it may be able to identify more failures and extra emissions which cannot be identified by the 4gas analysis, like those related to cold start.

2 OBJECTIVES, BACKGROUND AND SCOPE

The objective of this report is to estimate the costs and benefits from a potential introduction of examining OBD systems at periodic inspection, with and without the currently used 4gas analysis.

This report of Vito is intended to be part of study 3, OBD, in the 2nd CITA Programme of Research on Emissions.
The work to be done refers to work package 370 : the Estimation of the cost-benefit of inspecting OBD systems. The objective of this work package is formulated as : “to analyse the results of WP 350 and any other sources to estimate the emission reduction benefits of examining OBD systems at periodic inspection and to calculate the likely costs of such inspections; to evaluate the added benefit of continuing to measure exhaust emissions”.

In the context of the CITA study, several measurement campaigns have been done. In these tests, emissions of CO, NO_x and HC[1] of gasoline vehicles have been measured in normal operation. Subsequently, some faults have been introduced in the engine or exhaust treatment system, and the impact of these failures on the emissions have been measured.

In this report these results are used to estimate the potential impact on emissions from scanning OBD at periodic inspection. To this purpose, a model is build by Vito that uses the data from the tests, data and assumptions on failures. The benefits from the reduction of the emissions are valued in economic terms based on data from the European ExternE project. These data are based on a detailed assessment of the impacts of emissions on man and environment. The costs are estimated using data from national partners from CITA and from literature. In order to get an idea of the importance of regional variation within Europe of failures, impacts and the sensitivity of inspection scheme, the calculations are made for Belgium, the UK and Germany.

As there is hardly any literature or studies available in Europe on costs and benefits from vehicle inspection and maintenance and from OBD in particular.[2] , we had to build mainly on the results from the measurement campaigns and some generic information on environmental damage costs, failures and costs.

3 METHODOLOGY

3.1 Defining costs and benefits

The objective of this report is to evaluate the costs and environmental benefits of inspecting OBD systems at yearly inspection for gasoline passenger cars. This means that following factors need to be calculated:

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[1] In this report we use the term HC (hydro carbons) to be consistent with the CITA report. If necessary we used HC instead of VOC, even if the original source or text uses the term VOC.
[2] The most relevant studies are the studies in the context of the European Auto-oil II program, workgroup IV on inspection and maintenance. Another example is the background document on costs and benefits of the introduction of proposed new regulations for I/M programs (e.g. UK for roadside emissions).

- Benefit side :
  - B1 The impact of examining OBD systems on the emissions from gasoline vehicles.
  - B2 The benefits to society from a reduction of emissions, in monetary terms.
- Costs side:
  - C1 The costs of examining the OBD system at periodic inspections.
  - C2 The net costs to drivers for repair of the vehicle.

The benefits of environmental or other regulations, like examining OBD at yearly inspection, are the avoided environmental damages. To this purpose, the environmental damages must be calculated in a scenario with and without the envisaged regulation.

This study does not look at the total environmental damages of transport. It only focuses on air pollution damages (and benefits) originating from cars that do not meet regulation due to a well specified list of failures, as listed and described in detail in the report by CITA. The failures can be detected thanks to the inspection of the OBD system and are estimated to be representative for the additional value of inspecting OBD systems.

The environmental damages, dealt with in this report, are restricted to damages related to air pollution. This is a reasonable assumption, as we do not expect the failures to have an important impact on other types of externalities such as noise. It must however be noted that not all air pollutants are discussed. The main omission is emissions of particles ($PM_{2.5}$). This issues is also discussed in more detail further on.

The costs, dealt with in this report, are the extra costs the vehicle inspectorates are faced with in order to allow inspection of OBD. These include the investment costs (purchase of goods, adaptation of installations), training of staff and operation costs.

In addition, we have a brief look at the costs of time losses and for repairs for the motorists. The net costs for the motorists, such as potential avoided damages and the consequent repair costs or fuel costs savings, will however not be assessed within the scope of this study, due to a lack of data.

3.2 Cases in study

Three cases will be examined in this study: Belgium, Germany and the United Kingdom. These three countries were chosen, because the periodic inspection is organised differently in each of them:

- Belgium : centralised – yearly inspection;
- Germany: decentralised – biannually inspection – OBD replaces an other test;
- U.K.: decentralised – yearly inspection.

In the calculations, we will take into account this variation in inspection schemes, together with data and assumptions on failure rates for vehicles and differences in impacts on man and environment between countries in the EU.

3.3 Defining policy scenarios

Usually, the evaluation of costs and benefits requires the comparison of two scenarios, with and without the envisaged policy measure. The methodology, developed for this study, allows to compare the environmental damages from failures for 4 different policy scenarios:

- Scenario 1: neither 4gas analysis nor OBD is used in order to limit emissions as a consequence of a failure;
- Scenario 2: all cars have a OBD aboard which is examined at the periodic inspection, the 4gas analysis has been abandoned for the inspection;
- Scenario 3: the cars are inspected by use of the 4gas analysis (current situation), OBD is not a common practice, and is not examined at the inspection;
- Scenario 4: the inspection of the cars by 4gas analysis is assisted by examining OBD at the inspection.

Consequently, the additional environmental damages due to failures are calculated for these 4 different scenarios, see Table 1:

Table 1: Overview of the different scenarios that are considered

	Damages due to failures	Tools used at the inspection	
		4 gas analysis	OBD
Scenario 1	D1	no	no
Scenario 2	D2	no	yes
Scenario 3	D3	yes	no
Scenario 4	D4	yes	yes

The environmental benefits are the avoided damages, thanks to the inspection of the vehicles.

The main purpose of this report is to assess the benefit of examining OBD, in addition to the current 4 gas analysis. This benefit is equal to the difference between damages of scenario 3 and 4. However, we can put the benefit of OBD in a wider perspective of the benefits of inspection using 4 gas analysis. To this purpose we can distinguish 4 groups of benefits.

Table 2: Calculation of the added values of OBD or 4gas analysis

Benefits of		Formula
OBD	in addition to the current 4 gas	D4 – D3
OBD	as sole inspection tool	D1 – D2
4 gas analysis	as sole inspection tool	D1 – D3
OBD	in combination with the current 4 gas	D1 – D4

3.4 Defining levels of failures

Inspecting OBD in addition to the current 4gas analysis test can only have an environmental benefit if it allows to detect more failures than if only the 4gas analysis were in use. This implies that there are failures that can be detected by OBD whilst the 4gas analysis test cannot.

In this study, we define a failure as a malfunction at a certain part of the car. The list of failures is however restricted to those which were simulated in WP350. This implies that this report is likely to underestimate the benefits as the failure simulation during the test phase of the OBD-Study WP350 did not include all failures which may happen in the field. Furhtermore, taking account of the short time in which OBD had been in production and the difficulties that introduction of OBD caused, it seems very likely that the performance of the OBD in relation to fault detection will become improve in the future. Table 3 presents us an overview of which experiments were carried out on which cars. Technical details of the cars involved can be found in Appendix 1.

Table 3: Overview of the parts of the cars which were subject to a simulated failure at the different cars

Failure simulated at	On vehicle number																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Coolant temp. sensor	✓	✓	✓	✓	✓				✓	✓	✓		✓	✓			✓
Air mass flow sensor	✓			✓									✓				
MAP sensor		✓	✓					✓			✓	✓		✓	✓	✓	
Inlet air temp. sensor											✓	✓	✓	✓			
Throttle position sens.	✓											✓			✓		
Cylinder head sensor												✓					
λ-sensor	✓	✓	✓			✓		✓	✓	✓						✓	✓
Intake manifold								✓									
Sec. air injection	✓																
Idle speed actuator	✓																
Injectors	✓	✓															
Ignition, sparks	✓	✓	✓					✓	✓	✓					✓	✓	✓
EGR-valve		✓															
λ-sensor heater								✓	✓	✓	✓		✓				✓
catalyst	✓						✓	✓	✓	✓							✓
Evaporation system					✓												

MAP: manifold absolute pressure

Each failure has a certain chance of prevalence, further denoted as “p”. If it prevails, it can vary in level; in this study 4 different levels of failures are considered:

- Level A: the failure is present, but its effect is so limited that the OBD system is unable to detect it and the extra emissions, the failure causes, are so low that the car passes the 4gas analysis (for instance: a spark plug with a gap of 0.1 mm);
- Level B: the OBD is able to detect the failure; nevertheless passes the car the 4gas analysis, as the consequent extra emissions are still moderated (for instance: a malfunctioning precatalyst in combination with a well functioning main catalyst);
- Level C: the extra emission the failure causes are considerable enough to fail the 4gas analysis, nevertheless the OBD is unable to detect the failure (for instance: a λ-sensor with a deformed signal);
- Level D: the failure is so predominant that the 4gas analysis and the OBD detects the failure (for instance: a disconnected λ-sensor heater).

The probability of each level is denoted as “a”, “b”, “c” and “d”. The sum of the probabilities: a + b + c + d equals 1.

The definition of the levels of a failure are summarised in Table 4.

Table 4: Overview of the different levels of failures that are considered

	Failure type			
	Level A	Level B	Level C	Level D
Probability	a	b	c	d
Detectable by OBD	no	Yes	no	Yes
Detectable by 4gas analysis	no	no	Yes	Yes
Detected in Scenario 1	no	no	no	no
Detected in Scenario 2	no	Yes	no	Yes
Detected in Scenario 3	no	no	Yes	Yes
Detected in Scenario 4	no	Yes	Yes	Yes

3.5 Assessing the environmental damages

A failure can have an impact on the emissions of the vehicle. This impact varies from pollutant to pollutant and differs from level to level. In this study, only the extra emissions are considered: i.e. the difference between the emitted quantities by the vehicle with and without a failure.

The consequent environmental damage can then be found by multiplying this extra emissions by the pollutant specific environmental damage cost. This damage cost can be location specific.

So, the damage cost of a certain failure is given by:

$$D_{failure} = \sum_{pollutants} (a.E_{A,pollutant} + b.E_{B,pollutant} + c.E_{C,pollutant} + d.E_{D,pollutant}).C_{pollutant}$$

With:

- D: failure specific damage cost [EUR/year];
- a, b, c, d: distribution over the 4 levels defined [%]

- E: additional emission of a specific pollutant due to a specific failure [ton/year];
- C: pollutant specific environmental damage cost [EUR/ton].

Hence, for all scenarios defined in 3.3 and all cases defined in 3.2, the damage costs of failures are calculated as the follows:

$$D = p_{failure} \cdot \sum_{failures} DC_{failure}$$

With:

- D: failure specific damage cost [EUR/year];
- p: prevalence of the failure [%];

The difference in damage cost between the scenarios is caused by differences in prevalences of failures and distributions over levels (factors p, a, b, c and d). The damage cost can differ from one case to another, as a consequence in variation of pollutant specific environmental damage costs (factor C), which can be location specific.

3.6 Structure of the report

This report first analyses the results of the experiments carried out in WP350, indicating what effect the simulated failures had on the emissions (chapter 4).

The next chapter focuses on the external damage cost as a consequence of the extra emissions, due to the failures (chapter 5).

In chapter 6, the environmental benefits of introducing OBD are calculated for the three cases: Belgium, Germany and United Kingdom.

Then, the costs of inspecting OBD at the periodic inspection are assessed (chapter 7).

Finally, the costs are compared to the benefits (chapter 8).

4 EVALUTING THE EXTRA EMISSIONS DUE TO FAILURES

Before calculating the environmental benefits of introducing OBD at the periodic inspection, the results of the experiments, carried out in WP350, are analysed in order to have more insight into the effect of the simulated failures on the vehicle emissions.

First, an overview of the experiments is offered. Then, the results are discussed. At last, the chapter explains what data are taken for the calculations.

4.1 About the experiments

In WP350, 113 experiments were carried out on 17 different petrol cars in order to simulate failures at 16 different parts of these vehicles and 4 combinations of these failures, see Table 3. An overview of the available data on these 113 experiments is offered by Table 5. The simulated failures are discussed a little more in detail in Appendix 2.

Table 5: Overview of the availability of the OBD error code readings and the exhaust gas analyses for all experiments

Failure simulated at	Nr. of exp.	OBD error codes readings			Exhaust gas analyses					4gas/ OBD in x cases
		no codes MIL off	codes MIL off	codes MIL on	4gas Pass	4gas Fail	Type 1 Pass	Type 1 Fail	EUDC	
Coolant temperature sensor	15	6		7	4	5	2	2	7	7
Air mass flow sensor	6	2		3	1		1		1	
Manifold pressure sensor	10	4	4	2	1	1	1		1	2
Inlet air temperature sensor	3	3								
Throttle position sensor	4	3		1						
Cylinder head temp. sensor	1	1								
λ-sensor	37	18	1	16	14	12	2	3	9	24
Air flow sensor + coolant temperature sensor	1					1		1	1	
Coolant temp. sensor + inlet air temp. sensor + MAP sensor	1			1	1		1			1
Intake manifold	1	1			1					1
Sec. air injection	1			1						
Idle speed actuator	1			1						
Injectors	3	1		2						
Ignition, sparks	13	4	1	8	2	5	4		4	7
EGR-valve	1			1						
λ-sensor heater	6	2	1	3	2	2				4
Catalyst	5	2		3	2	3	1	1	5	4
Evaporation system	1					1	1		1	
MAP sensor + misfire	1		1			1		1	1	1
λ-sensor + misfire	1		1			1		1	1	1
λ-sensor + catalyst	1	1				1		1	1	1
TOTAL	113	48	9	49	28	33	13	10	32	53

MAP: manifold absolute pressure

Of these 113 experiments, 106 error codes readings are documented. In 61 experiments, the exhaust gases were analysed with the 4gas analysis test. It gives a rough estimation of the content of CO, CO_2, O_2 (vol%) and hydrocarbons (HC, ppm) of the exhaust gases. Also the λfactor is given. In more than half of these one or another limit was exceeded. In 53 cases, the 4gas analysis results can be compared to the OBD error codes.

In 23 cases, the cars were submitted to the Type1 homologation test. In 32 cases, similar analyses were carried out, but the test conditions were shorten to the EUDC only. The results of these tests report the CO, CO_2, HC and NO_x content of the exhaust gases. They are more accurate than the indicative 4gas analysis results.

4.2 Effect on the emissions

For the sake of this study, the 53 experiments of which both 4gas analysis results and OBD error code readings are available, are the most interesting ones. They allow to make a distinction between the four levels of the failure as defined in 3.4:

- A: no OBD error code is present and no I/M emission limit is exceeded;
- B: the OBD system has recorded at least one error code, but no I/M limit is exceeded;
- C: no OBD error code is present, but at least one I/M emission limit is exceeded;
- D: at least one OBD error code is recorded and at least one I/M limit is exceeded.

Table 6 shows what effect the different failures have on the exhaust gas emissions of the components CO, CO_2, HC and NO_x; it gives the extra emissions due to the failures, i.e. the emission with failure compared to the emission without.

The figures given in Table 6 are an average of the available Type1 and EUDC test results. If the emissions were not measured according to these test conditions, an estimation of the extra emission is then made based on the documented 4gas analysis results. The number of appropriate experiments is given too. The last row of the table presents the weighted averages of the extra emissions for each level and pollutant.

It is hard to draw conclusions from Table 6. Generally speaking, the extra emissions of level A failures are lower than those of level B failures, the extra emissions of level B failures lower than those of level C failures and so forth, although it is not always that consistent.

Also nothing specific can be said about the extra emissions of one or another failure. A malfunctioning catalyst for instance leads to elevated emissions of CO, HC and NO_x, especially at level C and D. A failure at the λ-sensor seems to lead to higher CO emissions, although the extent of extra emission vary substantially from one experiment to another.

Some figures in Table 6 are negative, especially the CO_2 related ones. One explanation could be an eventual worse combustion of the fuel as a consequence of the presence of the failure. This could lead to an elevated emission of CO and HC and a reduced CO_2 emission, but one might expect then that the reduction in CO_2 emission is in the same order of magnitude as the increase in CO and HC emission. Table 6 does not give evidence for this hypothesis. More likely are the negative values an indication of the lack of accuracy of the measurements. One must also keep in mind that the magnitude of the contents of the different pollutants in the exhaust gases differs too: the average emission of the test cars without failure amounts to about 190 g CO_2/km, 0.58 g CO/km, 0.079 g HC/km and 0.046 g NO_x/km (average of Test1 results taken).

Table 6: Effect of the failures on the emissions (g/km)

	Failure Level A: passes OBD - passes 4gas					Failure Level B: fails OBD - passes 4gas					Failure Level C: passes OBD - fails 4gas					Failure Level D: fails OBD - fails 4gas				
	Nr	CO	CO_2	HC	NO_x	Nr	CO	CO_2	HC	NO_x	Nr	CO	CO_2	HC	NO_x	Nr	CO	CO_2	HC	NO_x
Coolant temp. ss.	2	4.8	3.8	0.14	-0.01	2	0.08	-9.5	0.03	0.07						3	1.3	22	0.055	0.011
Manifold press. ss.						1	(0)	(6)	(-0.03)		1	0.70	-12	0.016	0.080					
λ-sensor	10	-0.04	-5.1	0.0	0.01	3	2.2	-4.5	0.030	0.43	6	3.1	-2.8	0.084	0.33	5	(3)	(-2)	(0.3)	
Coolant temp. ss. + inlet air temp. ss. + MAP ss.	1	0.20	37	0.13	0.022															
Intake manifold	1	(0.01)	(0.9)	(0)																
Ignition, sparks	2	0.073	2.1	0.03	-0.01						1	(3)	(1)	(6)		4	0.23	5.5	0.01	0.01
λ-ss. heater						2	(0.2)	(-5)	(0.2)							2	(2)	(3)	(0.4)	
Catalyst	1	0.21	10	0.015	0.015	1	0.19	-3.7	0.03	0	1	3.7	-8.6	0.92	2.7	1	4.4	-5.9	0.51	2.9
MAP ss. + misfire																1	29	-0.30	4.5	0.21
λ-sensor + misfire																1	22	-4.4	1.4	0.007
λ-sensor + catalyst											1	2.3	-10	0.26	1.3					
TOTAL	17	0.57	0.51	0.03	0.006	9	0.82	-4.5	0.06	0.24	10	2.8	-4.6	0.77	0.67	17	4.7	4.3	0.52	0.32

ss.: sensor; MAP: manifold absolute pressure

4.3 Input data for calculation

4.3.1 Distribution of the four levels

The methodology requires that for every failure a distribution over the 4 different levels is given (see chapter 3.4). For all failures and combinations of, a same distribution is taken, based on Table 5:

- 30% for level A (probability a); i.e. not detected by OBD, passes the 4gas analysis;
- 20% for level B (probability b); i.e. detected by OBD, passes the 4gas analysis;
- 20% for level C (probability c); i.e. not detected by OBD, fails the 4gas analysis;
- 30% for level D (probability d); i.e. detected by OBD, fails the 4gas analysis.

4.3.2 Effect on the emissions

Table 6 delivers part of the needed data for the calculations. Unfortunately, too many gaps are left in the table, so another approach is used.

All failures are supposed to have a similar effect on the emissions. Distinction is only made between single failures and combinations of two failures or more. The effect of a level A failure is supposed to be the same as a level B one and the effect of a level C failure the same as a level D one. The underlying idea of this choice is that the 4gas analysis can make a difference between failures with a significant effect on the emissions and failures without, whereas the OBD system cannot. Level A and B failures both pass the 4gas analysis test, level C and D failures both don't. As there is no consistency in the extra emissions of CO_2 due to the failures, the failures are supposed to have no effect on this pollutant, see Table 7.

Table 7: Extra emission of CO, HC and NO_x, due to failures: input data.

Extra emissions (g/km) due to failures simulated at:	Level A and B: passes 4gas analysis				Level C and D: fails 4gas analysis			
	Nr.	CO	HC	NO_x	Nr.	CO	HC	NO_x
Coolant temperature sensor	3	2.4	0.15	0.016	8	8.7	0.30	0.013
Air mass flow sensor	1	0.12	0.017	0.0079				
Manifold pressure sensor	1	(0)	(-0.03)		1	0.70	0.016	0.080
λ-sensor	14	0.36	0.0065	0.26	12	1.4	0.084	0.26
Intake manifold	1	(0.15)	(0)					
Ignition, sparks	2	0.073	0.030	-0.008	5	0.37	0.078	0.01
λ-sensor heater	2	0.0039	0.033		2	2.4	0.18	
Catalyst	2	0.20	0.020	0.010	3	3.7	0.88	2.5
Evaporation system					1	0.039	-0.004	-0.017
Single failures	**26**	**0.50**	**0.027**	**0.16**	**32**	**3.2**	**0.20**	**0.36**
Air flow sensor + coolant temperature sensor					1	24	0.81	0.29
MAP sensor + misfire					1	29	4.5	0.21
λ-sensor + misfire					1	22	1.4	0.070
λ-sensor + catalyst					1	2.2	0.26	1.3
Coolant temp. sensor + inlet air temp. sensor + MAP sensor	1	0.20	0.13	0.022				
Combined failures	**1**	**0.20**	**0.13**	**0.022**	**4**	**19**	**1.7**	**0.47**

MAP: manifold absolute pressure

5 EXTERNAL DAMAGE COSTS OF AIR POLLUTANTS

Chapter 4 analysed the effect of the defects on the emissions of CO, HC and NO_x. This chapter explains how emissions into the air can be translated into environmental damage costs.

First, the general approach is presented. As an illustration, the environmental damage cost for a Belgian petrol car is discussed. Finally, the input data for the calculation of the benefits of introducing OBD are given.

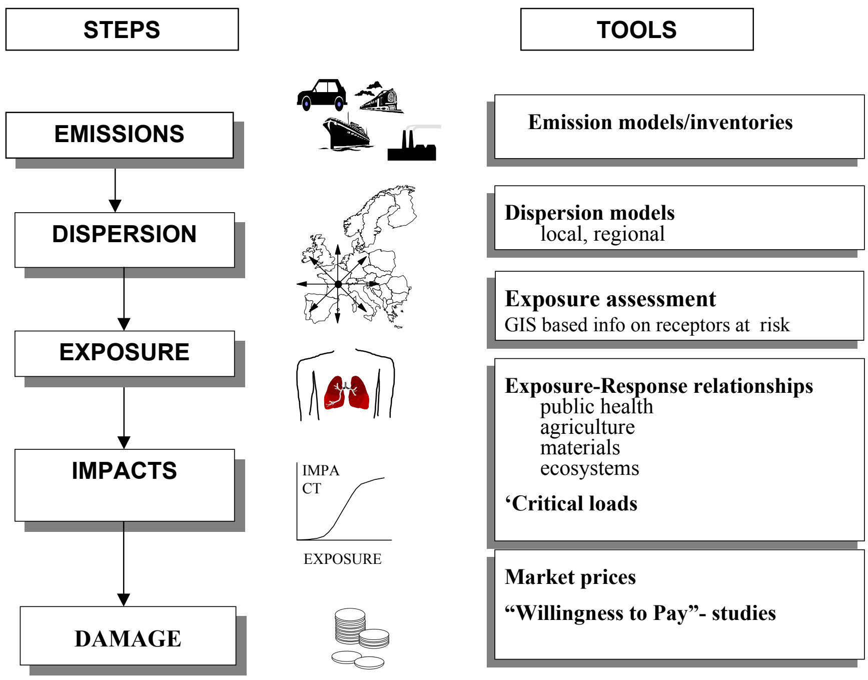
5.1 Approach

The environmental benefits of better inspection are the product of emissions saved and prevented impacts on man and the environment. For the latter, we have used the data from the European ExternE project, which is the most complete and up to date data-set on environmental impacts and damage costs in Europe, and which is widely used by the EC and other international, national and regional administrations.

5.1.1 Methodology

This European ExternE project provides an accounting framework based on an impact pathway methodology. It basically follows a pollutant from its emission until it causes an impact or damage. It estimates in detail the atmospheric dispersion of emissions, the exposure of man and environment to the pollutants and the resulting impacts on public health, agriculture and buildings, see Figure 1. More detailed descriptions of this methodology can be found and in Friedrich and Bickel, 2001.

Figure 1 : the impact pathway methodology



For monetarisation, we have compared the ExternE results with the guidelines of the EC, DG Env, and as the results are the same, we have used the data from the ExternE project on external costs per kg of emission, to estimate the benefits of improved inspection. For greenhouse gases, we have used another approach, based on avoided costs, which results in higher costs. For all pollutants of concern, except CO2, the most important externality – as far as it could be monetised - is their impact on public health. Especially the impact from particles, sulphates and nitrates on chronic mortality proved to be the dominant impact category. This reflects the major concern that has risen over the last years about the impact from small particles on human health, even at current ambient concentrations. Benzene and 1.3 butadiene are carcinogens and we have included this effect..

Table 8 shows which pollutants are considered in the calculation of the environmental damages of transport and what the pollutants have.

5.1.2 Impacts and damage costs per tonne pollutant

For all pollutants of concern, except CO2, the most important externality – as far as it could be monetised - is their impact on public health. Especially the impact from particles, sulphates and nitrates on chronic mortality proved to be the dominant impact category. This reflects the major concern that has risen over the last years about the impact from small particles on human health, even at current ambient concentrations. Benzene and 1.3 butadiene are carcinogens and we have included this effect..

Table 8: The relative share of impact categories in external costs estimates from air pollutants.

Impact category		CO	NO_x through nitrates	NO_x through ozone	NMHC ozone	HC
Public health	Mortality		72%	35%	35%	A: benzene B: 1-3 butadiene
	Morbidity	100%	28%	25%	25%	
Agriculture			-	40%	40%	
Materials			-	-		
Global Warming						C: methane
Ecosystems			N.M.	N.M.	NM	
Subtotals for emissions from transport (kEUR/ton)						
Belgium [a]		2	3 – 4.5	-2 – ? [b]	1.7	A: 0.6 – 2.5 B: 25 – 100 C: 460
EU range		0.05 - 20	0.02 – 8	-4 – +1 (most neg)	0.3 – 1.7	A: 0.6 – 7 B: 3 – 160 C: 460

N.M. = not monetised, but critical load exceedance data are available
- : not available
a : the range represents different locations in Belgium, except for ozone for which the range refers to marginal versus non marginal impacts.
b : based on EMEP matrices

The relative high figures for NOx and SO2 are related to the impacts from nitrates and sulphates, secondary particles formed from NO_x, SO_2 and ammonia (NH_3). Uncertainties relate to the background concentrations of ammonia, the formation of particles, their impact on public health and the valuation of these impacts. Impacts on buildings are relative important for SO_2 and may be important for particles (soiling), but their valuation for historic buildings is not properly accounted for. The net impacts on agriculture from SO_2 is almost negligible. Threshold values in exposure response functions apply for agriculture, materials and ecosystems, but not for public health.

The impact on ozone is more complex. NO_x contributes both to the formation and decomposition of ozone, and with current emission levels the net impact from NO_x emissions on regional ozone is estimated to be negative. Although this is the case for Belgium, UK and Germany, it is not similar for all EU countries. For HC emission on the contrary, marginal reductions at current levels will result in an reduction of ozone at the regional scale. For both pollutants, the local effect is complex to model and is not included.

Finally, it is important to note that the impacts on ecosystems could not be monetised and this is a very important blank in the accounting framework, especially for NOx because of exceedance of critical loads for acidification and eutrofication. This blank is important for a wide number of countries, but especially for countries as Belgium or Northern European Countries; it is less important for Southern European countries.

5.1.3 Global warming

It will not be surprising that it is more difficult to implement the impact pathway approach for global warming impacts, especially if long-term impacts have to be taken into account. Nevertheless, there is a lot of information available on costs and benefits of global warming for public health, energy and water supply and demand, agriculture, extreme weather events, protection against flooding, etc. These data can be integrated in an impact pathway framework. This results in a best estimate range for impacts between 2000-2100 between 0 and 16 Euro/ton CO2. (Tol, 2001) This range hides an even greater uncertainty for longer-term impacts and issues not accounted for. Therefore, it is argued that these data are too uncertain and too incomplete to use for cost-benefit analysis.
Another approach is to look at the marginal costs for the EU to meet the Kyoto target. This cost is a kind of 'shadow price' for each ton of CO2 emitted. This approach can be used for this study because, in order to meet Kyoto, any ton of CO2 saved thanks to OBD, has not to be saved in other transportation applications or other sectors, and is thus a benefit.
This approach results in a range of 10 to 40 Euro/ton of CO2, depending on how efficient policies will be and to which extent emission trading is allowed. (Torfs et al, 2002).

For the current study we used a figure of 20 € per tonne of CO2-equivalent to value global warming impacts from Methane.

5.1.4 Uncertainties

As indicated in Figure 1 the numbers used for the study are the result of an analysis in 5 steps. Consequently, the uncertainties in each step are cumulated and the overall uncertainties in the numbers is rather big. In the ExternE project it is estimated that for most impacts the 95 % uncertainty range varies between 20 % to 500 % of the best estimate. This range from ExternE has been used in the uncertainty analysis. (see paragraph 6.4). We have also used this range for the uncertainties on the global warming estimate, although in this field uncertainties are definitely bigger then for other pollutants. In addition to the best estimates, as indicated above,

we performed a Monte Carlo analysis to evaluate how sensitive our conclusions may be to the uncertainties in the estimates.
This numeric uncertainty however doesn't give the full picture of the uncertainty. Some omissions and working assumptions may be as important. Although there is a common understanding and growing number of studies that indicate that air pollution from traffic affects public health, it's quantification and valuation is still subject to uncertainty and discussion. For some health endpoints, like public health impacts from ambient CO and 1,3-butadiene, the evidence is limited and e.g. COMEAP argues not to quantify it. We follow ExternE in its' view that - for the purpose of this kind of studies. - an uncertain number may be a better proxy then zero.
Among the main omissions in damage data for this study is the local impact from NOx and HC on ozone formation and the impacts on ecosystems from acidification and eutrofication (NOx) and ozone (NOx and HC). As a consequence, the real uncertainty is bigger then the one reflected in the numbers.

5.2 Air pollution damage costs of petrol cars, Belgium.

As an illustration, the damage costs of a Belgian petrol car is discussed in this part of the report. It serves also as a framework against which the benefits of introducing OBD can be put.

Table 9: External cost per gasoline vehicle in Belgium for one year.

Type of car	$PM_{2.5}$	SO_2	Sulphates	Nitrates	Ozone	CO	Benzene	1,3-Butadiene	CO_2	Methane	Total
Euro 0	117	1.4	-3.5	154	-43	0.27	1.40	6.6	48	0.37	**280**
Euro 1	46	1.7	0.7	29	-12	0.10	0.13	0.06	57	0.32	**120**
Euro 2	46	1.7	1.2	13	-4.6	0.10	0.08	0.03	57	0.24	**115**
Euro 3	46	1.7	1.4	7.7	-2.0	0.08	0.08	0.03	57	0.24	**112**
Average	60.0	1.6	0.22	42.2	-13	0.13	0.36	1.4	56	0.28	**149**
	40%	1%	0,1%	28%	-8%	0,1%	0,2%	1,0%	37%	0,19%	**100%**

All external costs based on ExternE 2000, GHG effect of CO_2 and methane based on 20 € per tonne of CO_{2eq}.
Average : based on vehicle park 2001, rounded numbers.

The environmental damage costs per year of a petrol vehicle are around 150 EUR, varying between 280 for an older vehicle (Euro 0) to around 110 EUR for an Euro 3 vehicle, see Table 9, Figure 2).

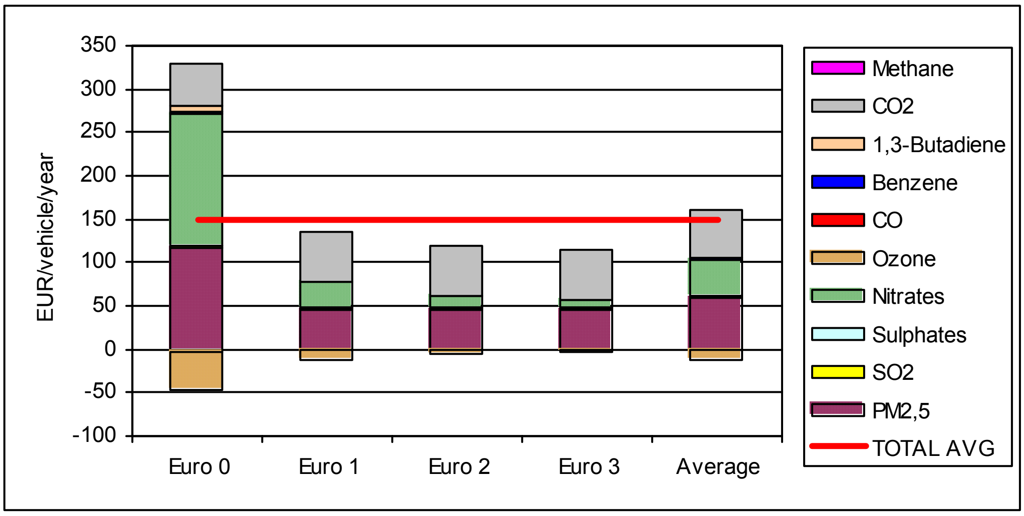
The major part of these damages are due to particle emissions (40%).

NO_x emission also contribute to a large extent: about 28% of public health impacts originates from exposure to nitrates. The net regional impacts on ozone of both NO_x and HC are negative (-13 %). It has to be noted that NO_x has important impacts on ecosystems, and from this perspective these figures are an lower bound of an unknown total.

The impacts of both CO and hydrocarbons (benzene, 1,3-butadiene) on public health are very small (total 1%), as well as the global warming impact from the methane fraction of the hydrocarbons.

The impacts of SO_2, both on public health, buildings and crops are also very small.

Figure 2: External costs per gasoline vehicle in Belgium for one year. (average for 2000)



Source : Vito.

5.3 Potential benefits of better maintenance and inspection

As indicated in chapter 4, we only have data for improvement of scanning OBD at inspection for emissions of NOx, HC and CO. These 3 pollutants only represent 11 % of the total air pollution damages costs.

It is estimated that the potential for emission reduction due to better maintenance and inspection is higher for CO and HC (35% and 25 % respectively) but more limited for NO_x (5 %) [3]. This means that the total potential for reduction of external costs for these three pollutants is rather limited (around 1 EUR per vehicle year). It also indicates that the real benefits of inspection and maintenance can only be assessed if data are available for the impact on particulate matter (even for petrol cars) and CO_2.

5.4 Input data for calculation

The data we used as input for the three studies are summarised in

Table 10. It shows how Damage cost vary on average between countries due to location specific factors. In general, public health impacts are higher in Belgium compared to UK or Germany because Belgium is – on average - more densely populated. Impacts from ozone and nitrates are more difficult to understand because a number of factors play a role, including background pollution, chemical reactions and competition between pollutants and density of receptors at risk (population, crops,..).

[3] Auto-oil II, WG 4 report

It has to be noted that this variation between countries is relatively small, and more extreme values are possible within Europe, especially for pollutants in very low populated areas (e.g. Finland) or high populated areas (big cities). The differences between the three selected case studies are certainly small compared to the overall uncertainty on the numbers.

Table 10: Damage cost of CO, HC and NO_x in Belgium, Germany and UK: input data.

Damage cost [EUR/ton]		Belgium	Germany	U.K.
CO	Public health	1.6	0.67	1.2
HC	Benzene, public health	1,500	530	980
	1,3-Butadiene, public health	56,000	21,000	38,000
	Methane, global warming	460	460	460
	Regional Ozone	1,700	1,700	1,000
	Local Ozone	Na	Na	na
	Combined, Subtotal	2,000	1,600	1,300
NO_x	Nitrates	3,100	5,100	3,500
	Regional Ozone	-1,300	-1,100	-1,400
	Local Ozone	Na	Na	na
	Ecosystems	Na	Na	na
	Combined, Subtotal	1,300	4,000	2,100

Na: not available
Source : Vito 2002, based on Bick et al, 2000 .

6 ENVIRONMENTAL BENEFITS OF INTRODUCING OBD

6.1 Case: Belgium

6.1.1 Basic data and assumptions

In Belgium, the general rule for passenger cars is that yearly inspection is required for vehicles that are 4 years old, or older. In some cases, younger vehicles also are subject to yearly inspection, e.g. when the vehicle is equipped with a towing hook. But for simplicity, we assume that in all scenarios considered, the number of cars that have to be inspected remain the same. In addition, we assume that all the vehicles are being repaired (immediately) after the inspection.

In 2001, of all 3,969,224 cars, that were registered in Belgium, 2,454,777 are petrol cars, of which about 1,940,000 are older than 4 years (NIS, 2002).

An expert study, carried out by Vito, revealed that the yearly mileage of a petrol car in Belgium is about 14,000 km.

One of the most important factors in the calculation of the environmental damages, is the prevalence p or the chance that a car is plagued by one or more failures. GOCA reports a failure rate of 2.5% for the environmental compliance test for petrol cars for 2000.[4] The share of cars suffering from a failure is however higher than the share of cars failing the 4gas analysis test. In Arizona, USA, it was found that about one-third of the motorists brought their car in for a tune-up prior to their next I/M test.[5] It is supposed that this figure applies for Belgium too. Hence, the 'real' failure rate is adjusted with 1.25% to 3.8%. This is however the share of failures detectable by the 4gas analysis. Failures, detectable by the 4gas analysis test, contribute for half of all failures considered in this study (see 4.3.1), hence, the 3.8% is double to 7.6% and rounded to 8%.

In the calculation, no distinction is made between the type of failure, only between the number of failures that car is plagued by (see 4.3.2). Based on figures, given by UTAC[6], about 3% of all cars is supposed to have one failure, about 2% two failures at the time and about 3% at least three.

6.1.2 Scenario 1: no OBD/no 4gas analysis

If neither 4gas analysis tests nor OBD error code readings were in use, none of the failures, which are subject of this study, can be detected. As a result, one can assume that the share of cars having a certain failure remains constant over the year. This share equals the expected probability p, which is 50% (see 6.1.1). The distribution of these cars over the different levels (level A: 30% - B: 20% - C: 20% - D: 30%; see 4.3.1) of that failure is constant too.

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4 VEILIGHEID EN MILIEU - 1525 inspecteurs in actie voor een veiliger leefmilieu, Persmededeling, http://www.goca.be/perscom/lijst.asp, GOCA, Belgium, downloaded on 17/8/2002.

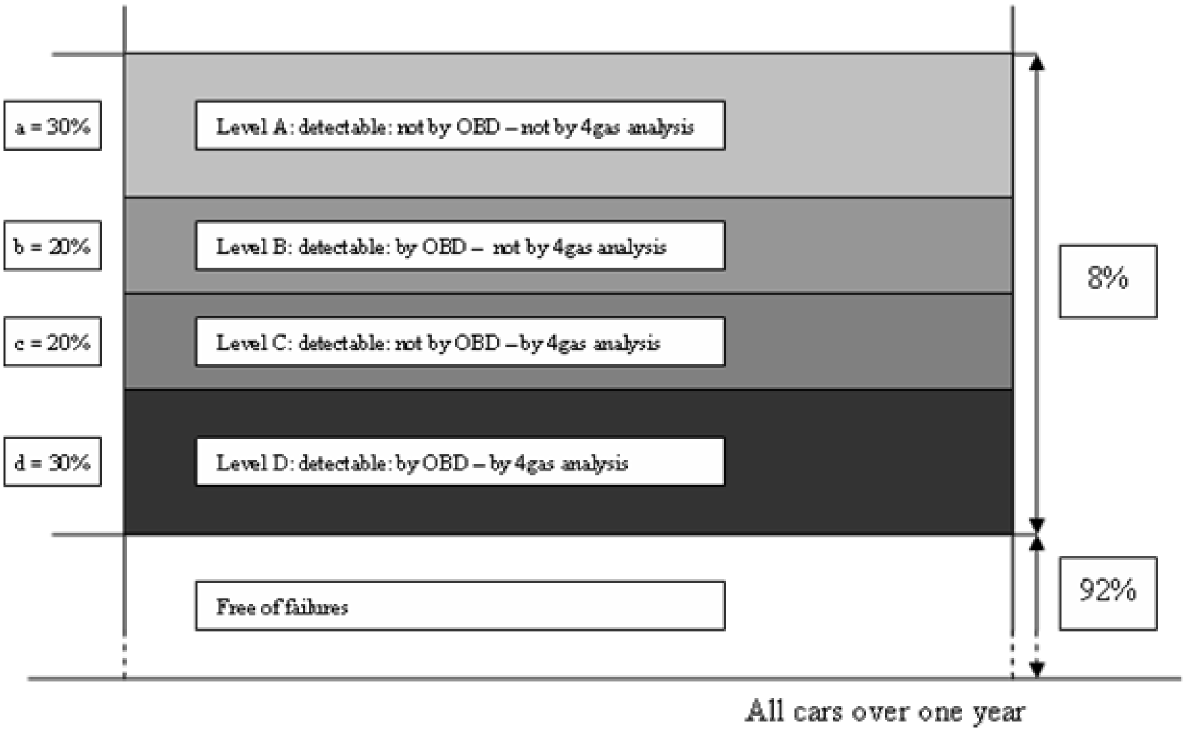
5 Wenzel T., Reducing emissions from in-use vehicles: an evaluation of the Phoenix inspection and maintenance program using test results and independent emissions measurements. Envir. Sc. & Pol., 4, pp. 359-376, 2001.

6 Controle technique périodique des véhicules automobiles, Rapport d'activité annuel 2001, Janvier 2002, UTAC/OTC, Monthlery, France

Schematically, the situation is as depicted in Figure 3.

These hypotheses do not exclude that a car, which did not have any failure at the start of the year, can get one during the year. Like so, if a car has a certain failure, it can worsen during that same year (a failure of level C becomes a level D one for instance). It is however assumed that cars, which are getting worse, are getting repaired and that cars, which are too bad, are replaced by new ones.

Figure 3: Probabilities of the different levels of failures if neither 4gas analysis nor OBD is in use.



6.1.3 Scenario 3: only 4gas analysis in use - no OBD

Of every car, failures of the level C and D are detected by the 4gas analysis and are supposed to be completely banned just after the inspection. The failures either have been repaired or the cars were replaced by new ones.

When following all these cars the next year following the inspection, one can see that the cars start to have failures. These failures are supposed to show up at a constant rate. At the end of the year, just before the next inspection, each level of failure C or D is supposed to have the expected probability, i.e. 20% for level C and 30% for level D (see 4.3.1).

Figure 4 presents the situation for this scenario. For simplicity, the start of years during which every individual car is followed, has been shifted to the same day. Practically, introducing the 4gas analysis, half's the prevalence of failures of level C and D.

The use of 4gas analysis tests at the inspection in Belgium saves about 49% of the emissions of CO (7,100 ton saved), 46% of HC (620 ton saved) and 43% of NO_x (230 ton saved) due to the failures. For the sake of comparison, the total emission by the petrol cars in Belgium in 2000 amounts to about 410 kton (kiloton) CO, 57 kton HC and 40 kton NO_x.

The reduction in emission of CO, HC and NO_x corresponds to an environmental benefit of about 1.6 million EUR, mainly thanks to the saving in HC emission, see Figure 5. This means that per car per year, about 0.80 EUR is saved, to be compared to the total damage cost of a petrol car, which amounts to about 100 EUR per year, see 5.2.

This saving is allocated to the levels of failures detected in Figure 4.

Figure 4: Environmental benefits for Belgium in scenario 3.

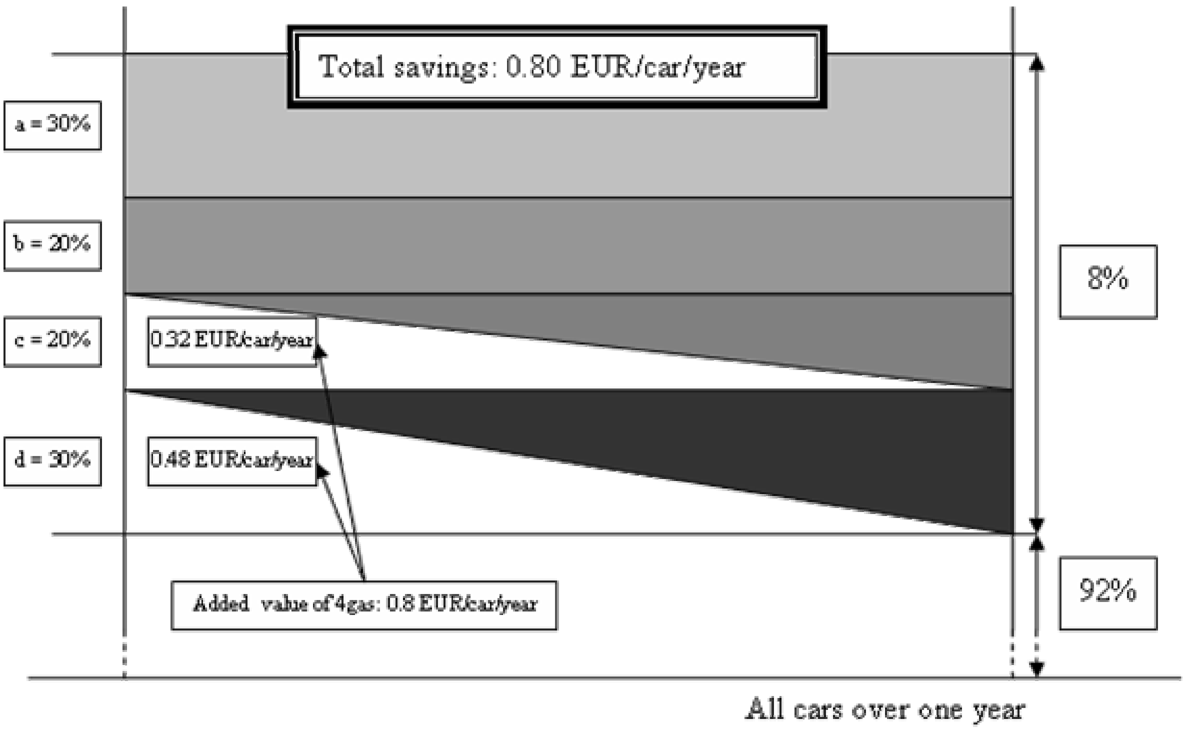
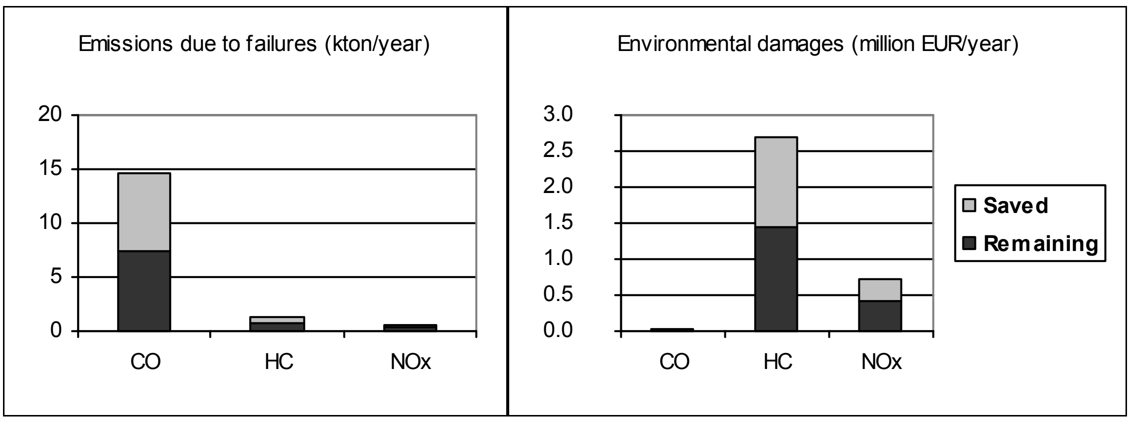


Figure 5: Total savings in emissions and environmental benefits for Belgium in scenario 3.

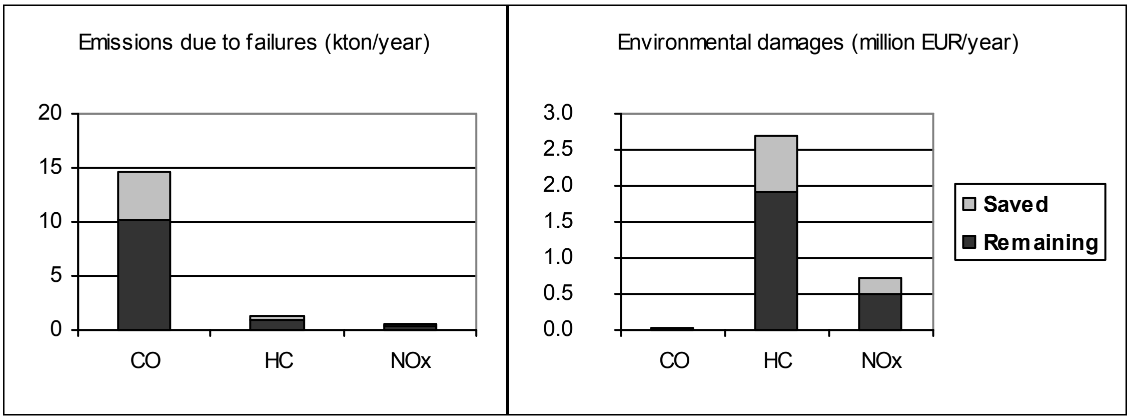


6.1.4 Scenario 2: only OBD in use - no 4gas analysis

Compared to Scenario 3, no failures level C are detected at the inspection, in stead failures level B are.

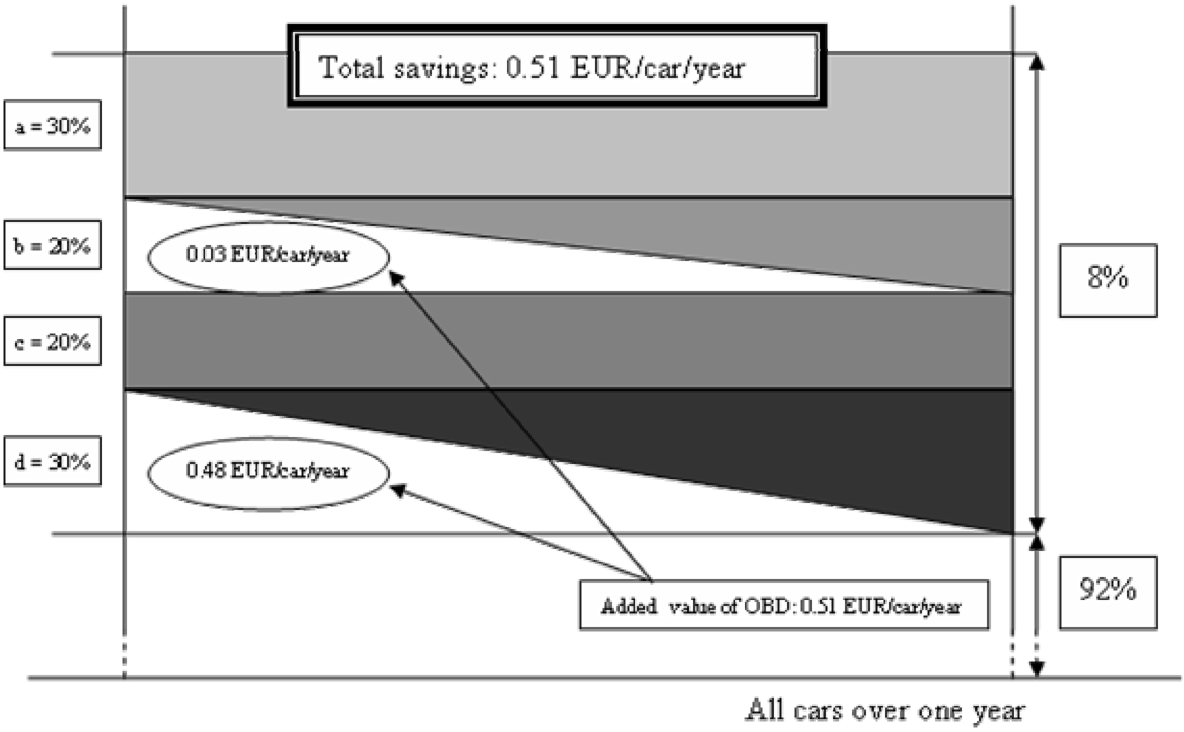
This has a serious impact on the environmental benefits, as the impact of failures level B is much less that that of failures level C. The reduction in the emissions of CO (4,300 ton), HC (390 ton) and NO_x (160 ton) due to failures amounts to 29% in stead of 43-49% as in scenario 3 (see Figure 6).

Figure 6: Total savings in emissions and environmental benefits for Belgium in scenario 2.



The environmental benefit drops with 0.29 EUR to 0.51 EUR/car/year, see Figure 7.

Figure 7: Environmental benefits for Belgium in scenario 2.

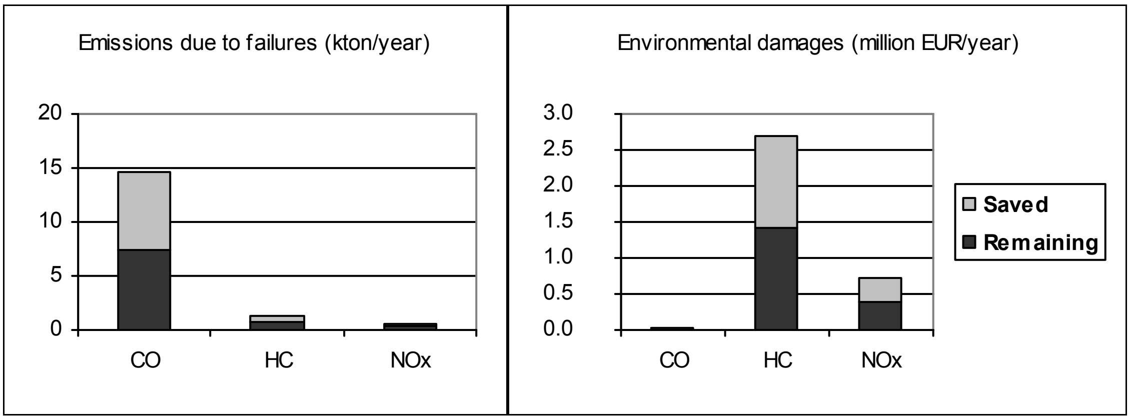


This environmental benefit can only increase if the affectivity of the OBD system increases (less failures are not seen by the OBD system) and/or if the OBD system is able to detect failures with a more important impact on the emissions (e.g. failures related to a cold start).

6.1.5 Scenario 4: both OBD and 4gas analysis in use

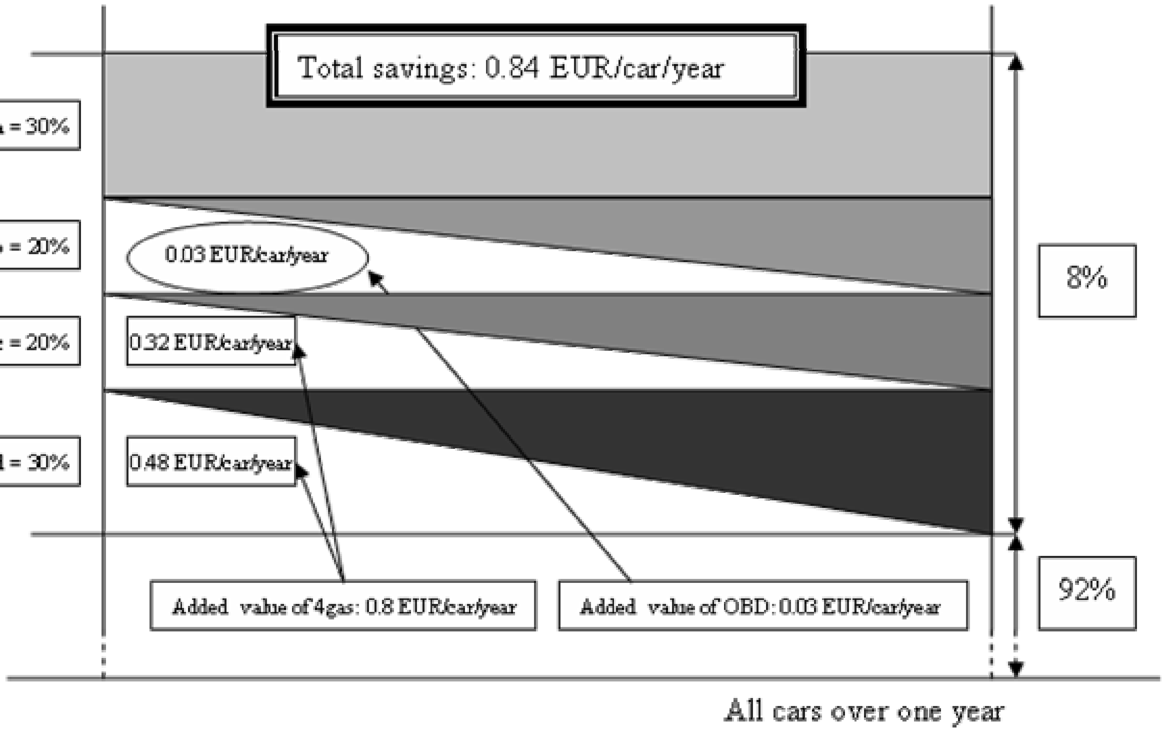
Compared to failures detected in Scenario 3, failures level B are detected additionally. But, as failures level B have a minor impact on the emissions as the failures already detected in Scenario 3, the additional emission reduction is limited: 0.4% CO (total reduction compared to Scenario 1: 49%); 1.5% HC (total reduction: 48%) and 2.8% NO_x (total reduction: 46%) (See Figure 8).

Figure 8: Total savings in emissions and environmental benefits for Belgium in scenario 4.



The environmental benefit amounts to 0.84 EUR/car/year. The introduction of OBD readings at inspection does not add very much to this environmental benefit, only 0.03 EUR/car/year.

Figure 9: Environmental benefits for Belgium in scenario 4.



6.1.6 OBD: additional benefits

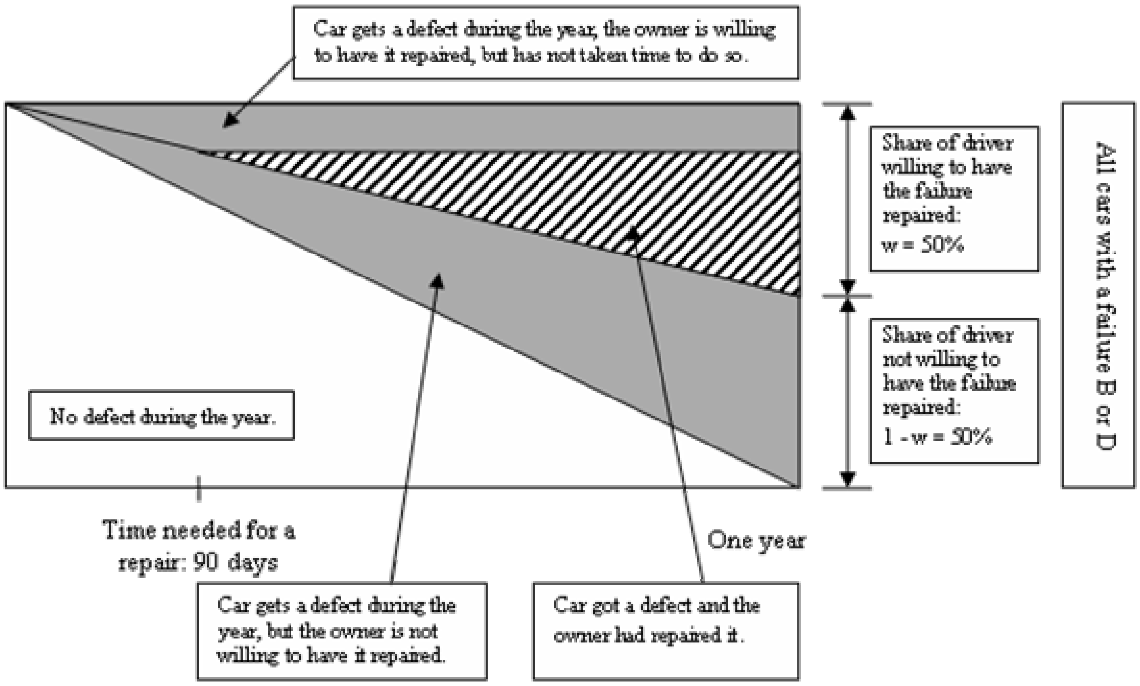
There is one special feature about the OBD system, which allows an extra reduction in emission to be realised: the MIL. This alerts the driver that an error code has been affirmed by the system and invites the driver to do something about it. In that way, the date of the repair of the failure, that would have been imposed by the inspection board, can be advanced.

For the sake of this study, it is assumed that a certain percentage of the driver is willing to have their car repaired. This share is denoted as “w” (willingness to repair) and a value of 50% is supposed.

Those drivers do need a certain time to have the failure repaired; they do not rush to the garage as soon the MIL illuminates. In the meanwhile, they drive the car which still suffers from the failure. This lapse of time is further denoted as “t”. A value of 90 days (3 months) is supposed, which is about the time span between two periodic maintenances.

Let us now have a look to the prevalence of failures level B or D, taking the effect of the MIL into account, see Figure 10.

Figure 10: Effect of the MIL on the prevalence of failures level B or D.



At the start of the year, none of these failures do occur, as they are banned by the last inspection. During the year, they start to show up and the MIL informs the drivers about their presence. Half of the drivers (share 1-w = 50%) do not care about them and continue to drive their car with a failure. The other half (share w = 50%) at the other hand wants to do something about it; however, no repair is done before 90 days (lapse of time t). From then on, these cars are supposed to be repaired at the same rate as the rate at which new failures show up. This means that the share of cars waiting to be repaired remains constant. In the last t days before the inspection, all the car owners who are detecting a failure are supposed to catch up with the repair, so that they present a repaired car to the inspection.

The introduction of OBD has cut the prevalence of failures level B into half, see the white triangle in Figure 10. The alerts by the MIL further reduces the prevalence of the failures, see the shaded triangle in Figure 10. The area of the latter triangle is $w/2.(1-t/365)^2$.

From Figure 10, it can be seen that if no one is willing to have the failures repaired (w = 0%) or if the willing drivers wait the whole year before they take initiative (t = 365 days), the added value of the MIL vanishes. At the other hand, if any of the drivers would be willing to have the failure repaired (w = 100%) and they have it repaired at the same day the MIL illuminates (t = 0 days), there are no environmental damages due to this kind of failures left.[7]

This allows us to calculate the additional environmental benefits of the MIL, see Figure 11 and Figure 12.

[7] Even if all drivers would be willing to have the failure repaired, the value of the factor w would not be the full 100%, because a failure level B or D is present as soon as an error code is in the OBD system. The driver can only be informed by the presence of the failure if the OBD system affirms the failure. From Table 5 it can be seen that of the 58 occurrences, in which OBD error codes were present, the MIL was on in 49 cases (85%).

Both in Scenario 2 (only OBD readings at the inspection) and in Scenario 4 (OBD assists the 4gas analysis), an extra 1.200 ton CO, 110 ton HC and 44 ton NO_x are avoided. This corresponds to a reduction in environmental damage of 0.28 million EUR per year or 0.15 EUR/car/year, the vast majority in failures level D.

Figure 11: Additional environmental benefits by the MIL in Scenario 2.

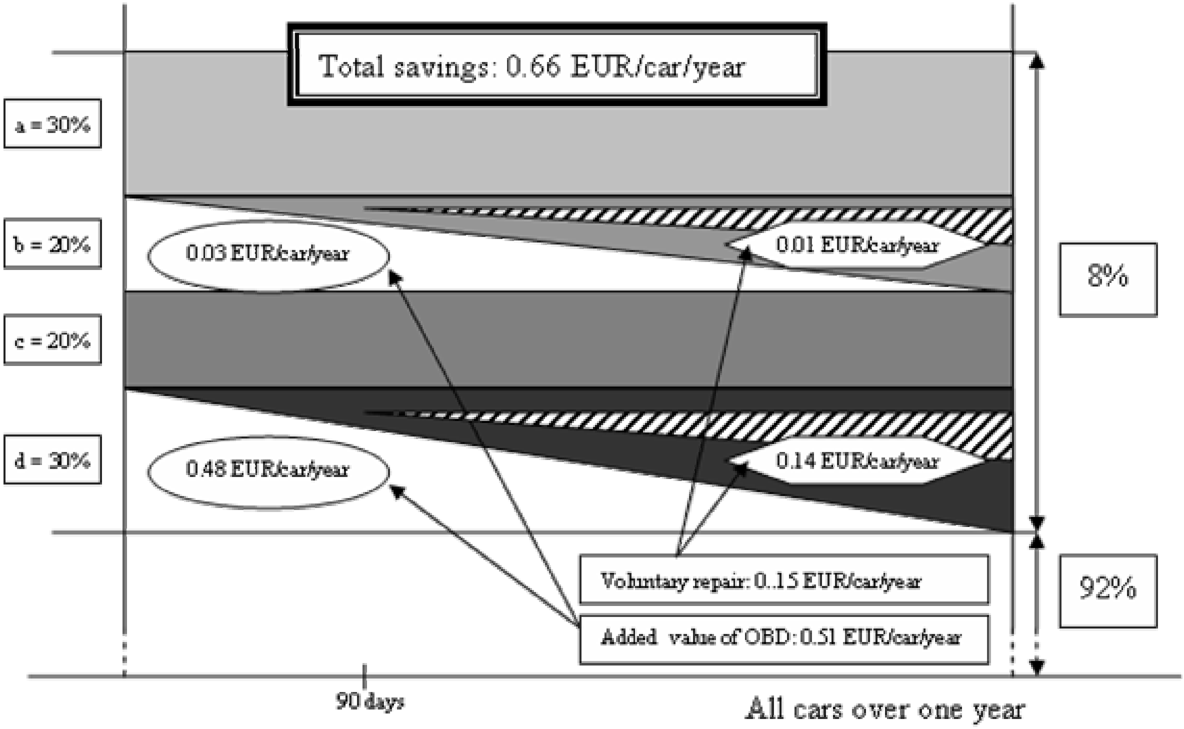
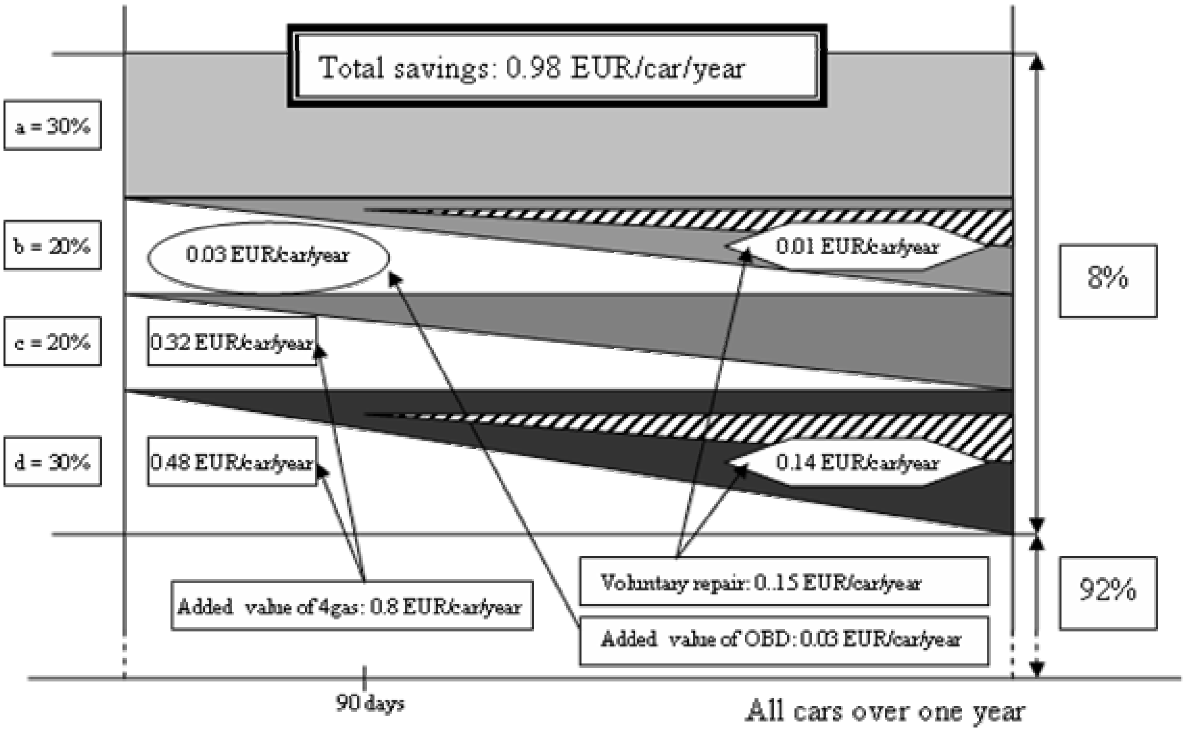


Figure 12: Additional environmental benefits by the MIL in Scenario 4.



6.1.7 Summary

Table 11 summarises the findings of the calculation of the environmental benefits for Belgium.

Table 11: Summary of the added values of 4gas analysis and OBD for Belgium.

Added value (EUR/car/year)			4gas analysis	OBD			Total
			Imposed repair	Imposed repair	Voluntary repair	Total	
Scenario 2	OBD	~~4gas~~		0.51	0.15	0.66	0.66
Scenario 3	~~OBD~~	4gas	0.80				0.80
Scenario 4	OBD	4gas	0.80	0.03	0.15	0.18	0.98

If OBD error code readings are read next to the currently in use 4gas analysis test, about 1 EUR per car per year is saved as a consequence of avoided emissions as a result of the detection of failures at cars. The added value OBD however is very limited, only 0.18 EUR per car per year. The vast majority of this benefit is a result of the advanced repairs by drivers willing to repair their vehicle after they have been alerted by the MIL.

The benefit of OBD as a sole inspection tool amounts to about 0.66 EUR per car per year and is less than the benefit of the currently in use 4gas analysis test. The former only exceeds the latter test if the willingness to repair would be increased to 99% (with a delay of 90 days to repair) or if the delay to repair the failure would be shortened. (Even if this delay would be zero days, still 57% of the drivers must be willing to have the failures repaired before the added value of OBD starts to exceed that of the 4gas analysis.)

6.2 Case: Germany

6.2.1 Basic data and assumptions

As in Belgium, car owners are invited to present their car at periodic inspection as soon the car is four years old or more. In Germany, there are about 29 million petrol cars with that age. Their yearly mileage is about 12,500 km.[8]

However, unlike Belgium, the periodic inspection is not an annual test but an biannual one, which makes it harder to compare the German situation to the Belgian one.

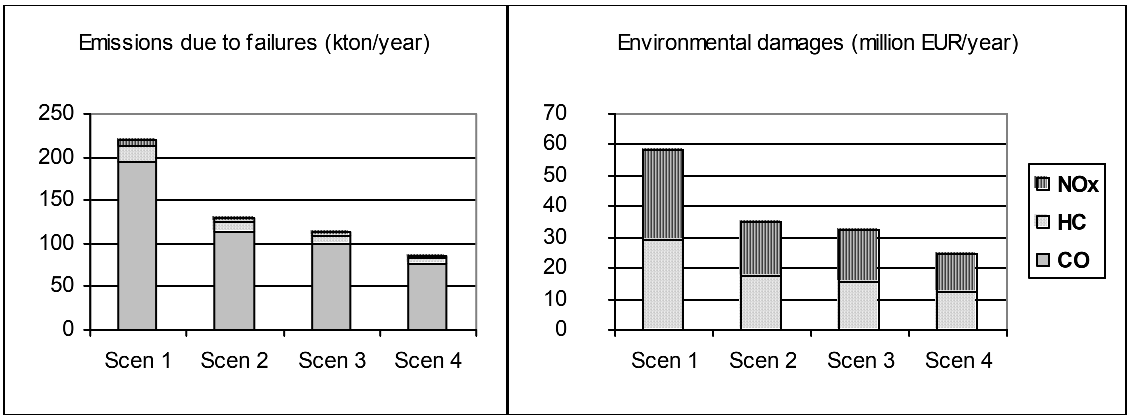
For the calculation of the environmental benefits of introducing OBD at inspection, most of the basic data, used for Belgium, are applied for Germany too. Hence, a prevalence for failures of 8% is assumed, just like in Belgium. This prevalence is however spread over two years, implying that in Germany failures show up at a rate which is half of the Belgian one. This difference is supposed to account for the differences in fleet characteristics and inspection system.

A willingness to repair of 50% and a delay of 90 days, before the repair is done, are taken, as they were taken for Belgium.

6.2.2 Environmental benefits

Figure 13 shows what emissions and environmental damages are avoided in Scenario 2, 3 and 4.

Figure 13: Total savings in emissions and environmental benefits for Germany.



Inspecting OBD next to the currently in use 4gas analysis test saves for the whole of Germany about 6.1 million EUR/year, to be compared to the 26 million of damages, which are saved by the 4gas analysis. If OBD were the sole inspection tool in use, only 22 million EUR per year of damages would be avoided.

When dividing by the number of cars, one finds that the added value of OBD as an assisting tool, next to the 4gas analysis, amounts to 0.21 EUR per year per car, mainly as a consequence

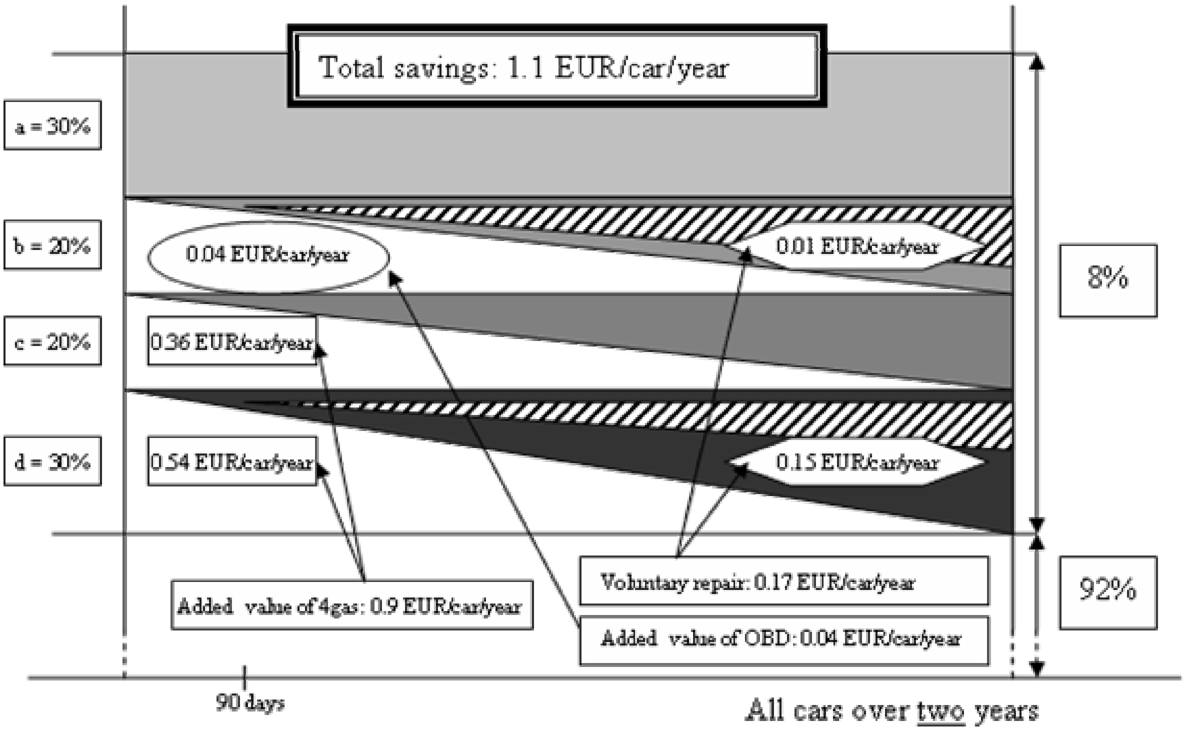
[8] MEET, Methodology for calculating transport emissions and energy consumption, …

of voluntary repairs, see Table 12. In total, the inspection can avoid 1.1 EUR of environmental damages per car per year, about the same value as for Belgium. These savings are allocated to different levels of failures in Figure 14.

Table 12: Summary of the added values of 4gas analysis and OBD for Germany.

Added value (EUR/car/year)			4gas analysis	OBD			Total
			Imposed repair	Imposed repair	Voluntary repair	Total	
Scenario 2	OBD	~~4gas~~		0.58	0.17	0.75	0.75
Scenario 3	~~OBD~~	4gas	0.90				0.90
Scenario 4	OBD	4gas	0.90	0.04	0.17	0.21	1.1

Figure 14: Allocation of the environmental benefits for Germany to the different levels of failures.



6.3 Case: UK

6.3.1 Basic data and assumptions

Like in Belgium, periodic inspection in the UK is an annual event. About 20 million petrol cars are inspected every year. The yearly mileage of these cars is about 16,000 km (MEET).

For UK, an emissions performance failure rate for cars at the annual MOT test of about 4.3% is reported.[9] This is almost twice the failure rate of Belgium. No explanation for this difference

9 Enforcement of Vehicle Emissions Standards by local authorities to help improve local air quality – Draft Regulatory Impact Assessment: Local authority roadside vehicle emissions testing scheme,

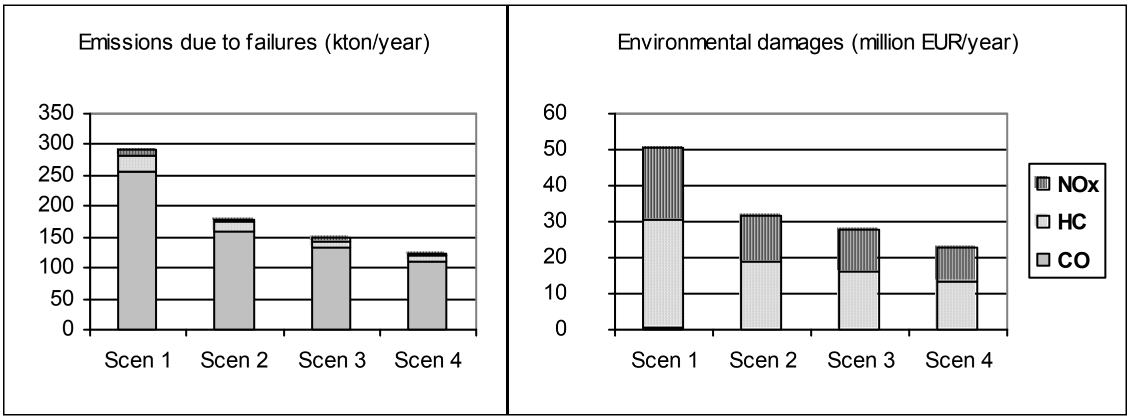
could be found. For the calculation of the environmental benefits, a value of 12% (one failure: 4.5% - two failures: 3% - three or more failures: 4.5%) is taken; for the underlying assumptions, see 6.1.1).

For the rest of the basic data, the same values as for Belgium are taken.

6.3.2 Environmental benefits

The 4gas analysis test avoids about 23 million EUR per year. Adding inspection of the OBD error codes leads to an additional environmental benefit of 5.2 million per year, whereas relying on OBD as the sole inspection tool saves about 19 million EUR per year, see Figure 15.

Figure 15: Total savings in emissions and environmental benefits for United Kingdom.



This leads to an added value of OBD, as an assisting tool, of 0.26 EUR per car per year, which is one-fourth of the added value of the already in use 4gas analysis test (1.1 EUR/car/year), see Table 13. This value of OBD is higher than the Belgian one, but this is because a higher prevalence of failures was assumed. If the same prevalence were taken for the UK, the added value would amount to 0.17 EUR/car/year, which was the result for Belgium.

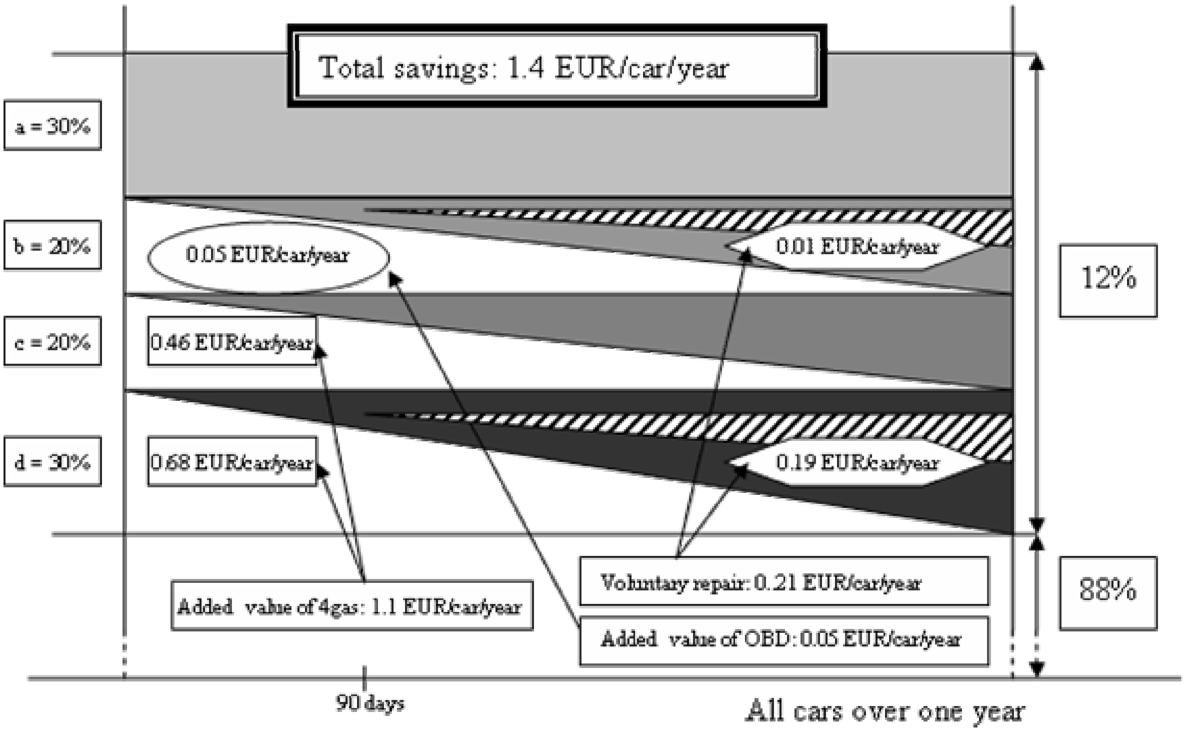
Table 13: Summary of the added values of 4gas analysis and OBD for UK.

Added value (EUR/car/year)			4gas analysis	OBD			Total
			Imposed repair	Imposed repair	Voluntary repair	Total	
Scenario 2	OBD	~~4gas~~		0.74	0.21	0.94	0.94
Scenario 3	~~OBD~~	4gas	1.1				1.1
Scenario 4	OBD	4gas	1.1	0.05	0.21	0.26	1.4

The added values of the different inspection tools is allocated to the different levels of failures in Figure 16.

http://www.roads.dft.gov.uk/consult/emissions/03.htm, UK Department for Transport, UK, downloaded on 19/08/2002

Figure 16: Environmental benefits for UK in scenario 4.



6.4 Sensitivity analysis

The calculation of the benefits of introducing OBD as an inspection tool is based on quite a number of assumptions and the reliability of the end result is dependent on the accuracy of the input data.

In order to assess the accuracy of the added values of either the 4gas analysis or OBD, a sensitivity analysis was carried out. This was only done for the results for Belgium, as the calculation for Germany and the UK gave approximated values. The method applied was the Monte-Carlo analysis; this requires that for every input parameter a distribution is given. Then the computer repeats the calculation a certain number of times, at every run another likely value for each input parameter is taken. At the end, the method gives a distribution of the results of the calculation. The distributions of the input parameters for the calculation of the added values for Belgium are presented in Table 14. Especially the specific damage costs for the various pollutants lack accuracy. A broad range on the willingness to repair and the delay of time for the repair of the failures is taken too.

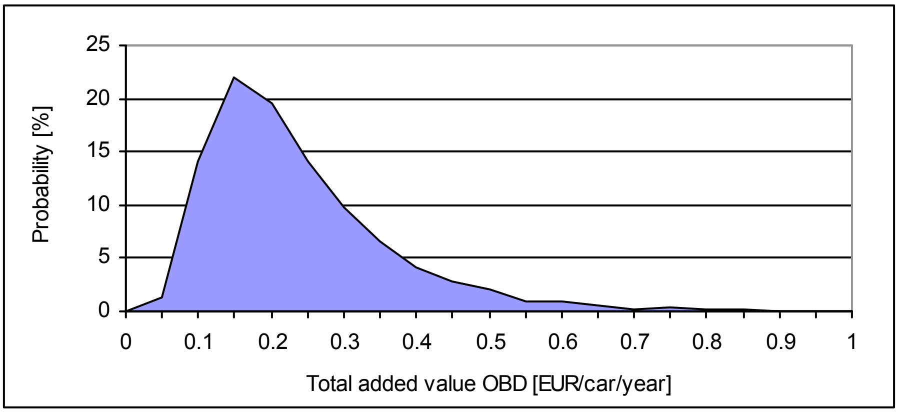
The sensitivity analysis concludes that each of the calculated added values is distributed according to the lognormal distribution. For illustrative purposes, the distribution of the total added value of OBD is presented by Figure 17.

Table 14: Distribution of the input data for Belgium.

Parameter		Value	Distribution	Standard deviation (SD)or range
Average mileage [km/year]		14,000	Normal	SD: 700 km/year
Willingness to repair [%]		50	Uniform	Range: 15-85%
Delay to repair [days]		90	Triangular	Range: 30-120 days
Prevalence [%]	1 failure	3	Normal	SD: 0.3%
	2 failures	2	Normal	SD: 0.2%
	>2 failures	3	Normal	SD: 0.3%
Emission factors [g/km]		*	Normal	SD: 20% of value
Specific damage costs [EUR/ton]		*	Lognormal	Range: 20% - 500% of value

** pollutant specific*
Source :

Figure 17: Distribution of the total added value of OBD in Belgium [EUR/car/year].



The results of the sensitivity analysis are given by Table 15. The 95%-confidence intervals are very broad for each of the values, typically between 40% and 250% of the mean value. This is mainly due to the lack of accuracy of the HC related damage cost, as the benefits are dominated by the avoidances of HC emissions. Also the willingness to repair contribute for a large extent to the uncertainty of the result.

Table 15: 95%-confidence interval of the added values of the 4gas analysis and OBD for Belgium.

Added value [EUR/car/year]		Median	95%-confidence interval
4gas analysis		0.82	0.35 – 2.0
OBD	Imposed	0.033	0.015 – 0.076
	Voluntary	0.15	0.037 – 0.49
	Total	0.18	0.058 – 0.56
Total		1.0	0.43 – 2.5

Anyhow, Table 15 demonstrates that the environmental benefit of OBD next to the 4gas analysis test is 0.56 EUR/car/year at the most.

7 COSTS OF OBD INSPECTION

7.1 Introduction

The total costs of scanning OBD during periodic include three different categories :

a) For all vehicles to be inspected : costs of the inspection, including net investment costs and net operation costs. In the end, these costs will be reflected in inspection fees and are charged to the motorist. These costs depend on the organisation of the inspection. For all the vehicles to be inspected by that organisation, the inspection costs are the same and it is a period costs following the inspection scheme (e.g. annually).

b) For all vehicles to be inspected : time losses for the motorists. It is reasonable to assume that the motorist will loose the additional time of scanning OBD. In addition, queues and waiting time may increase.

c) For vehicles with failures, which were only detected by the OBD inspection : the costs of repair, minus the benefits of the repair (in terms of avoided future repair costs, fuel savings).
One can discuss to which extent this category of costs need to be included. In a similar cost-benefit study by the vehicle inspectorate of the UK it is argued that these maintenance costs are not relevant because the repair costs are not additional costs. "The compliance costs for motorists should arguably be zero because the proposal imposes no new burdens on them - that is, it is already an offence to use a vehicle which does not comply with prescribed emissions standards." (Vehicle inspectorate, 2002,p….). On the other hand, maintenance costs were included in looking at the cost-effectiveness analysis of maintenance and inspection in the framework of Auto-oil II. (*Auto oil p….)*
In this report we will briefly discuss this cost category to assess its potential importance.

It is realistic to assume that the additional costs of scanning OBD at inspection will lead to increased fees and that the motorist will pay for these costs through higher fees. So in the end, these three costs are all borne by the motorists.
In order to compare costs and benefits, we need to estimate the total costs of the inspection of OBD for all cars to be inspected during the inspection period (e.g. one year). However, our main focus will be on the inspection costs.

From a methodological and data point of view, the analysis of the costs is more straightforward, and therefore in this report more attention needs to be paid to the estimation of the benefits. Nevertheless the information which is available remains limited, e.g. for additional time required for scanning OBD at periodic inspection and especially related to the net costs of repair.

7.2 Costs of scanning OBD at inspection

7.2.1 Costs categories to be included.

Costs of inspection of OBD include :

1. Investment costs for equipment,
   training of staff

financial costs
2. Operation costs : costs of staff.

7.2.2 Different regimes of organisation of inspection.

As the organisation of vehicle inspection differs between countries in the EU, we have looked at the costs for three different types of organisation of the inspection:

- In Belgium the inspection is organised centrally. The 74 inspection stations inspect on average 45000 cars annually, of which 226000 gasoline cars. This relatively high turnover of cars per day allows for a more efficient use of equipment and specialised personal.[10] Inspection is due annually, for vehicles of a certain age, and is mainly based on the 4gas analysis.

- In the UK inspection is decentralized and more then 19000 garages are authorized to carry out MOTs. They inspect on average around 1200 cars annually, of which around a 1000 gasoline cars. [11] Inspection is due annually, for vehicle of a certain age, and is mainly based on the 4gas analysis.

- In Germany the inspection is also decentralized, but the number of cars inspected per station is around 5 times higher then in the UK (5800 cars/year). [12] Inspection is due two-yearly for vehicles of a certain age. In addition to the 4gasanalysis, time is required for a more detailed inspection of motor and catalyst. The latter could be replaced by the scanning of OBD at inspection, so that scanning OBD may not necessarily require extra time.

7.2.3 Costs of scanning OBD at inspection.

Table 16 gives an overview of the costs of OBD inspection, expressed per vehicle inspected. We discuss the main input parameters, their uncertainty and results. The results of the uncertainty analysis using Monte Carlo is summarised in Table 16 and Figure 18.

The investment costs per car inspected are relatively small in the total costs but vary significantly between the different schemes. The costs for the scan tool are indicative, as the real cost is likely to vary in reality, depending on e.g. volumes and market conditions. In addition, costs for training are added. For Belgium, these figures are based on estimates from GOCA. As we did not have data for other countries, we have extrapolated the Belgian data, i.e. training costs are similar to investment costs in the scan tool. We used a 5 year depreciation period for all countries, and added a financial cost of 8 %. These assumptions are similar to data used in other studies, e.g. for Auto-oil II. The total annual costs per inspection station are the highest in Belgium, but this just reflects the effect of a centralized organization of vehicle inspection. To interpret these data, we need to compare them per vehicle inspected.

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[10] Source: Goca, Group of accredited motorvehicle inspection bodies, Belgium personal communication, info on website and Vito.
[11] Source: Vehicle Inspectorate, UK
[12] Source : Dekra

To that purpose we have used the average number of vehicles inspected per station. To take account of the variety among the stations, we we allowed the numbers of cars inspected to vary around 50 % of that average in the uncertainty analysis.

Table 16: Economic costs of scanning OBD at periodic inspection for different organisation schemes. Best estimates for the average inspection station and uncertainty analysis.

Costs (Euro)	Organization scheme of the inspection			
	Belgium	**UK**	**DE (OBD add)**	**DE (replaces)**
Investment Costs				
per inspection station				
Equipment (2),	10 000	1 250	1 250	1 250
Training (2)	10 000	1 250	1 250	1 250
Total investment cost	20 000	2 500	2 500	2 500
Depreciation period	5	5	5	5
Yearly costs	4 000	500	500	500
financial costs (8%)(2)	320	40	40	40
Total annual costs, per inspection station	4 320	540	540	540
per inspected vehicle				
Number of cars inspected /year (4)	26 216	1 068	5 000	5 000
Investment cost vehicle inspected	***0,16***	***0,51***	***0,11***	***0,11***
Operational costs, per vehicle inspected				
Time required (in minutes) (5)	2,5	4	3,25	3.25
Avoided time requirements				- 3.25
Net time required (in minutes)	2,5	4	3,25	0
hourly rate (6)	65,5	50	50	50
Operational costs/ vehicle inspected	***2,73***	***3,33***	***2,71***	***0,00***
Total costs per vehicle inspected	**2,89**	**3,84**	**2,82**	**0,11**
Median (7)	*3,2*	*3,4*	*2,7*	*0,1*
Minimum (7)	*1,7*	*1,8*	*1,3*	*-1,5*
Maximum (7)	*5*	*4,4*	*4*	*1,7*

DE (OBD add) OBD test additional test to existing scheme, DE (replaces) OBD test replaces existing test, no additional time required.

(2) Based on data provided by Goca for BE and Dekra for DE, data per unit for DE are used for UK

(3) based on 8 % financial costs, in line with Auto-oil I

(4) based on data from Goca (BE), Vehicle Inspectorate (UK), Dekra (DE) and Vito

(5) based on data from Goca (BE) and ranges from Dekra. For comparison it is assumed that the lower Number of cars per day is reflected in more time per inspection required in DE and UK.

(6) Based on data from Goca (BE) and Dekra (DE) and auto-oil II for UK.

(7) Median, Minimum and maximum of a 95% interval range, based on a Monte Carlo analysis of the most important parameters

A more decentralised scheme like the UK has a higher cost per vehicle inspected then a centralised system like Belgium. Investment costs per vehicle are in the same order of magnitude for Belgium and Germany. Although one would expect investment costs in Belgium to be lower, the data from Goca and Dekra suggest the opposite, but it is not clear to which extent they are fully comparable. The uncertainty analysis however shows that the uncertainty

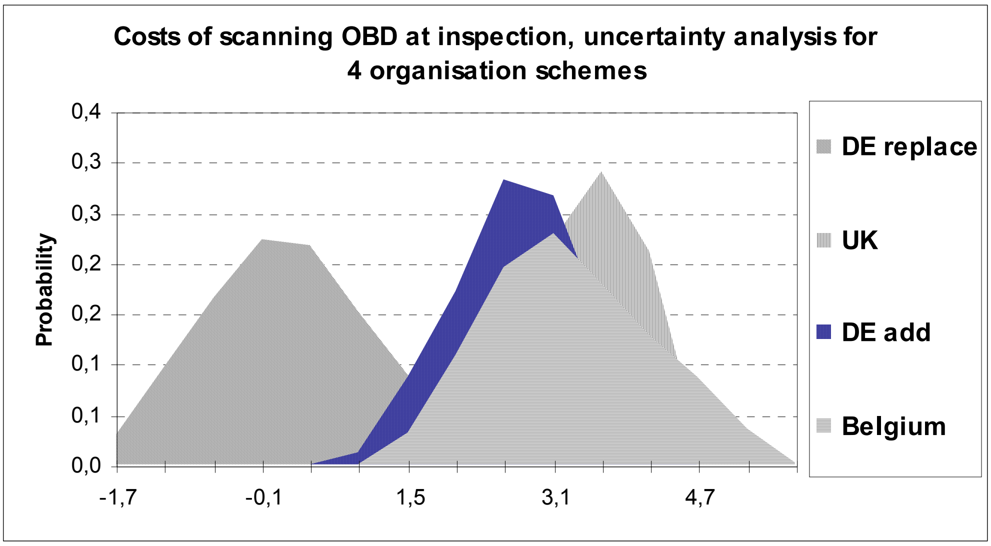
on the investment costs does not contribute significantly to the total uncertainty on the costs of scanning OBD.
The total costs are dominated by the time required for scanning the OBD, which is estimated as a range from 1 to 5 minutes (as indicated by Dekra) with a mid estimated of 2.5 (figure indicated by Goca). It is unclear to which extent these data will be representative for a potential future scanning of OBD at inspection, as we have to take account of the fact that the existing procedure will be simplified (no need to attach an engine speed pickup, no need to measure engine temperature). Overall, it may be that there will be no big increase of costs for the introduction of an OBD test (zero or even negative in Germany). Therefore, we have rather estimated an upper boundary of the inspection costs.

For the comparison of the different schemes, we have assumed that it takes more time in a decentralised system. The wage costs vary from 50 € hour (rate used in Auto-oil II, and by Dekra). Goca gives a more specific rate of 62.5 € for Belgium. The best estimate for total costs in Table 16 is dominated by these labour costs, and this is confirmed by the uncertainty analysis. Also for the German case in which scanning OBD replaces an existing test, the net time requirements or savings dominate the cost estimate.

In summary, the best estimate of the total cost of scanning OBD varies from 0.1 € for the German case where OBD replaces a current test to almost 4 € for the UK. The uncertainty analysis widens this scope a bid further, from a benefit of 2 € in the above mentioned German case to 5 € for Belgium (in which it is estimated that scanning OBD requires 5 minutes with a high wage cost).

It is not surprising that the cost will differ between systems as it is already the case for the current fees for inspection, both for inspection related to environmental standards as for the total fee of the inspection. (see further)

Figure 18 : 100%-confidence interval of the costs of scanning OBD for different organisation schemes (in Euro/vehicle inspected)



7.3 Time losses by for motorist.

It is reasonable to assume that the motorist will loose the additional time of scanning OBD. In addition, waiting time may increase due to a general slower throughput of the inspection process. If the additional time is limited to maximum 5 minutes, there are arguments in literature not to take these into account, as some UK and Dutch studies have showed very small or zero unit values for very small time savings (<5 minutes).[13] If we do value a time loss of 5 minutes, and use the default value by the World Bank (of 30% of household income per hour being used for the valuation of non-work time) , then the maximum cost for motorist would be around 0.25 € per vehicle inspected.

7.4 Costs of repair for the motorists

7.4.1 Gross costs of repair

We have not looked into more details of the costs of repair, but they are likely to be an order of magnitude higher. We used data from earlier studies to evaluate cost-effectiveness of maintenance and inspection, to get an idea of the potential order of magnitude :

Table 17: Gross economic costs of repair for vehicles with failures.

Type of failure requiring	% of occurrence	Costs EUR	
Minor repair	65 %	100	47 %
Major repair	34 %	200	49 %
Replacement of catalyst	1 %	600	4 %
Average costs		139	100 %

Data valuable for Euro I/II/III petrol cars, Page 92
Based on .., page 93, rounded by Vito

Per vehicle repaired this would amount around 140 Euro/vehicle, with a range of 100 Euro for vehicles requiring minor repairs up to 600 Euro for replacement of catalyst.

The additional number of vehicles that need repair because of OBD is estimated to be around 2 %. The additional costs of repair can be estimated to be around 3 € per vehicle inspected, which is in the same range as the costs of scanning the OBD.

These data also illustrate that if OBD were able to avoid future repair costs, this benefit may be significant and compensate for the costs of scanning OBD.

7.4.2 Net costs of repair for the motorist

Information leaflets provided by inspection agencies to drivers argue that an early reaction to the MIL-signals of the OBD system can results in important cost savings for consumers in terms of avoided more serious damages and fuel savings. Within a short search to check this statement, we do not find scientific studies to confirm these statements. Realistic examples of

[13] Kenneth M. Gwilliam, The Value of Time In Economic Evaluation of Transport Projects, Lessons from Recent Research, Transport NO. OT-5, World Bank, January 1997

cases are described in the leaflets, but we do not have enough information to check to which extent the statement is valid for all failures.

7.5 Total costs of OBD inspection

7.5.1 Additional costs of inspection

It is realistic to assume that the additional costs of scanning OBD at inspection will lead to increased fees and that the motorist will pay for these costs. On average, this would increase the yearly costs for motorist with 0.1 € to 4 €, if we only look at increased fees. These figures could double if we also include costs of time losses for motorist and gross repair costs, but as indicated above, the estimation of both categories is based on limited information and is incomplete.

Table 18: Total Economic costs of OBD inspection (Euro per vehicle inspected)

Cost category	BE	UK	DE (1)	DE (2)
Best estimate : Increased fees for inspection	**2,89**	**3,84**	**2,82**	**0,11**
Additional cost categories				
time costs for motorists	0,13	0,21	0,17	0,00
Gross repair costs	2,78	2,78	2,78	2,78
Gross repair benefits	n.a.	n.a.	n.a.	n.a.
TOTAL costs	**5,80**	**6,83**	**5,77**	**2,89**
Minimum (1)	1,7	1,8	1,3	-1,5
Maximum (2)	7,9	7,4	6,9	4,5

DE (OBD add) OBD test additional test to existing scheme, DE (replaces) OBD test replaces existing test, no additional time required.
n.a. not available
(1) is the minimum estimate of the 95 % range for the increased fees. See Table 16
(2) Includes the maximum fee increase (95 % range)+ time costs of motorist + repair costs.

7.5.2 Comparison with current fees and compliance costs with environmental regulation.

Compared to the current fees, scanning OBD at inspection could significantly increase the costs of inspection of environmental regulation. The costs could double in Belgium, as motorists are charged around 3 € for the environmental inspection for a gasoline car. [14] In the Netherlands, the list of tariffs indicates that consumer's are charged 9.05 EUR for the 4gas analysis.[15] However, the impact on the total fees for inspection would be lower (e.g. around 5 % for the Netherlands or France to 10 % for Belgium).

[14] KB 15 maart 1968.houdende algemeen reglement op de technische eisen waaraan de auto's, de aanhangwagens en hun veiligheidstoebehoren moeten voldoen, art 23 autokeuring, ART 23undecies – Keuringskosten (http://www.fedpol.be/fedpol/wegcode/tech23d.htm)

[15] http://www.rdw.nl/diensten/index_tarieven.htm

The range of costs as indicated above is not likely to significantly increase the total costs of compliance with environmental regulation. For the Netherlands, it is estimated that the total costs of meeting environmental targets for air pollution is around 55 EUR per vehicle and year for gasoline vehicles for 1999 (Source, CBS, 2002). Around 6 % of these environmental costs for all vehicles can be attributed to inspection, which can be estimated to be around 6.5 EUR per vehicle. If the latter would increase with 3 € per vehicle inspected, then the total cost of regulation would increase with 1,5 %.

Impact on total yearly costs of vehicle use is limited, and can be estimated to be around 0.01 % for the cheapest gasoline cars in Belgium, assuming the average 14000 km annual mileage (based on annual costs per km driven as calculated by the auto magazine "De Autogids"). At maximum, total costs could increase with 0.25 %.

Table 19: Impacts of cots of OBD inspection on cost indicators (Belgium)

Costs indicators	**costs per vehicle/year**			**% increase**		
	min	mid	max	min	mid	max
costs of OBD inspection	1,5	3	5			
costs of environmental inspection	3	3	3	50%	100%	167%
costs of total inspection	27,5	27,5	27,5	5%	11%	18%
costs of environmental regulation (1)	55	55	55	3%	5%	9%
total costs of driving (2)	3500	3500	3500	0,04%	0,09%	0,14%

(1)Based on data for the Netherlands
(2) Based on data for total annual costs for a small gasoline car, driving 14000 km.

8 COST-BENEFIT ANALYSIS OF OBD INSPECTION

8.1 Costs

A first conclusion is that it is possible that OBD does not impose additional costs to the motorists. This is the case if OBD replaces an existing test, as can be the case in Germany. Second, the net costs of a future implementation of scanning OBD may be cheaper compared to our estimates if the existing procedure will be simplified. Third, it is claimed that OBD could be economic for motorists thanks to avoided future repair costs and fuel savings, but we don't have data to support his claim.

Table 20: Illustration of the methodology : results of the case studies

	Belgium	UK	DE add	DE repl
Costs for motorist				
Additional fee for scanning OBD	**2,89**	**3,84**	**2,82**	**0,11**
Range (min- max) (3)	*1,7 - 5*	*1,8 – 4.4*	*1,3 – 4*	*-1,5 – 1.7*
Net repair costs	na	na	na	na
Total net costs	na	na	na	na
Benefits for environmental & public heath				
Scanning OBD at inspection (1)	0,03	0,05	0,04	0,04
Early repair due to OBD (1)	0,15	0,21	0,17	0,17
Impact on PM, CO2 (2)	na	na	na	na
Subtotal for OBD	**0,18**	**0,26**	**0,21**	**0,21**
Range (min- max)(3)	*0.06 – 0.6*	*0.1 – 0.9*	*0.07 – 0.7*	*0.07 – 0.7*
Total Benefits	na	na	na	na
Benefits for environmental & public health of 4 gas and OBD (for comparison)				
4-gas analysis (1)	0,8	1,1	0,9	0,9
Total (OBD + 4gas)	1,0	1,4	1,1	1,1

DE (OBD add) OBD test additional test to existing scheme, DE (replaces) OBD test replaces existing test, no additional time required
NA : not available
(1) Benefits relate to impacts of CO, HC and NOx
(2) impacts on emissions is not known (PM) or not clear (CO2)
(3) 95 % interval range of uncertainty analysis

Not taking into account the special 'German case' or the claimed benefits, the additional fee for scanning OBD at periodic inspection may vary from 1 to 5 € per vehicle inspected, depending on the type of organisation (investment costs are cheaper for a centralised system) and additional time needed. Although this will increase significantly the environmental inspection costs it will only affect marginally the total costs of compliance with environmental regulations or total annual costs for the motorists.

These figures may neither be representative for an implementation of OBD test, as these numbers probably did not take account of the fact that the existing procedure will be simplified (no need to attach an engine speed pickup, no need to measure engine temperature). Overall, there will be no big increase of costs for the introduction of an OBD test (zero or even negative in Germany).

8.2 Benefits

8.2.1 Approach

Do environmental benefits outweigh these additional costs ?
A first conclusion from the test data is that scanning OBD offers benefits because it discovers failures in addition to the 4gas analysis. It is very difficult to estimate how much cars OBD will catch in addition, and for which failures. Second, we need to estimate how much additional emissions these failures cause. For both issues, the test data does only give an incomplete picture and more research is needed.

For the quantification of the benefits in the case studies , we had to make assumptions to estimate these numbers. These assumptions take into account the data on current failures, the results from the test and the indication from the test data that the most polluting vehicles will already be caught by the 4 gas analysis. For the estimation of the benefits, we could only make reasonable assumptions for those pollutants that were measured (CO, NOx, HC) and we had to exclude CO_2 because the data from the tests were not consistent. Based on these assumptions, we can illustrate how the methodology works for a cost-benefit analysis, but the results themselves only tell part of the story and are likely to underestimate the real benefits to an uncertain degree.

These estimates of emissions were further valued in economic terms based on data from the European ExternE project. These data are based on a detailed assessment of the impacts of emissions on man and environment and are generally used as the most complete and up-to-date data to assess environmental externalities.

8.2.2 Results

To have a proper understanding of the environmental benefits, we have distinguished two categories. We illustrate these benefits with the numbers of the case studies, keeping in mind that they refer to a limited number of pollutants and additional identified failures and are thus not estimates of the total benefits.

- First, there are the benefits of avoided additional emissions from vehicles that would not have failed the 4gas analysis test. We have data for impacts on emissions of CO, HC and NO_x. The best estimate for this effect varies around 0.03 € to 0.05 € per vehicle per year, with some variations between countries.
- Second, we have estimated the effect of “voluntary” early repair thanks to OBD. It is likely that failures captured by OBD are repaired earlier and prior to inspection, because the motorist is informed about the problem. As this early action affects both failures that 4gas analysis and OBD can capture, the potential benefits of this early repair effect is 4 times bigger then the effect of scanning OBD at inspection. The total benefit of OBD may the amount to around 0.2 € to 0.25 € per vehicle inspected. It is reasonable to expect that motorists will react more and faster to the MIL indicating a failure, if one is aware that the OBD will be scanned at inspection. We don’t have any information how big this effect may be, but the calculations are based on the assumption that 50 % of the motorist react to the MIL lamp within 90 days.

  Although in terms of tonnes CO looks the most important pollutant, when we take into account the damages to man and the environment, the avoided emissions of NOx and especially HC are more important. There are differences between countries which are explained by different failure rates, mileages and different impacts and damages per tonne pollutant. As a result, benefits in the UK and Germany are respectively 40 % and 10 % higher compared to Belgium.

The total annual benefits per vehicle of OBD inspection are low compared to the costs and to other data. It only represents less then 0.3 % of the total environmental damage costs of modern gasoline vehicles. On average, total environmental damages from a gasoline car in Belgium are around 150 Euro per year. If the OBD test helps to reduce a few percent of the most important pollutants, the benefits are very likely to exceed the costs.

8.3 Comparing costs and benefits

As usual for cost-benefit analysis of environmental regulation, both costs and the environmental benefits are incomplete and uncertain. Therefore, one can only come to strong conclusions if either costs or benefits clearly outweigh the other, e.g. by an order of magnitude. If not, the assumptions and omissions need to be taken into account when drawing conclusions from the data.

In the current situation, and with information currently available, we can only quantify a limited number of additional environmental benefits of scanning OBD at periodic inspection are limited and this subtotal of the environmental benefits on themselves are not big enough to outweigh the additional inspection costs. However, as indicated above, given the limited information on both costs and effects of scanning OBD at inspection, we are likely to have overestimated the costs, and underestimated the total number of emissions reduced and their related benefits. Therefore, our analysis does certainly not exclude that the total benefits of scanning OBD at inspection may exceed the costs.

First, the costs of scanning OBD for the motorist may be lower or even negative, if a more simplified procedure is used, and may be negative for certain inspection schemes or for all if OBD really can help to reduce costs of maintenance and repair.

Second, there are several arguments that the benefits may be higher.

- As the picture of the additional failures captured by OBD is incomplete, total benefits in terms of additional vehicles caught are likely to be higher. Furthermore, taking account of the short time in which OBD had been in production and the difficulties that introduction of OBD caused, it seems very likely that the performance of the OBD in relation to fault detection will become improve in the future.
- An important omission to the benefits estimate is that the two most important pollutants – CO_2 and PM, that both account for around one third of total damages – are not included in the analysis. For PM, there are no data available on the potential impact of OBD or 4 gas analysis inspection on emissions. For CO_2, some data are available, but they do not offer a clear picture how CO_2 may be affected by the specific failures that only OBD manages to capture.
- A last remark relates to the potential longer term benefits of OBD and scanning OBD. As OBD is likely to improve over the years to come, it offers the potential to capture a much wider range of failures, including failures that 4gas analysis – or a similar approach – may not be able to capture, like failures affecting cold start emissions.

8.4 Is scanning OBD a cost-effective approach to emission reduction ?

In addition to the cost-benefit analysis, we have illustrated how we can evaluate whether scanning OBD may be an cost-effective approach to reach the emission reduction objectives, i.e. is scanning OBD more expensive compared to other potential measures required to reach the emission reduction objectives the European governments agreed upon. The exercise focuses on Belgium, with a rough extension to the UK. To this purpose we have compared our best estimates of OBD with the marginal cost data of other measures, as identified by Vito[16] (Belgium) and literature (UK).

A problem for this type of analysis is that we have to attribute the costs of scanning OBD to the different pollutants. In a cost-effectiveness study for Auto-oil II all the costs were are attributed to CO, but we did not follow this approach as the benefits of controlling CO are really marginal. On the contrary, we have attributed all the costs to NO_x and HC, as these are two pollutants Belgium agreed to reduce significantly in the framework of controlling ground level ozone, acidification and eutrofication (the UNECE Göteborg protocol), and some additional reduction in the framework of the EU National Emission Ceilings (NEC). In order to reach these objectives, Belgium will have to implement a lot of emission control measures, including relative expansive ones. Will OBD be cheaper compared to these measures ?

There are no scientific rules to attribute the costs to either HC or NO_x, therefore we calculated three scenario's, attributing none, half and all of the costs to either NO_x or HC. We have taken all the benefits of OBD, including both the imposed and voluntary ones. The results are presented in Table 21. Of course, the remarks we made above about the overestimation of costs and underestimation of emission reduction is valid here.

Table 21: Illustration of the cost-effectiveness analysis of scanning OBD for HC and NOx, for Belgium and UK

	Belgium		UK	
	HC	**NO_x**	**HC**	**NO_x**
Costs of scanning OBD				
Costs per vehicle inspected (€ per vehicle)	3		4	
total costs of scanning OBD, annual (million €)	6		76	
emissions avoided (ton)	132	60	2300	1060
Cost of scan OBD per tonne pollutant (k€)				
Attributed to HC, NO_x				
50 % HC, 50 % Nox	20	50	17	36
100 % HC, 0 % NOx	40	0	33	0
0 % HC, 100 % NOx	0	100	0	72
Costs of other measures to reduce pollutants				
marginal costs for NEC (k€ per tonne pollutant)	(50) *	10	7,6	0,4

Source : Vito for Belgium, AEAT report for marginal costs UK, rounded numbers
** for HC, emissions and emission reduction measures are less known, the emission reduction objectives cannot be reached, a limited number of additional measures are possible but at sharply rising marginal costs.*

[16] K. Marien, J. Duerinck & R. Torfs (Vito), F. Altdorfer (ECONOTEC), Economische impactmodules voor het EUROS model, Eindrapport, Studie uitgevoerd in opdracht van de Federale Dienstenvoor wetenschappelijke, technische en culturele aangelegenheden, Vito & ECONOTEC, 2001/IMS/R/140, Augustus 2001.

In these cases the costs for NO_x vary from 0 €, 50 k € (kilo Euro) and 100 k€ per tonne emission reduced. (rounded numbers). Apart from the first scenario (0 €), this is relatively expensive compared to other measures. For NO_x, Vito has estimated that the marginal costs to reach the emission reduction of NEC is around 10 k€ per tonne of NO_x. (rounded number to reflect uncertainties).

For HC the situation is different as both emission sources and reduction measures are less known. Vito could not identify enough measures to reach neither the Göteborg nor NEC emission reduction objectives. A number of measures can be taken, up to a marginal costs of 50 k€ per tonne of HC. A few further measures are possible but a high costs. Compared to this marginal cost of 50 k€, it looks like at first sight that scanning OBD can be a cost-effective option, if we attribute all the costs to HC. In practise however, it is doubtful to which extent the reduction measures with these higher costs of up to 50 € per tonne HC will be implemented, as the overall costs are very high. So our conclusion is that for our mid estimate of the costs of scanning OBD, it is a rather expensive measure to control HC and NOx emissions compared to other measures in different sectors.

For the UK,we made a similar illustration. Although our mid estimate for the costs per vehicle inspected are somewhat higher, the costs per tonne emission avoided thanks to OBD are somewhat lower then for Belgium, because we assumed a higher rate of failures. The marginal control costs of other reduction measures are however an order of magnitude lower then for Belgium, for both NOx and VOC (although data are not fully comparable) (DETR) [17].

Even with the limited data, this illustration shows that the conclusions on cost-benefit and cost-effectiveness may differ between countries, due to facts related to vehicle park and inspection schemes, as well as to costs in other sectors.

8.5 Conclusions

In this report, a methodology has been developed for the cost-benefit and cost-effectiveness analysis of scanning OBD at periodic inspection. This methodology has been applied to case studies for Belgium, UK and Germany, based on the information available from the test programme and generic information. This application has shown that there are important gaps in the data availability related to the additional number of failures identified by OBD compared to 4-gas analysis as well as their impact on emissions. The analysis of the environmental impacts of these emissions is on data from the European ExternE project. These data are based on a detailed assessment of the impacts of emissions on man and environment.
The methodology has been illustrated with case studies for Belgium, UK and Germany, based on the data from the test programme, and some assumptions to fill the data gaps. his exercise cannot make a full assessment of all the benefits. Although this limited exercise does not allow us to do a full cost-benefit analysis, the results are important both in terms of setting priorities for further research and to evaluate implementation alternatives.

Scanning OBD at periodic inspection identifies additional vehicles with failures, so that inspection is more complete. The costs will depend on a number of factors, especially the

[17] Costs and benefits for the UK of Complying with the EC National Emissions Ceilings and Ozone Directive and the UNECE multi-pollutant, multi-effect protocol, Report produced for Department of the Environment, Transport and the Regions, AEA Technology, April 2000

required additional time. For this factor, our figures are based on the limited experience during the tests and future implementations may be simpler and requiring less time. From this perspective, we have rather given an upper boundary of the costs. The difference between centralised and decentralised systems is less important. The best estimate for Belgium and the UK leads to a cost around 3 € per vehicle inspected, which is likely to significantly increase the fees of inspection for emissions. The situation may be different in Germany where the net cost may be zero as OBD may replace another test. For the other inspection regimes, the total costs of environmental regulation of transport will only increase marginally, and the effect on overall transportation costs is negligible. It is not clear whether OBD may lead to benefits in terms of avoided repair costs or fuel savings, as claimed in leaflets. Overall, there will be no big increase of costs for the introduction of an OBD test (zero or even negative in Germany).

Based on current data we cannot conclude to which extent these costs are outweighed by the environmental benefits. As we only have data for impacts on emissions of HC, NO_x and CO, we can only estimate the benefits related to these emissions. To this purpose, we have to make assumptions about number of vehicles with failures only identified by OBD. The benefits for these three pollutants, which are a subtotal of total benefits, are not big enough to compensate for the costs as identified. In addition, we added benefits related to an earlier repair of vehicles following the MIL lamp indicating a failure. It is reasonable to assume motorists will react more and quicker if they know that OBD will be scanned anyhow at inspection. Also if we add these benefits, they are significantly lower then the costs. The numbers show some variation in the benefits between the three countries studied, and that the potential impact of early repair by motorists can be relatively important.

This study however does not exclude that the benefits may be larger then the costs, because we don't have data to estimate the impacts on emissions of PM and CO_2, which are the two most important pollutants from recent gasoline vehicles (weighted as environmental damage costs). If impacts on these pollutants would be in the same range as for NOx or HC, the benefits may be larger then the costs. On average, total environmental damages from a gasoline car in Belgium are around 150 Euro per year. If the OBD test helps to reduce a few percent of these damages to society, it will be money well spent.

Finally, it is unclear how more failures OBD will identify, in addition to 4-gas analysis, and we had to make some estimates based on the limited information from the tests. This remark may become even more important as it is likely that OBD will improve and will be able to identify more failures and extra emissions which cannot be identified by the 4gas analysis, like those related to cold start.

We have illustrated the cost-effectiveness analysis of scanning OBD as a measure to contribute to the emission reduction objectives for HC and NOx. This illustration for Belgium and the UK shows that the conclusions on cost-benefit and cost-effectiveness may differ between countries, due to facts related to vehicle park and inspection schemes, as well as to costs in other sectors.

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APPENDIX 1 : TECHNICAL DETAILS OF THE PETROL CARS

N°	Partner	Verification of Approval 98/96	Engine type	Engine capacity	Communication protocol	EGR	Air injection	Transmission	Motorised throttle	Manifold pressure sensor	Pre-catalyst	Main catalyst	Secondary air injection valve	Pre-muffler	Main muffler	Mileage
1	DEKRA	Yes	R4	2000	ISO 91412	No	Yes	Manual	Yes	No	No	Yes	Yes			28200
2	DEKRA	Yes	R4	1600	ISO 91412	Yes	No	Manual	Yes	Yes	Yes	Yes	Yes			6650
3	DEKRA	Yes		2800	SAE J1850VPM	Yes		Automatic	Yes	Yes	No	Yes	No			14300
4	RWTÜV	Yes	R4	1000	ISO 91412	No	No	Manual				Yes				20720
5	RWTÜV	Yes	R4	2000	ISO 91412	Yes	No	Manual	Yes		No	Yes	No			2022
6	RWTÜV	Yes	R4	1500	ISO 91412	Yes	No	Manual	Yes	Yes	Yes	Yes	No			1022
7	RWTÜV	Yes	R4	1500	ISO/DIS 14230 4	No	No	Manual		Yes	No	Yes	No			2137
8	GOCA	Yes		1360	KW 2000	No		Manual	No		No	Yes		No	Yes	2365
9	GOCA	Yes		1948	ISO 9141	No		Automatic	No		No	Yes		No	Yes	15947
10	GOCA	Yes		1997	ISO 9141	No		Manual	No		Yes	Yes		No	Yes	2270
11	VI	Yes	V6	2500	ISO 9141			Automatic		Yes	Yes	Yes				35882
12	VI	Yes		1600	J1850 PWM	No	No	Manual		Yes	No	Yes	No			4056
13	VI	Yes	4 cylinder	1200	KWP 2000 FAST	Yes	No	Manual		Yes	No	Yes	No			401
14	VI	Yes	4 cyl. turbo	2000	ISO 9141	No	No	Manual	Yes	Yes	Yes	Yes				13510
15	UTAC	Yes	4 cylinder	1600	ISO 91412	No	No	Manual	No	Yes	No	Yes		Yes	Yes	1830
16	UTAC	Yes	4 cylinder	1300	ISO 14230	No	No	Manual	No		No	Yes		Yes	Yes	114
17	BIVV	Yes		1970	91/441/CEE	No	Yes	Automatic	Yes		Yes (2)	Yes		No	Yes	747

APPENDIX 2 : EXPERIMENTS OF WP350: AVAILABLE RESULTS

First the sensor failures are dealt with, then the actuator failures.

2.1.1 Sensor failures

- Coolant temperature sensor

15 tests with a malfunctioning coolant temperature sensor were carried out. In 3 cases, the sensor was disconnected. In the other cases, a resistor was built in the wiring between the sensor and the control unit by which a coolant temperature varying from 10 to 60°C.

In 13 tests, the presence of OBD error codes was checked for. The exhaust gases were analysed by the 4gas analysis in 9 cases and according to Type1 test in 4 cases.

- Air mass flow sensor

The sensor was disconnected in 2 tests and the signal of the sensor was deformed in 4 others.

In only one case, the exhaust gases were analysed. Unfortunately, no comparison between those results and the OBD error code readings can be made.

- Intake manifold absolute pressure sensor

In 4 of the 10 tests, the sensor was disconnected. In all others a resistor, in order to deform the signal, was built in line.

In the former cases only, 4gas analysis results are given, together with OBD readings. Full gas analysis results are given for one test, in which a resistor was built in line. Helas, no OBD error codes are reported for this experiment.

- Intake air temperature sensor

3 tests were carried out. In all of these, a resistor was built in the wiring between the control unit and the sensor. Only OBD error code readings are reported, no mention is made of exhaust gas analyses.

- Throttle position sensor

The sensor was disconnected in one test and a resistor was built in line in 3 others. Like so the experiments with the intake air temperature sensor, only error code readings are available.

- Cylinder head temperature sensor

In one experiment, the signal of the sensor was deformed by use of a built-in resistor. OBD error codes were read, but the exhaust gases were not analysed.

- Upstream and downstream λ-sensor

In most of the tests, 37 in total, a failure at the λ-sensor, upstream or downstream, was simulated.

25 experiments concern a deformation of the signal. OBD error code readings are lacking for 2 of these tests and of 4 experiments, no exhaust gas analysis results are reported. The remainder of the experiments is well documented.

The sensor was disconnected in 9 experiments. The OBD error codes were read in all cases; the exhaust gases were analysed in 4 tests.

In the rest of the tests, the sensor was either built out completely, coming loose or the wiring of the downstream λ-sensor was connected with the wiring of the downstream one.

- Combined sensor failures

In 1 experiment, the signals coming from the sensors measuring the coolant temperature, the manifold absolute pressure and the inlet air temperature were deformed. Both exhaust gas analyses and error code readings are available.

In another test, resistors were built in line in the wirings of both the coolant temperature sensor and the air flow sensor. In this case, only the analyses of the exhaust gases are documented.

2.1.2 Actuator failures

- Intake manifold

A hole of 1 mm was drilled in the intake manifold of 1 car. The exhaust gases were analysed and reactions of the OBD system are noted.

- Secondary air injection valve

Currant was taken causing a malfunctioning secondary air injection valve of 1 car. Only the OBD error codes are documented.

- Idle speed actuator

At one car, the idle speed actuator was disconnected. The error codes are documented, but no mention is made of the effect of the failure on the emissions.

- Injectors

In 2 tests, the injectors were disconnected and the signal was deformed in a third one. The report mentions only the reaction of the OBD system on the simulated failures.

- Ignition system, sparks

A failure at the ignition system was simulated in 13 experiments. Sparks were disconnected in 2 tests. In the others, misfire was simulated by introducing a spark with a gap varying from 0.1 to 0.3 mm.

In all cases, information is available on the OBD error codes. In 7 of the 11 misfire experiments, the composition of the exhaust gases is given too.

- λ-sensor heater

Of 4 experiments, in which the heater was disconnected, the OBD error codes can be compared with the results of the 4gas analysis.

In 2 other tests, the sensor signals were deformed by use of a built-in resistor. Only the codes are documented.

- EGR valve

A dummy valve was built in one car and the reaction of the OBD system was documented, but no exhaust gas analysis results.

- Evaporative emission control system

The evaporation emission control system was replaced by a canister loaded with charcoal and simultaneously a failure at the solenoid valve was simulated.

Exhaust gas analyses are documented, but no error codes.

- Catalyst

A dummy catalyst was built in 5 cars.

In all experiments but one the OBD error codes can be compared to the exhaust gas analysis results.

- Combined failures

A spark plug with a gap of 0.15 mm was tested in combination with a coolant temperature sensor with a resistor built in the wiring at one car and in combination with a malfunctioning manifold pressure sensor at another. A third experiment looked at the effects of a malfunctioning λ-sensor in combination with a partly thermally destructed catalyst.

In all three the cases, the analyses of the exhaust gases are fully documented. OBD error codes are only missing for the first experiment.