European Commission

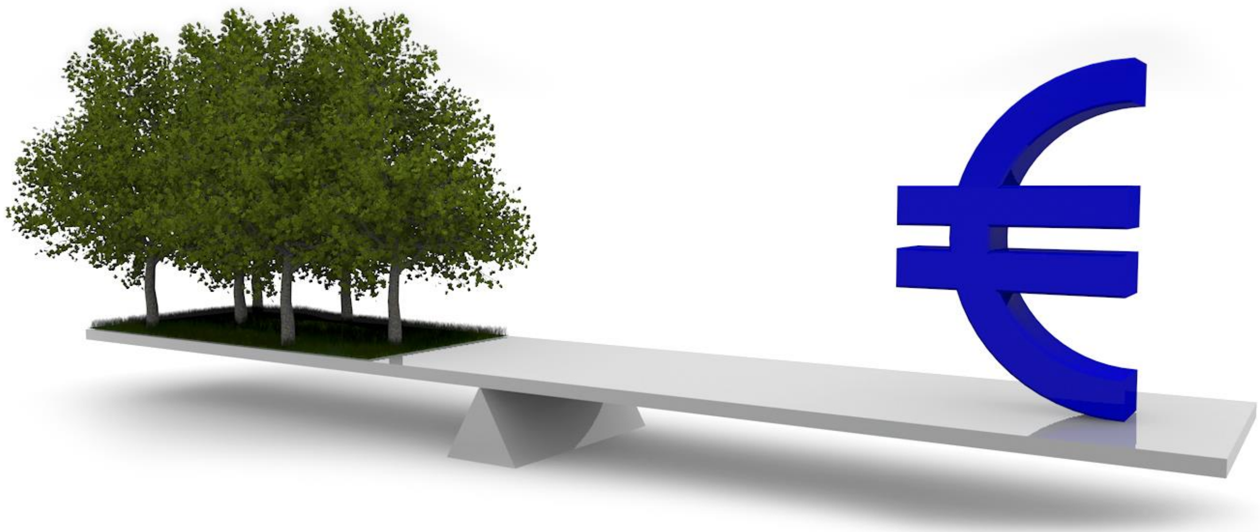
JRC SCIENTIFIC AND POLICY REPORTS

Estimating the Costs and Benefits of Introducing a New European Evaporative Emissions Test Procedure

Final Report

Authors
Anwar Gary Haq, Giorgio Martini and Giorgos Mellios

2013



Report EUR 26057 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Energy and Transport

Contact information
Giorgio Martini
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 441, 21027 Ispra (VA), Italy
E-mail: giorgio.martini@jrc.ec.europa.eu
Tel.: +39 0332 78 9293
Fax: +39 0332 78 5236

http://iet.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

This publication is a Reference Report by the Joint Research Centre of the European Commission.

JRC83722

EUR 26057 EN

ISBN 978-92-79-32364-5 (pdf)
ISBN 978-92-79-32365-2 (print)

ISSN 1831-9424 (online)
ISSN 1018-5593 (print)

doi: 10.2788/59642

Luxembourg: Publications Office of the European Union, 2013

Printed in Italy

Contents

Executive Summary

- Non-methane volatile organic compounds (NMVOCs) are a major component of pollutant emissions from gasoline-fuelled road transport. NMVOCs emissions originate from fuel escaping from the combustion process and from the fuel system.
- NMVOC Emissions which arise from the vehicle's fuel system are called evaporative emissions. These occur as a result of fuel volatility combined with the variation in ambient temperature and the temperature changes in the vehicle's fuel system.
- NMVOCs act as ozone precursors and contribute to the formation of ground-level ozone and photochemical oxidants associated with urban smog. Volatile fuel gases and elevated levels of urban ozone both pose a threat to human health.
- In order to improve the capability of European petrol cars to control evaporative emissions in real world driving conditions, especially with rising ethanol fuel use, it is now considered necessary to revise the European legislation on evaporative emissions.
- EC Regulation (715/2007) and EC Communication (2008/C 182/08) require a review of the evaporative emissions test procedure to improve the control of evaporative emissions.
- A revised test procedure for evaporative emissions, and its possible implementation together with the new Euro 6 emission standards, is currently under discussion by the European Commission.
- Four different scenarios were examined to determine the costs and benefits of the implementation of a new regulation for the period 2015-2030. This is also the period Euro 6 vehicle emission standards will come into force**.**
- The scenarios were designed to address the main issues regarding real-world evaporative emissions and the impact of ethanol on them:
    - Scenario 1 addresses the issue of limited canister purging under typical urban driving conditions (short trips, low average speeds).
    - Scenario 2 (in addition to scenario 1) addresses extended parking events by requiring the use of larger canister volumes.
    - Scenario 2+ (in addition to scenario 2) addresses the issue of activated carbon degradation, especially in the presence of ethanol in the fuel.
    - Scenario 3 (in addition to scenario 2+) addresses the impact of ethanol on fuel permeation through the plastic material of the fuel system.
- In the base case scenario and scenarios 1, 2, 2+ it is assumed that in the period 2015-2021 the share of vehicles equipped with monolayer tanks will progressively decrease. This assumption is based on plastic tank manufacturers projected production of monolayers tanks.
- In scenario 3 it is assumed that all new vehicles are equipped with multilayer tanks from a given date (2015 in this specific case) due to the introduction of legal requirements limiting the maximum permeation rate of fuel systems.
- In order to estimate the costs associated with the implementation of each scenario a survey of stakeholders attending the EC Expert Working Group on Evaporative Emissions was undertaken. In addition, indicative costs presented in a United States Environmental Protection Agency (USEPA) regulatory impact analysis of the control of vehicle evaporative emissions (1993) were also used after having been adjusted for inflation and converted to Euros.
- Another approach was also undertaken to estimate the impact of the new test procedure on the cost of a vehicle. Costs can be distinguished between direct vehicle manufacturing costs (e.g. raw material, labour and energy costs in assembling materials into new technology) and indirect costs (e.g. research and development, changes in corporate staffing, additional training).
- The approach used in this study is based on the use of indirect cost multipliers (ICMs). The ICMS range from 1.05 to 1.45 in the short-run and from 1.02 to 1.26 in the long-run depending on technological complexity. The difference between the short- and long-run timescales are mainly related to research and development and warranty costs, which are projected to decrease over time. Due to the uncertainty in determining the technology complexity associated with each scenario, both low and medium technological complexity is examined.

- The costs of the additional hardware components needed for each scenario were estimated and multiplied by the indirect cost multipliers. The assumption is that the new test procedure will require a technology that can be classified as something intermediate between a low complexity and a medium complexity technology.
- In order to estimate the annual additional cost due to the introduction of a revised test procedure, the additional cost per vehicle was multiplied by the projected sales of Euro 6 gasoline vehicles.
- The environmental benefits in terms of NMVOC emissions avoided for each scenario compared to the base case were calculated. The base case represents the situation in which no new legislative measures are introduced.
- The computer program 'Calculate Emissions from Road Transport (COPERT)' model was used to estimate EU evaporative emissions from the Euro 6 petrol vehicle population over time. The COPERT Model calculated average daily NMVOC emissions per vehicle (g/day) for each scenario (2015-2040).
- The average grams (g) per day reduction were calculated by subtracting the estimated scenario g/day emissions from the baseline scenario (no action). The average daily reduction was then multiplied by 365 to get the average reduction per vehicle per year and converted to kilograms. The average emission reduction per year was converted to tonnes then multiplied by high and low external marginal damage to obtain the benefit of NMVOC avoided per vehicle.
- The average evaporative emissions (in grams/vehicle per day) of Euro 6 petrol cars in 2040 are projected to be more than double compared to 2015 levels for the base case. This is due to the ageing of the vehicle fleet and the degradation of the activated carbon. This is mainly due to small vehicles which are assumed to have a higher degradation rate compared to medium and large cars.
- In order to determine the benefits of NMVOC emission reductions and damage avoided, low and high marginal damage costs (MDC) from the CAFE Programme were used to calculate the economic value of the damage avoided. These marginal damage costs are limited to the ozone on people and crops. They underestimate the real impact of NMVOCs as the impact on ecosystems and cultural heritage are excluded from the analysis.
- Significant emissions reductions can be achieved by the implementation of a revised test procedure. The introduction of durability requirements – resulting in better carbon quality – has the greatest reduction potential, followed by an extension of the diurnal test to 48 hours – resulting in bigger canisters and a more aggressive purging strategy.
- The average low and high MDC per tonne of NMVOC emissions for the EU27 were calculated and used in the benefit analysis. The low MDC for the EU27 was €1,098 while the high MDC was €3,303.
- These nominal current values (excluding inflation) were used to calculate annual benefits for society. The value of annual benefit in terms of damage avoided for each scenario was calculated by multiplying the tonne NMVOC avoided (difference between scenario emissions and base case) by the high and low MDC figures.
- Benefits and costs stretch over time. Since individuals prefer the present to the future, then future benefits are taken into account using a discount rate to provide a Net Present Value (NPV) i.e. the discounted costs minus the discounted benefits. The cost-benefit rule is that the present value of benefits must exceed the present value of costs.
- The choice of an appropriate discount rate is key to assessing the extent of sacrifices society should be taking now to prevent or slow down environmental damage affecting future generations. Low discount rates make the future more important, high discount rates make it less so. A range of discount rates were used as part of a sensitivity analysis. These included 10%, 6%, 3% and 0%.
- In addition to the NPV, a benefit-cost ratio (BCR) for each scenario was calculated. This is another indicator that can be used in cost benefit analysis. If the benefit-to-cost ratio is greater than 1 then the benefits outweigh the costs. The higher the number the more benefits for society.
- Under scenario 1 a more aggressive purging strategy is expected to be implemented. At a 6% discount rate the NPV is positive. When the fuel saved is included in the analysis the total benefits for scenario 1 is positive at € 209,701,648. The average BCR is above 2.40.
- Under scenario 2 a more aggressive purging strategy is expected to be implemented, the diurnal test is extended to 48 hours. At a 6% discount rate the average NPV is positive. When the fuel saved is

included in the analysis the total benefits for scenario 2 is positive at €249,937,409. The average BCR is 1.35.

- Under scenario 2+ a more aggressive purging strategy is implemented, the diurnal test is extended to 48 hours, and canister durability is introduced. At 6% discount rate the average NPV is positive. When fuel saved is included in the analysis the total benefits for scenario 2+ is €1,253,822,519. The average BCR is 2.43.
- Under scenario 3 a more aggressive purging strategy is expected to be implemented, the diurnal test is extended to 48 hours and tank and canister durability requirements are introduced. The average NPV is negative at 6%. When the fuel saved is included in the analysis the total benefits for scenario 3 is positive at €843,144,182. The average BCR is 1.67.
- An alternative approach to estimating the costs and benefits of the proposed test procedure is to calculate it on a per vehicle basis. These costs and benefits are calculated over the useful life of the vehicle (10 and 15 years).
- Scenario 3 has an average additional cost of €20 per vehicle compared to €9 in scenarios 2 and 2+. The average emission reduction benefit per vehicle in both scenario 2+ and 3 are similar at approximately €6-7 (10 years useful life). When the benefits of fuel saved is added to the emission reduction scenario 3 has a slightly higher average benefit per vehicle of approximately €13.3 compared to €12.7 in scenario 2+. When a useful life of 15 years is considered the same values rise to €9.2, €9.2 and €9.5 for emission reduction benefits for scenarios 2, 2+ and 3 respectively and €18.2, €18.9 and €20 when fuel saved is included.
- The analysis found that on a per vehicle basis under scenario 2+ the benefits derived from a reduction in evaporative emissions range from €6-9. When the benefits from fuel savings are added scenario 2+ total benefits range from €13-18. This is compared to average additional cost per vehicle of €9.
- The additional costs in scenario 1 are lower (€1-2) but so are the total net benefits (€3-4). In contrast, the additional costs are much higher in scenario 3 (€20) although the total net benefits are slightly higher €13-19.
- The indirect cost multipliers used here do not include manufacturer's profit. This has been criticised due to the automotive industry participating in a near monopolistic competitive market. Since cost estimates assume long-run conditions, long-run supply assumptions should be used to ensure consistency. The ratio of profit to indirect cost is estimated to be 0.06.
- There is also a degree of uncertainty in ICMs associated with individual technologies. ICM uncertainty values range from 13 per cent lower to 13 per cent higher than the primary values. Taking into consideration this level of uncertainty and the manufacturer's profit the ICM values were further amended.
- The NPV for scenario 2+ is reduced to € 86,573,135 using the amended ICM and taking into consideration uncertainty. When fuel-saved is included this value increases to €1,193,686,213.
- Even in more conservative estimates, under the conditions considered, scenario 2+ remains the most cost-effective policy option for the implementation of the proposed new test procedure for evaporative emissions.
- The average net benefit of implementing scenario 2+ is €146,709,441 at a 6% discount rate is considerably higher than €14,660,997 under scenario 1. Scenarios 2 and 3 result in an average net cost.
- All the net benefits discussed above are averages for the EU 27. However, it should be taken into account that there are large differences among EU Member States. Much higher benefits are expected for southern countries with a hot climate than for northern countries.
- In conclusion, the cost-benefit analysis undertaken here has demonstrated a net benefit in implementing a modified test procedure for NMVOCs under scenario 2+. This involves the implementation of a more aggressive purging strategy over 48 hours and greater canister durability.

ABBREVIATIONS AND ACRONYMS

AMDCW	Average marginal damage cost weight
BCR	Benefit cost ratio
BWC	Butane working capacity
CAFÉ	Clean Air for Europe Programme
COPERT	Computer Programme to Calculate Emissions from Road Transport
EC	European Commission
EEA	European Environment Agency
EMS	Engine management system
EU	European Union
FID	Flame ionisation detector
g	grams
GWC	Gasoline working capacity
IC	Indirect costs
ICM	Indirect cost multiplier
JRC	Joint Research Centre
kg	kilogram
MDC	Marginal damage costs
MDCW	Marginal damage cost weighting
MSMDC	Member State marginal damage cost
NMVOC	Non-methane volatile organic compounds
NPB	Net present benefit
NPC	Net present cost
NPV	Net present value
O3	Ozone
OBD	On-board diagnostics
OEM	Original equipment manufacturers
PM	Particulate matter
RPE	Retail price equivalent
TNPB	Total net present benefit
USEPA	United Stated Environmental Protection Agency
VC	Vehicle cost
VOC	Volatile organic compounds
VOLY	Value of Year Loss
VSL	Value of Statistical Life

LIST OF TABLES AND FIGURES

1 INTRODUCTION

Non-methane volatile organic compounds (NMVOCs) are a major component of pollutant emissions from gasoline-fuelled road transport. NMVOCs emissions originate from fuel escaping totally or partially from the combustion process (exhaust emissions) and from the fuel system (i.e. storage tank, carburettor or injection system and fuel pipes). Emissions which arise from the vehicle's fuel system are called evaporative emissions. These occur as a result of fuel volatility combined with the variation in ambient temperature and the temperature changes in the vehicle's fuel system. Evaporative losses occur during the operation of the vehicle (running losses), immediately after the vehicle is switched off after operation (known as 'hot soaks'), refuelling and when the vehicle is parked as a consequence of changes in diurnal temperatures.

NMVOCs act as ozone precursors and contribute to the formation of ground-level ozone and photochemical oxidants associated with urban smog (Parrish *et al*., 2009; von Schneidemesser *al.*, 2010). Volatile fuel gases and elevated levels of urban ozone both pose a threat to human health (Smith *et al*., 2009; Geiss *et al*., 2011). In 2009 17 per cent of the EU urban population lived in areas where the European Union (EU) ozone target value for protecting human health was exceeded (EEA, 2012). However, EU emissions of NMVOCs are decreasing and fell by 55 per cent in the period 1990-2009. This has been due to the success of European air quality policies limiting emissions of main air pollutants from road transport (EEA, 2010).

European Commission (EC) Directive 98/69/EC (Euro 3 and Euro 4 standards) outlines current European legislation on evaporative emissions. As a result of the implementation of this legislation all modern vehicles are equipped with an activated carbon canister trapping the vapours generated inside the tank and preventing their release in the atmosphere. Since the introduction of Directive 98/69/EC neither the evaporative emission standards nor the test procedure have changed. However, two new legislative steps to further reduce exhaust emissions have been implemented (Euro 5/6). At the same time, European policies aimed at reducing oil dependency in the transport sector has been introduced to promote the widespread use of biofuels, of which bioethanol is the most popular. Ethanol has potential negative impacts on evaporative emissions. This is because of the increased volatility of petrol containing ethanol and the effect of ethanol on permeation rate of plastic materials. Ethanol may also reduce the working capacity of the carbon canister due to the polarity of the ethanol molecule, which makes purging it from the activated carbon more difficult.

The Swedish Transport Administration (STA) (formerly Swedish Road Administration) undertook an in-service conformity programme for evaporative emissions and found about a 30 per cent failure rate in the evaporative emission test compared to 10 per cent failure rate in a similar German in-service conformity programme (Johansson and Schmidt, 2009). In the Swedish analysis, the most likely explanation of the high non-compliance rate is a reduced working capacity of the carbon canister. This is due to contamination with ethanol and is most probably a result of the high ethanol use in transport fuel in Sweden.

In order to improve the capability of European petrol cars to control evaporative emissions in real world driving conditions, especially with rising ethanol fuel use, it is now considered necessary to revise the European legislation on evaporative emissions. EC Regulation (715/2007) and EC Communication (2008/C 182/08) requires a review of evaporative emissions test procedure to improve the control of evaporative emissions. [1]The review addresses the:

1. effective control of evaporative emissions throughout the useful life of vehicles under real world driving conditions;

[1] See JRC Report EUR 25640 EN (2012) for further information on the issues related to the impact of ethanol on evaporative emissions and the current European test procedure for evaporative emissions.

2. improved durability of the evaporative emission control system over the useful life of the vehicle; and
3. impact of ethanol containing fuel on evaporative emissions.

In this report we examine the costs and benefits for the EU 27 Member States of modifying the current EU evaporative emission test procedure.

EC Regulation 715/2007
on the type approval of motor vehicles with respect to light passenger
and commercial vehicles (Euro 5 and Euro 6)

Article 4 (2)

"*In addition, the technical measures taken by the manufacturer must be such as to ensure that the tailpipe and evaporative emissions are effectively limited, pursuant to this Regulation, throughout the normal life of the vehicles under normal conditions of use.*"

"*… In order to improve control of evaporative emissions and low ambient temperature emissions, the test procedures shall be reviewed by the Commission*."

EC Communication 2008/C 182/08
on the application and future development of Community legislation concerning vehicle emissions
from light-duty vehicles and access to repair and maintenance information (Euro 5 and 6)

9 Evaporative emissions

"*Due to the wider introduction of biofuels, the Commission intends to review test procedures for evaporative emissions. This review should consider whether greater global harmonisation is desirable through alignment of the European test procedure with that used in the United States. In doing so, consideration may be given to introducing in-service conformity or durability requirements to control the effects of long term use of fuels containing ethanol on evaporative emissions.*"

2 EVAPORATIVE EMISSIONS TEST PROCEDURE

Figure 1 presents a typical layout of an evaporative emission control system in European cars. Current European legislation sets a limit for evaporative emissions of 2 grams/test and defines the procedure to measure them. In order to comply with the relevant emission standard, modern vehicles rely on an evaporative emission control system consisting of an activated carbon canister that adsorbs fuel vapours and prevents the release of them to the air.

When the vehicle is parked and the engine is switched off, the carbon canister traps petrol vapours produced in the tank by petrol evaporation. The canister controls evaporative emissions by preventing the release of fuels from the gasoline tank by gas adsorption with activated carbon (Huang et al., 2011). When the vehicle is running, in certain operating conditions and under the control of the engine management system (EMS), part of the combustion air is drawn through the canister and into the engine. This results in the activated carbon being purged and the fuel vapours desorbed from the activated carbon and burned in the engine. EC Directive 98/69/EC outlines current limits and test procedure for evaporative emissions (See Figure 2).

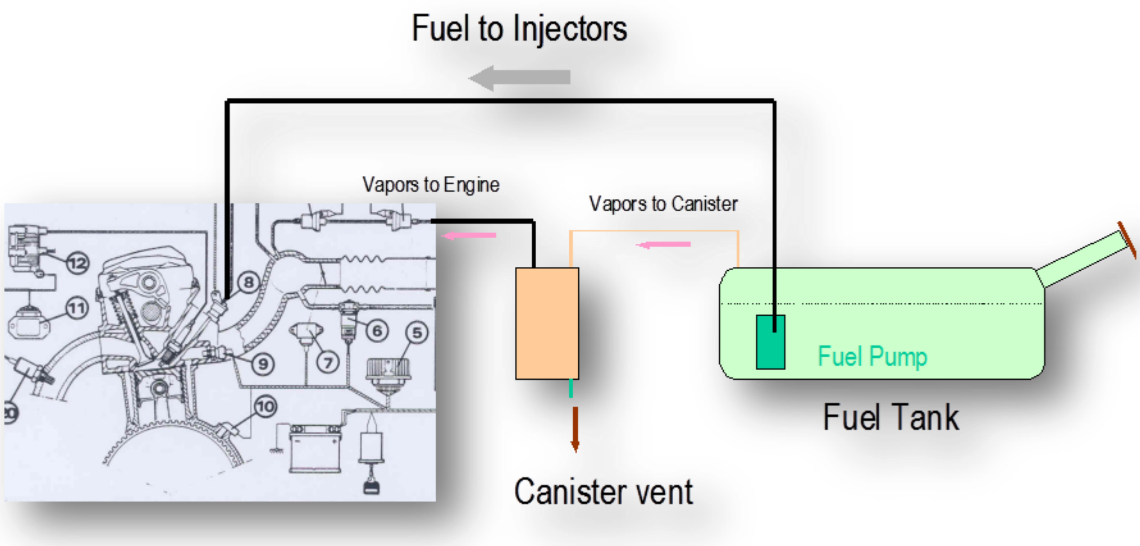
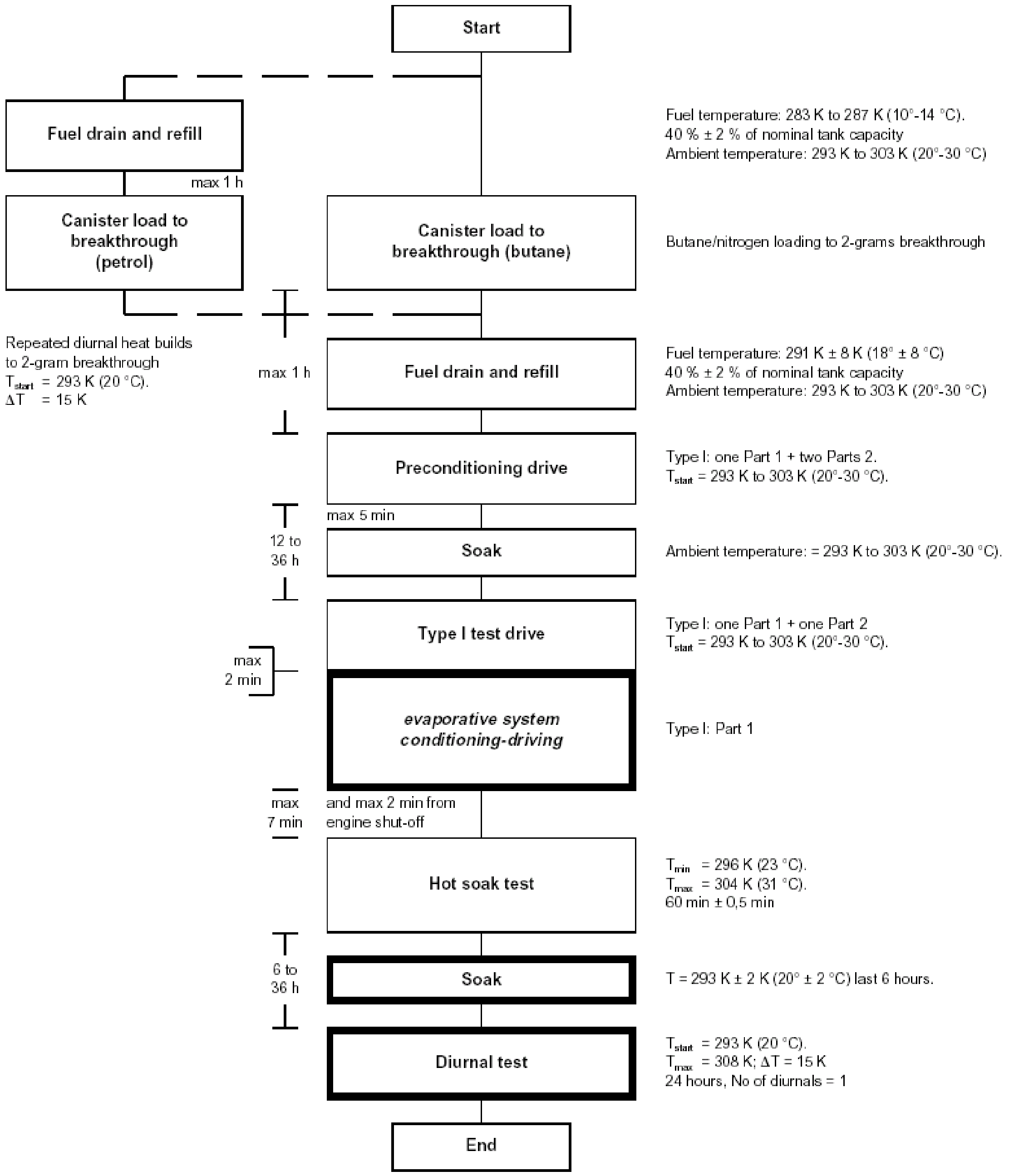


Figure 1: Typical layout of an evaporative emission control system of European cars

Figure VI.1

Evaporative emission determination

3 000 km run-in period (no excessive purge/load)
Ageing of canister(s) verified
Steam clean of vehicle (if necessary)



Note:
1. Evaporative emission control families — details clarified.
2. Tailpipe emissions may be measured during type I test drive, but these are not used for legislative purposes. Exhaust emission legislative test remains separate.

Figure 2: Standard EU Evaporative Emissions Test Procedure (EU Directive 98-69-EC)

The test procedure is designed to determine hydrocarbon evaporative emissions during 'hot soaks' immediately after driving and as a consequence of fluctuations in diurnal temperature during parking. The test involves preparing the vehicle by conditioning the carbon canister and the vehicle. The carbon canister conditioning consists in loading the activated carbon with a mixture of nitrogen and butane until 'breakthrough' occurs, as defined in the legislation. This is defined as the situation when 2 grams of hydrocarbons are emitted by the canister. Once this is achieved the vehicle is driven for some time (as prescribed by the test procedures) to purge the canister (vehicle conditioning). This is when part of the combustion air is taken through the vent of the canister while the vehicle is in operation. In this way hydrocarbons are removed from the activated carbon and burnt in the engine.

Immediately after the vehicle conditioning, a 'Hot Soak Test' is undertaken which simulates the condition of a vehicle parked after being driven for a certain distance. This is then followed by a 'Diurnal Test' which simulates the situation of a vehicle parked for 24 hours in summer. An airtight chamber (VT SHED) is used to measure the evaporative emissions during the vehicle test cycle. A Flame Ionisation Detector (FID) monitors the VOC concentrations in the chamber. The overall test result is the sum of the mass emissions of hydrocarbons from both the Hot Soak and Diurnal Loss tests. The EU limit for evaporative emissions (Hot Soak + Diurnal) is 2 grams of hydrocarbons per test. This is less stringent than the US evaporative emission legislation.

The US evaporative emission standards allow much lower emissions per test, but also the test procedure is generally much stricter. As an example, the US evaporative emission test procedure undertakes two- and three-day diurnal tests compared to the one-day diurnal test required by the EU test procedure. It also has a shorter conditioning driving cycle and well defined durability requirements (See JRC Report EUR 25640 EN (2012).

The introduction of a new EU test procedure similar, at least for some aspects, to the US procedure will have cost implications for car manufacturers as well as benefits for society. This report presents the analysis of the costs and the benefits associated with different scenarios for a range of proposed new measures.

METHODOLOGICAL APPROACH

In order to assess the costs and benefits to society of introducing a modified test procedure for evaporative emissions, the following steps were undertaken:

- Development of different scenarios
- Estimation of costs to car manufacturers of implementation
- Estimation of NMVOC emissions from Euro 6 petrol vehicles over time under each scenario
- Marginal damage costs and the Net Present Value of each scenario
- Per vehicle costs and benefits, including fuel savings.

3 COST-BENEFIT ANALYSIS

Cost-benefit analysis (CBA) is a technique for measuring whether the benefits of an action (e.g. introducing a measure to reduce vehicle emissions) are greater than the costs (i.e. health costs of people affected by air pollution), judged from the viewpoint of society as a whole (Hanley and Barbier, 2009). The costs and benefits of different policy options can be expressed as:

- Net Present Value (NPV): the value that results from present costs minus present benefits;
- Benefit-Cost Ratio (BCR): the ratio of present value of social benefit to present value of social costs over time.

In this study we examine four different scenarios to determine the costs and benefits of implementation of a revised vehicle test procedure to reduce evaporative emissions. Two approaches are used to estimate the NPV. The first approach examines the costs and benefits for the total EU Euro 6 petrol vehicle fleet while the second approach examines costs and benefits on a per vehicle basis.

SCENARIOS

The European Commission is currently discussing a revised test procedure for evaporative emissions and its possible implementation together with the new Euro 6 emission standards. Main issues are presented below.

1. The current strategy to purge the carbon canister adopted in European cars is usually optimised for the conditioning procedure as defined in the legislative test procedure. This requires that after the loading to breakthrough of the carbon canister, the vehicle is driven over three complete new European driving cycles (NEDC) for a total of 59 minutes and 33 km. Real vehicle activity data recorded by means of GPS systems shows that the typical distance covered in urban environments is much shorter (see JRC Report EUR 25640 EN). Approximately 60 per cent of the trips in urban areas are at low speeds and are below 5 km. One of the consequences of low speed and short distance is that the carbon canister may not be effectively purged in real world driving conditions compared to tests undertaken in the laboratory according to the current testing procedure.

2. The current test procedure requires a one-day diurnal test to be undertaken to account for the evaporative emissions emitted during parking events. The US legislation on evaporative emissions requires both two- and three-days diurnal tests. The US emission limit refers to the day showing the highest evaporative emissions. In addition, under US legislation on refuelling emissions, the carbon canister has to be designed to be able to adsorb the vapours displaced by the liquid fuel entering into the tank. As a result, carbon canisters used in US vehicles are much larger compared to the carbon canister fitted to European cars. This means that in case of extended parking (e.g. 2-3 days or more) typical European carbon canisters are easily saturated, resulting in disproportionately high evaporative emissions.

3. Ethanol has a significant impact on evaporative emissions. There are three main effects that have to be considered:
   a. The increased volatility of fuel when ethanol is splash blended (i.e. simply added) into petrol. This aspect can be partially compensated by not allowing splash blending. The current fuel quality Directive 2009/30/EC allows Member States to require a waiver for the maximum vapour pressure to be met by petrol-ethanol blends. At the moment no Member State has requested such a waiver but it is also true that even if petrol-ethanol blend comply with the limit on vapour pressure set by the fuel quality Directive, an increase of fuel volatility in vehicle’s tanks will be unavoidable if in certain areas fuel without and with ethanol will coexist (commingling effect). Increased volatility of

tank fuel will increase the vapour load to the canister which will become easily saturated. A larger canister would reduce the impact of such effect.

b. Hydrocarbons can escape the vehicle's fuel system by permeating through plastic and rubber components (e.g. hoses, seals, and in vehicles with a non-metallic tank) and the fuel tanks itself. Permeation does not occur through an identifiable opening; instead individual fuel molecules penetrate (i.e. they effectively mix with) the walls of the various components and eventually find their way to the outside. Fuel permeation is significant only for plastic or elastomeric materials. Fuel permeation rate depends on the material used for the fuel system and on the chemical species contained in the petrol; in particular, alcohols such as methanol and ethanol can significantly increase the permeation rate. Ethanol is believed to lead to an increase in permeation due to the tendency of ethanol to evaporate more readily than other fuel components and to the smaller size of the ethanol molecule. Several US studies have demonstrated that ethanol leads to a significant increase of evaporative emissions through fuel permeation (CRC, 2006; 2010). This is also true for modern multilayer tanks although they have much lower permeation rates in absolute terms compared to monolayer tanks.

   Currently approximately 35 per cent of new vehicles sold in Europe are equipped with monolayer tanks (data provided by PlasFuelSys, the European association of plastic tank manufacturers). It is envisaged that without the legal requirement for the introduction of multilayer tanks, monolayer tanks will be progressively phased-out. After 2021 these will be no longer in mass production.

c. Residual hydrocarbon concentration in the canister after purging can influence evaporative emissions as this can reduce the working capacity of the canister. Polar molecules such as ethanol (or water) or heavier hydrocarbons are usually harder to purge from the carbon. It has been shown that activated carbon affinity for ethanol vapours is greater than for olefins and aliphatic hydrocarbons. Therefore it is possible that ethanol's propensity to be held by activated carbon, in conjunction with its hygroscopic nature may decrease the working capacity of the canisters and result in increased diurnal emissions. This is considered the most likely explanation for the high failure rate (approximately 30 per cent) in the evaporative emission tests that has been observed in Swedish in-use compliance programmes on passenger cars.

Four different scenarios were examined to determine the costs and benefits of implementation of a new regulation for the period 2015-2030, the year Euro 6 vehicle emission standard will come into force. Table 1 summarises the different scenarios and its envisaged impact on vehicle technology.

In the base case scenario and scenarios 1, 2, 2+ it is assumed that in the period 2015-2021 the share of vehicles equipped with monolayer tanks will progressively decrease (i.e. 35%, 32%, 26%, 19%, 11%, 4%, 0%). This assumption is based on the projections for the production of monolayers tank provided by PlasFuelSys, the Association of European Plastic Tank Manufacturers. In scenario 3 it is assumed that all the vehicles are equipped with multilayer tanks from a given date (2015 in this specific case) due to the introduction of legal requirements limiting the maximum permeation rate of fuel systems.

Table 2 provides a summary of the differences between the current and proposed test procedure for each scenario. Estimated Euro 6 petrol vehicle fleets figures were used to determine the costs and benefits of the implementation of the new test procedure (EC4MACS, 2013). The vehicle population in each year from 2015 to 2040 is the sum of the population of the previous year and of the new sales minus the vehicles scrapped (see Figure 3). The useful life of a car is estimated on average to be 10-15 years. The analysis covers also the period 2030-2040 assuming no new sales of Euro 6 from 2030 onwards as emissions are due to the ageing population of the vehicles sold during the period 2015-2030. This assumption is needed to take into consideration the benefits coming from the vehicles sold in the period 2020-2030. For example, the additional costs associated with a vehicle sold in 2030 will be counted on the cost side for the period 2015-2030, however, the benefits will occur in the period 2030-2040.

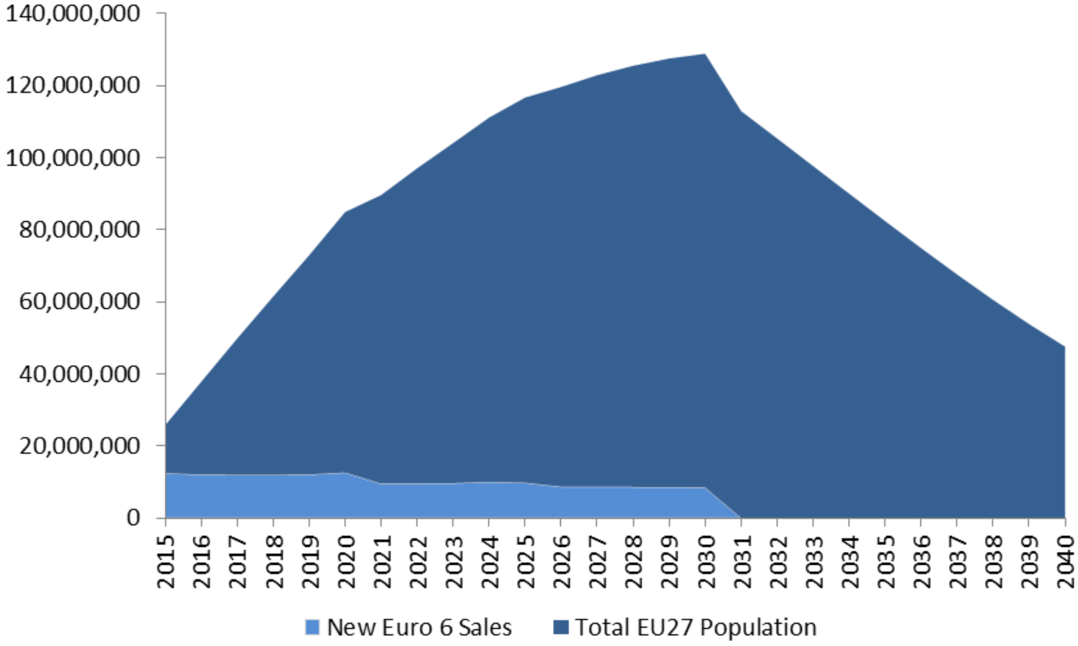


FIGURE 3: The evolution of the EU Euro 6 petrol vehicle sales

Source: EC4MACS (2013)

Table 1: Scenarios for a new European Emissions Test Procedure

	Expected impacts on vehicle						
	Canister	Purge valve	Engine calibration/ vehicle model	Packaging	FacilitieS	Certification	Low permeation tanks & hoses
Scenario 1		X	X				
A more aggressive purging strategy is implemented In scenario 1 a more aggressive canister purging strategy is adopted. This is achieved by reducing the canister purging time of the test procedure. Compared to the current version of the procedure, under this scenario the carbon canister is loaded to 'breakthrough' after the pre-conditioning drive. This reduction is partially compensated by an extension of the conditioning drive by adding an extra urban driving cycle (UDC) which results in a net reduction in the driving time and distance driven to purge the canister from 59 mins/33 kms (3 complete NEDC) to 43 mins/19 kms (1 complete NEDC + 2 UDC). Moreover, of these 19 km only 4 will consist in extra-urban driving conditions, the rest being urban driving cycle. It is expected that the adoption of a more aggressive purging strategy will result in better purged canisters especially in urban driving conditions increasing their capability of trapping gasoline vapours after short trips.							
Scenario 2	X	X	X	X	X	X	
A more aggressive purging strategy is implemented and the diurnal test is extended to 48 hours Scenario 2 assumes the introduction of an aggressive purging strategy as outlined in scenario 1 but with the addition of a two-day diurnal test. The scenario assumes: a reduction in the driving time and distance driven from 59 mins/33 kms to 43 mins/19 kms and an increase in the carbon canister volume. In this case, it is expected that in addition to better purged canister the extra-working capacity of the canister available will trap gasoline vapours over extended parking events more efficiently.							
Scenario 2+	X	X	X	X	X	X	
A more aggressive purging strategy is implemented, the diurnal test is extended to 48 *hours and canister durability requirements are introduced* Scenario 2+ has the same assumptions as in scenario 2 except it requires the use of higher activated carbon quality in the canister with a lower degradation rate. This will require the implementation of a specific durability requirement for the working capacity of the carbon canister.							
Scenario 3	X	X	X	X	X	X	X
A more aggressive purging strategy is implemented, the diurnal test is extended to 48 hours and tank and canister durability requirements are introduced Scenario 3 assumes that in addition to what is outlined in scenario 2 durability requirements are introduced to control carbon canister efficiency degradation as well as fuel permeation. The scenario assumes: a reduction in the driving time and distance drive from 59 mins/33 kms to 43 mins/19 kms; increase in the carbon canister form 0.9 to 1.8 litres, use of higher activated carbon quality; and the use of less permeable materials.							

Table 2: Summary of the differences between the current and proposed test procedure in each scenario

Assumptions	Current	Modified
Scenario 1		
Typical canister size		No change
Canister Conditioning (*Drive time/distance driven*)	59 min/33 km	43 min/19 km
Scenario 2		
(Typical *canister size*)		Increased volume
Canister Conditioning (*Drive time/distance driven)*	59 min/33 km	43 min/19 km
Scenario 2+		
Typical canister size		Increased volume
Canister Conditioning (*Drive time/distance driven*)	59 min/33 km	43 min/19 km
Activated carbon	No requirement on long term performance	Introduction of a maximum deterioration rate
Scenario 3		
Typical canister size		Increased volume
Canister Conditioning (*Drive time/distance driven*)	59 min/33 km	43 min/19 km
Fuel system material	-	Forced adoption of permeable fuel tanks
Activated carbon	No requirement on long term performance	Introduction of a maximum deterioration rate

4 ESTIMATING COSTS

In order to estimate the costs associated with the implementation of each scenario a survey of stakeholders attending the EC Expert Working Group on Evaporative Emissions was undertaken. The Expert Working Group includes car manufacturers, suppliers, Member States and test service companies. The EC JRC conducted the survey of stakeholders attending the Expert Working Group in May and September 2011. The survey examined the impact of a new test procedure on engine technology, performance and cost. A total of nine questionnaires were completed: 1 Member State, 3 Original Equipment Manufacturers (OEM) suppliers, 4 car manufacturers and 1 test service company.

In addition, indicative costs presented in a United States Environmental Protection Agency (USEPA) regulatory impact analysis of the control of vehicle evaporative emissions (1993) were also used after having been adjusted for inflation and converted to Euros. The estimated costs used in the analysis were reviewed by the Expert Working Group and it was agreed that they would form the basis of the analysis. Since in several cases different cost values were provided by manufacturers it was decided to take the lowest and the highest figures provided (low cost and high cost estimate) (see Table 3).

Table 3: The estimated costs associated with the implementation of new evaporative emissions for each scenario

Hardware Costs (Direct costs)	Low	High
Larger canister/vehicle	€ 5	€ 8
Purge valve/vehicle	€ 1	€ 2
On-board diagnostics (OBD)/vehicle	€ 12	€ 45
Low permeation tank and hoses/vehicle	€ 25	€ 30
Indirect Costs		
Engine calibration/vehicle model	€ 1,000,000	€ 1,000,000
Certification/vehicle	€ 0.15	€ 0.25
Facilities (1 Shed) *	€ 813,727	€ 813,727
Packaging/vehicle **	€ 0.75	€ 0.90

*amortized over 10 years at 10%/Year
** EPA (1993)

The additional testing facilities (SHED) and the number of engines that need to be re-calibrated were estimated in order to calculate the impact in terms on the cost of each vehicle sold. In addition to this analysis of the extra costs due to the proposed test procedure, another approach was undertaken to estimate the impact on the cost of a vehicle. This approach is based on the use of indirect costs multiplier.

Indirect Costs Multiplier

Costs can be distinguished between direct vehicle manufacturing costs (e.g. raw material, labour and energy costs in assembling materials into new technology) and indirect costs (e.g. research and development, changes in corporate staffing, additional training). While direct manufacturing costs are straightforward to estimate, indirect costs are more difficult (Rogozhin *et al*., 2010). The automotive industry has often applied scaling factors to changes in estimated direct costs to capture changes in indirect costs and to predict the full impact of vehicle modifications on the selling price (USEPA, 2009).

The retail price equivalent (RPE) multiplier is a commonly used scaling factor that implicitly assumes that incremental changes in direct manufacturing costs have a common (percentage) change on all indirect cost components as well as profits.

A criticism of the RPE multiplier is that the indirect costs of vehicle modifications are not likely to be the same for different technologies. Modified multipliers known as indirect cost (IC) multipliers have been used to specifically evaluate indirect costs that are likely to be affected by vehicle modifications. They can be used when the absence of information does not allow using indirect cost data specific to the modification. IC multipliers take into consideration the technical complexity of vehicle modifications and are adjusted over time as modifications become assimilated into the automotive supply chain.

Rogozhin *et al*. (2010) outlined a number of advantages of using IC multipliers compared to the RPE. They:

- explicitly recognise the indirect costs are not constant across all technologies;
- allow greater flexibility in application allowing specific values to be changed;
- provide a more accurate estimate of the indirect costs and therefore total costs associated with new technologies.

IC multipliers are derived from the RPE multiplier by using adjustment factors to indirect costs contributors. The magnitude of the adjustment depends on technology complexity, which is the degree of innovation in an automobile manufacturer's products, product architectures and processes induced by the technology. More complex technologies are expected to have a larger impact on indirect costs than less complex technology. Time frame also influences the IC multipliers as higher indirect costs are expected initially in the short-run (1-5 years) and lower impacts in the long-run (after 5 years) as companies assimilate the new technologies. Many indirect costs are likely to be at one-time or short run activities (e.g. educating dealers and upgrading mechanic's equipment) (Rogozhin *et al*., 2010).

Table 4 shows that the IC multipliers range from 1.05 to 1.45 in the short-run and from 1.02 to 1.26 in the long-run. The difference between the short- and long-run timescales are mainly related to research and development and warranty costs, which are projected to decrease over time.

Table 4: Short- and long-run multiplier calculations (Low rolling resistance tires, the dual clutch system and a hybrid vehicle are examples respectively for low, medium and high complexity technology)

	Short-run effects (first 5 Years)			Long-run effects (after 5 years)		
Technology complexity	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
IC Multiplier	1.05	1.20	1.45	1.02	1.05	1.26

Source: Rogozhin *et al*. (2010)

The costs of the additional hardware components needed for each scenario were calculated and multiplied by the ICM figures. The assumption is that the new test procedure will require a technology that can be classified as something intermediate between a low complexity and a medium complexity technology. For this reason, it has been decided to use both ICMs. In addition, after 5 years from the introduction of the measures forcing the adoption of the technology, the ICM for the long run effect is adopted. Table 5 presents the additional cost per vehicle for implementing the test procedure under each scenario for the combination of low/medium technology and short/long run. These costs do not take into consideration any tax incentives that could be used by EU Members States to promote more fuel efficient vehicles and the profit of the vehicle manufacturer. Table 5 provides for each scenario a set of four different estimated total costs using the direct costs from Table 3 and the ICMs. These costs are now indicated as Low, Medium-Low, Medium-High and High.

Table 5: Estimated extra costs per vehicle for each scenario using the Indirect Cost Multiplier (Euro)

	Direct costs (Hardware) *From Table 3*	Total additional cost/vehicle Short run		Total additional cost/vehicle Long run	
		Low/Tech	Med/Tech	Low/Tech	Med/Tech
Scenario 1					
Low cost	1	1.05	1.20	1.02	1.05
High cost	2	2.10	2.40	2.04	2.10
Scenario 2					
Low cost	6	6.30	7.20	6.12	6.30
High cost	10	10.50	12.00	10.20	10.50
Scenario 3					
Low cost	31	15.49	21.53	31.62	32.55
High cost	40	17.70	24.60	40.80	42.00

The same additional costs are assumed for scenario 2+ and scenario 2. The only difference between these scenarios is in terms of vehicle's technology is the use of better activated carbon quality which should result in a small difference in the additional cost per vehicle. It is believed that this additional cost is within the range of the low and high costs assumed.

In order to obtain the annual cost (AC), the estimated low and high vehicle costs (VC) for each scenario were multiplied by the annual Euro 6 sales to obtain the estimated total AC.

ESTIMATING ANNUAL VEHICLE COSTS
AC = VC * Euro 6 sales

5 ESTIMATING BENEFITS

Societal benefits can be determined by estimating the evaporative emissions avoided due to the introduction of the revised test procedure. In this study the computer program 'Calculate Emissions from Road Transport (COPERT)' model was used to estimate EU evaporative emissions from the Euro 6 petrol vehicle population over time (EEA, 2009). COPERT is a well-recognised and widely used tool for road transport emission inventories, and has been used in several EC impact assessment studies (Ntziachristos *et al*., 2009). The underlying methodology used for calculating evaporative emissions in COPERT is described in detail in EMEP/EEA air pollutant emission inventory guidebook (1.A.3.b.v) (EEA, 2009). A number of modifications were made to COPERT (version 4) to enable the evaluation of environmental benefits of the proposed test procedure. These included:

Parking distribution

Based on real-world activity data from GPS recordings from a sample fleet of approximately 20,000 passenger cars over a period of one month, a parking activity table was created.[2] Table 6 provides a distribution of the parking events into different parking durations and the time of the day that the parking event takes place. Compared to previous versions of COPERT 4 (up to version 9), the parking duration has been extended from 12 to 120 hours (5 days).

Trip distribution

In order to better estimate the canister status when entering a parking event, the distance driven prior to each parking event is taken into account in the calculations. Based on the same activity data described above, a trip distribution is introduced in the modified model and a purge volume over each trip is calculated. Two standard purge rates are used to calculate the purge volume: one for small cars (9.66 l/km), and one for medium and large cars (16.68 l/km), based on experimental data from a small sample of seven vehicles.

The Gasoline Working Capacity (GWC) of the carbon canister is then calculated for each trip prior to a parking event. For all three scenarios the purge rate is increased (to 16.7 l/km for small cars and 28.97 l/km for medium and large cars) assuming the same purge volume is maintained for a shorter conditioning driving.

Table 6: Parking activity data

	Parking duration tpark (h)													
Parking end-time t2 (hh:mm)	0.5	1	1.5	2	2.5	3	3.5	...	118	118.5	119	119.5	218	
01:00	0.22%	0.07%	0.07%	0.06%	0.05%	0.06%	0.05%	...	0.00%	0.00%	0.00%	0.00%	0.00%	**0.81%**
02:00	0.14%	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%	...	0.00%	0.00%	0.00%	0.00%	0.00%	**0.48%**
03:00	0.11%	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%	...	0.00%	0.00%	0.00%	0.00%	0.00%	**0.38%**
04:00	0.09%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	...	0.00%	0.00%	0.00%	0.00%	0.00%	**0.33%**
05:00	0.13%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	...	0.00%	0.00%	0.00%	0.00%	0.01%	**0.55%**
06:00	0.37%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	...	0.00%	0.00%	0.00%	0.00%	0.01%	**1.43%**
07:00	1.21%	0.06%	0.02%	0.01%	0.00%	0.00%	0.00%	...	0.00%	0.00%	0.00%	0.00%	0.03%	**4.45%**
08:00	2.50%	0.24%	0.08%	0.03%	0.02%	0.01%	0.01%	...	0.00%	0.00%	0.00%	0.00%	0.05%	**6.20%**
09:00	2.75%	0.48%	0.21%	0.09%	0.04%	0.02%	0.01%	...	0.00%	0.00%	0.00%	0.00%	0.05%	**5.61%**
10:00	2.91%	0.63%	0.33%	0.18%	0.11%	0.07%	0.03%	...	0.00%	0.00%	0.00%	0.00%	0.06%	**5.74%**
11:00	3.11%	0.75%	0.40%	0.25%	0.19%	0.13%	0.10%	...	0.00%	0.00%	0.00%	0.00%	0.05%	**6.16%**
12:00	2.95%	0.78%	0.42%	0.28%	0.21%	0.19%	0.20%	...	0.00%	0.00%	0.00%	0.00%	0.05%	**7.00%**
13:00	1.85%	0.87%	0.53%	0.28%	0.16%	0.12%	0.12%	...	0.00%	0.00%	0.00%	0.00%	0.05%	**5.64%**
14:00	1.73%	0.67%	0.63%	0.47%	0.26%	0.16%	0.11%	...	0.00%	0.00%	0.00%	0.00%	0.06%	**5.42%**
15:00	2.22%	0.61%	0.38%	0.33%	0.31%	0.26%	0.18%	...	0.00%	0.00%	0.00%	0.00%	0.06%	**5.71%**
16:00	2.97%	0.73%	0.42%	0.32%	0.25%	0.21%	0.20%	...	0.00%	0.00%	0.00%	0.00%	0.06%	**6.73%**
17:00	3.25%	0.83%	0.48%	0.32%	0.25%	0.22%	0.21%	...	0.00%	0.00%	0.00%	0.00%	0.05%	**7.79%**
18:00	3.46%	0.99%	0.60%	0.38%	0.27%	0.21%	0.17%	...	0.00%	0.00%	0.00%	0.00%	0.05%	**8.35%**
19:00	2.92%	0.97%	0.61%	0.41%	0.28%	0.19%	0.16%	...	0.00%	0.00%	0.00%	0.00%	0.04%	**7.51%**
20:00	1.41%	0.55%	0.43%	0.31%	0.20%	0.15%	0.10%	...	0.00%	0.00%	0.00%	0.00%	0.03%	**4.35%**
21:00	0.79%	0.24%	0.33%	0.34%	0.23%	0.15%	0.10%	...	0.00%	0.00%	0.00%	0.00%	0.03%	**2.89%**
22:00	0.67%	0.19%	0.20%	0.27%	0.29%	0.22%	0.13%	...	0.00%	0.00%	0.00%	0.00%	0.02%	**2.54%**
23:00	0.54%	0.16%	0.14%	0.19%	0.22%	0.20%	0.17%	...	0.00%	0.00%	0.00%	0.00%	0.01%	**2.14%**
00:00	0.73%	0.11%	0.11%	0.10%	0.11%	0.12%	0.10%	...	0.00%	0.00%	0.00%	0.00%	0.01%	**1.79%**
	39.00%	**10.04%**	**6.46%**	**4.68%**	**3.52%**	**2.76%**	**2.23%**	**...**	**0.01%**	**0.01%**	**0.01%**	**0.01%**	**0.78%**	**100.00%**

Source: Mellios (2012)

[2] Octo Telematics Italia S.r.l., www.octotelematics.it, accessed December 2012

Effect of ethanol on permeation emissions
Based on data provided by the Association of European Plastic Fuel Tanks and Systems Manufacturers, different permeation rates are used for fluorinated (0.6 g/day) and for multilayer (0.2 g/day) tanks containing non-ethanol fuels. For ethanol containing fuels (E5 – E10), 0.3 g/day additional emissions from the fuel and vapour control system were assumed. These include permeation, as well as other sources, such as small leakages.

Durability
In order to estimate the deterioration of canister performance with mileage, data from the in-service test programme conducted in Sweden were used (Johansson and Schmidt, 2009). Based on SHED tests from the Swedish programme, it was found that for ethanol containing fuels the degradation of the activated carbon is higher for small cars and lower for medium and large cars. More specifically, the efficiency of the activated carbon decreases by 1 per cent every 8,000 km for small cars (i.e. approximately 20 per cent decrease over vehicle lifetime), and by 1 per vent every 32,000 km for medium and large cars (i.e. approximately 5 per cent decrease over vehicle lifetime). For scenario 3 it is assumed that small cars are equipped with better carbon quality, having an improved efficiency similarly to medium and large cars.

Table 7 provides a summary of the differences in the various input parameters used in COPERT between the current and proposed test procedure for each scenario. The modified model was then adjusted to simulate the different scenarios, and to perform emissions calculations for all 27 EU Member States. Estimated Euro 6 petrol vehicle stock and activity data provided by the EC4MACS project[3] were used. Annual emissions for the period 2015-2040 for each scenario were calculated assuming no new sales of Euro 6 petrol cars from 2030 onwards as explained above.

The main observations from this analysis can be summarised as follows:

- The average evaporative emissions (in grams/vehicle per day) of a Euro 6 petrol vehicle in 2040 are projected to be more than double compared to 2015 levels for the base case. This is due to the degradation of the activated carbon, mainly from small vehicles which are assumed to have a higher degradation rate compared to medium and large cars.
- Significant emissions reductions can be achieved by the implementation of a revised test procedure. The introduction of durability requirements – resulting in better carbon quality – has the greatest reduction potential, followed by an extension of the diurnal test to 48 hours – resulting in bigger canisters and a more aggressive purging strategy.

[3] EC4MACS (www.ec4macs.eu) is a LIFE+ project which provides the modelling framework for integrated assessment of air emission policies in Europe. The project has developed detailed projections of activity, energy consumption and air emissions for all European Member States, based on the PRIMES 2010 baseline scenario. The data used in the present study originate from the road transport projections within EC4MACS.

Table 7: Differences in COPERT input data between the current and proposed test procedure in each scenario

Assumptions	Current	Modified
Scenario 1		
Purge rate (litres/km)	9.66 – small cars 16.68 – medium and large cars	16.77 – small cars 28.97 – medium and large cars
Canister size (litres)	0.8 – small cars 1.0 – medium cars 1.5 – large cars	0.8 – small cars 1.0 – medium cars 1.5 – large cars
Durability (*Percentage decrease over vehicle lifetime*)	20% – small cars 5% – medium and large cars	20% – small cars 5% – medium and large cars
Scenario 2		
Purge rate (litres/km)	9.66 – small cars 16.68 – medium and large cars	16.77 – small cars 28.97 – medium and large cars
Canister size (litres)	0.8 – small cars 1.0 – medium cars 1.5 – large cars	1.6 – small cars 2.0 – medium cars 3.0 – large cars
Durability (*Percentage decrease over vehicle lifetime*)	20% – small cars 5% – medium and large cars	20% – small cars 5% – medium and large cars
Scenario 3		
Purge rate (litres/km)	9.66 – small cars 16.68 – medium and large cars	16.77 – small cars 28.97 – medium and large cars
Canister size (litres)	0.8 – small cars 1.0 – medium cars 1.5 – large cars	1.6 – small cars 2.0 – medium cars 3.0 – large cars
Durability (*Percentage decrease over vehicle lifetime*)	20% – small cars 5% – medium and large cars	5% – small cars 5% – medium and large cars

The environmental benefits in terms of evaporative NMVOC emissions avoided for each scenario compared to the base case were calculated. The base case represents the situation in which no new legislative measures are introduced. Figure 4 presents the total emissions in tonnes of VOC and Figure 5 the average emission factors in g/vehicle per day.

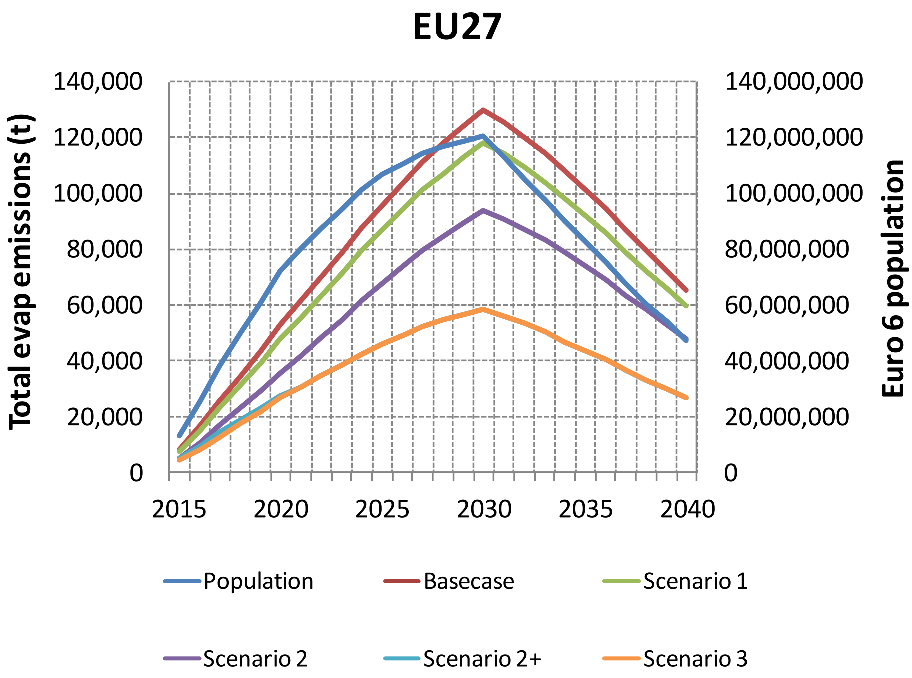


Figure 4: Total evaporative emissions and Euro 6 population for the EU27 from 2015-2040*

* Scenario 2+ can only been see up until 2020 then it follow the same line as scenario 3.

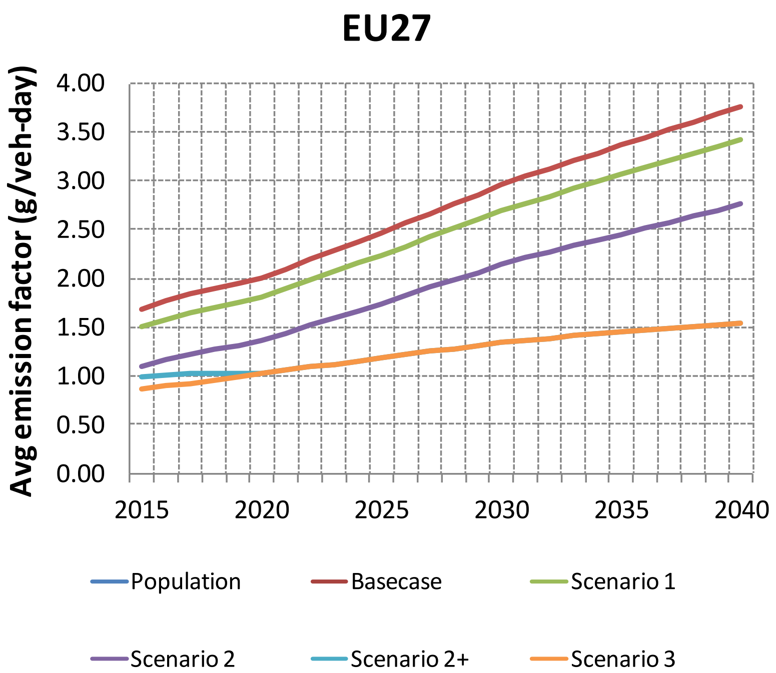


Figure 5: Average daily evaporative emissions for the EU27 from 2015-2040

NMVOCs have an impact on health and environment which is a cost to society. In order to determine the benefits of NMVOC emission reductions and damage avoided, low and high damage costs (DC) from the CAFE Programme (AEA Technology, 2005) were used to calculate the economic value of the damage avoided. These marginal damage costs are limited to the assessment of exposure of people and crops to ozone and therefore underestimate the real damage VOC costs as the impact on ecosystems and cultural heritage are excluded from the analysis. Also, direct impact of VOCs on human health was not considered in the analysis (see Table 8).

The different estimated values of the marginal damage per a given country are due to the metric used and the assumptions made. The differences between the countries are mainly due to the population density and to the climate. The EU wide average value given in Table 8 has been calculated using an approach that is not described in the reference document. A new weighted EU wide average value has been calculated for the purpose of this CBA taking into account the evaporative emissions resulting from the passenger car fleet of each country estimated by using COPERT.

A damage cost weighting (DCW) was calculated for each EU Member State for the years 2015 and 2040. Per country emissions for each scenario were taken from the COPERT model for the same period. To calculate a weight for each Member State the country emissions were divided by the total EU27 emissions. An average weight was obtained for each country across all four scenarios these were used to calculate damage costs for each country.

ESTIMATING THE DAMAGE COST FOR AN AVERAGE EU27 COUNTRY

(1) $DCW = MS_e / EU27_e$

(2) $DC = DCW * MSDC$

(3) $DCW\ EU27 = DC_1 + DC_2 \ldots + DC_{27}$

Where:

DC	= Direct cost
DCW	= Damage cost weight
DCW EU27	= Weighted marginal damage cost for EU27
MS_e	= Member State emissions
$EU27_e$	= Total EU27 emissions
WMDC	= Weighted damage cost
MSDC	= Member State damage cost

The average low and high DC per tonne of NMVOC emissions for the EU27 was then calculated and used in the benefit analysis. The low DC for the EU27 was €1,098 while the high DC was €3,303.

Damage cost/ton of NMVOC	Low	High
EU wide average weighted over the evaporative emissions	€ 1098	€ 3303

These nominal current values (excluding inflation) were used to calculate annual benefits (AB) for society. The value of AB in terms of damage avoided for each scenario were calculated by multiplying the tonne NMVOC avoided (difference between scenario emissions and base case) by the high and low MDC figures.

ESTIMATING ANNUAL BENEFITS

AB = (Base case emissions – Scenario emissions) * MDC

Estimating Fuel Saved

Fuel savings occurs due to vapours trapped by the carbon canister and fewer vapours being lost from the tank. The fuel savings associated with the implementation of the new test procedure can be estimated from the amount of NMVOC avoided. In order to calculate fuel savings it is assumed all fuel saved is in the form of butane (USEPA, 1993). One kilogram of butane is equivalent to 1.06 kg gasoline. Total fuel savings are estimated over 15 years which are considered the useful life of the vehicle for EU Member States. It is assumed that 1 litre of gasoline costs €1.5.

$$\text{Yearly value of fuel saved (€)} = \left[\text{Yearly average emission reduction (kg)} \times \frac{1.06\ \text{(kg)}\ \textit{1 kg of butane = 1.06kg gasoline}}{0.74\ \text{Density of gasoline (kg/l)}} \right] \times \text{Cost of fuel (€/litre)}$$

6 CALCULATING THE NET PRESENT VALUE

In order to obtain the Net Present Benefit (NPB), the total AC are subtracted from the total AB. Benefits and costs stretch over time. Since individuals prefer the present to the future, then future benefits are taken into account using a discount rate to provide a Net Present Value (NPV) i.e. the discounted costs minus the discounted benefits. The cost-benefit rule is that the sum of the present value of benefits must exceed the sum of the present value of costs (Pearce, 1998).

NET PRESENT BENEFIT

NPB = (AB – AC)

Discount rate allows the value of future costs and benefits in today's terms to be measured. A high discount rate indicates a preference for consumption now rather than in the future. The choice of an appropriate social discount rate is key to assessing the extent of sacrifices the whole of society should be taking now to prevent or slow down environmental damage affecting future generations. Low social discount rates make the future more important, high social discount rates make it less so. A range of social discount rates were used as part of a sensitivity analysis. These included 10%, 6%, 3% and 0%.

NET PRESENT VALUE

$$\mathbf{NPV = NB_0 + NB_1/(1+\mathit{r})^1 + NB_2/(1+\mathit{r})^1 + NB_3/(1+\mathit{r})^1 + \ldots + NB_\mathit{n}/(1+\mathit{r})^\mathit{n}}$$

<u>Where:</u>
NB = Benefits = Saved Costs in a time period
r = Discount rate
n = # of years to discount
NB_0 = base year

In addition to the NPV, a benefit-to-cost ratio (BCR) for each scenario was calculated. This is another indicator that can be used in CBA. If the BCR is greater than 1 then the benefits outweigh the costs. The higher the number the more benefits for society.

BENEFIT-COST RATIO

BCR = Total Net Benefits/Total Net Costs

7 PER VEHICLE COSTS AND BENEFITS

An alternative approach to the estimating the costs and benefits of the proposed test procedure for the total EU Euro 6 petrol vehicle fleet is to undertake calculations on a per vehicle basis. These costs and benefits were calculated over the useful life of the vehicle (10 and 15 years). The COPERT Model was used to calculate average daily NMVOC emissions per vehicle (g/day) for each scenario (2015-2040). The average grams (g) per day reduction were calculated by subtracting the estimated scenario g/day emissions from the baseline scenario (no action). The average daily reduction was then multiplied by 365 to obtain the average reduction per vehicle per year and converted to kilograms. The average emission reduction per year was converted to tonnes then multiplied by high and low external marginal damage to obtain the cost per tonne of VOC avoided per vehicle (AEA Technology, 2005).

The NPV was calculated over 10 and 15 years useful life for both the damages avoided per vehicle and the fuel saved using a discount rate of 6 per cent. The NPV of damages avoided and the fuel saved were added together to obtain the total benefits per vehicle using low and high MDCs. A sensitivity analysis was undertaken using different discount rates of 0%, 3% and 6%.

(a)

Net vehicle emission reduction (g/day) = **Baseline vehicle emission (g/day)** - **Estimated scenario vehicle emission (g/day)**

(b)

Yearly average emission reduction in kilograms (kg) = **Net vehicle emission reduction (g/day)** X **365 days** / **1000**

(c)

Yearly damage avoided per vehicle (€) = **Yearly average emission reduction (tonne)** X **Marginal Damage Cost (€/tonne)**

Table 8: EU VOC damage cost (€) per tonne emission for 2010, with three sets of sensitivity analysis

PM Mortality	**VOLY - Median**	**VSL - Medium**	**VOLY - Mean**	**VSL - Mean**
O3 Mortality	VOLY - Median	VOLY - Medium	VOLY - Mean	VOLY - Mean
Health core?	Yes	Yes	Yes	Yes
Health sensitivity?	No	No	Yes	Yes
Crops	No	Yes	Yes	Yes
O3/health metric	SOMO 35	SOMO 35	SOMO 0	SOMO 0
EU wide	€ 950	€ 1,400	€ 2,100	€ 2,800
Member State				
Austria	€1,700	€ 2,600	€3,800	€5,200
Belgium	€2,500	€ 3,500	€5,300	€7,100
Bulgaria	€ 950	€ 1,400	€ 2,100	€ 2,800
Cyprus	€ 950	€ 1,400	€ 2,100	€ 2,800
Czech Republic	€1,000	€ 1,400	€2,300	€3,000
Denmark	€720	€ 970	€1,600	€2,000
Estonia	€140	€ 190	€340	€420
Finland	€160	€ 220	€390	€490
France	€1,400	€ 2,000	€3,100	€4,200
Germany	€1,700	€ 2,500	€3,900	€5,100
Greece	€280	€ 400	€670	€880
Hungary	€860	€ 1,300	€2,000	€2,700
Ireland	€680	€ 950	€1,600	€2,000
Italy	€1,100	€ 1,600	€2,600	€3,500
Latvia	€220	€ 300	€520	€650
Lithuania	€230	€ 330	€550	€710
Luxembourg	€2,700	€ 4,000	€5,900	€8,000
Malta	€430	€ 580	€1,000	€1,300
Netherlands	€1,900	€ 2,700	€4,100	€5,400
Poland	€630	€ 900	€1,400	€1,900
Portugal	€500	€ 700	€1,200	€1,600
Romania	€ 950	€ 1,400	€ 2,100	€ 2,800
Slovakia	€660	€ 960	€1,500	€2,000
Slovenia	€1,400	€ 2,000	€3,200	€4,400
Spain	€380	€ 510	€920	€1,100
Sweden	€330	€ 440	€780	€980
United Kingdom	€1,100	€ 1,600	€2,500	€3,200

VOLY: value of life years,
SOMO35: Sum of means over 35 days parts per billion (ppbV)
SOMO: Sum of means over 0 day parts per billion (ppbV)

Source: AEA Technology (2005)

8 RESULTS

This section presents the results of the CBA for the total Euro 6 petrol vehicle fleet (Approach 1) and per vehicle (Approach 2)

APPROACH 1: NET PRESENT VALUE OF EMISSION REDUCTION AND FUEL SAVED FOR EURO 6 PETROL VEHICLE FLEET

Scenario 1

Under scenario 1 a more aggressive purging strategy is expected to be implemented. Table 9 presents the average NPV for scenario 1 with minimum and maximum figures using a 6% discount rate. A sensitivity analysis is undertaken using a range of discount rates (0%, 3%, and 10%). At a 6% discount rate the NPV is positive. Table 10 presents a positive NPV of fuel saved under scenario 1. When the fuel saved is included in the analysis, the average total benefits is positive at €209,701,648 (see Table 11).

Table 9: Summary of net benefit for scenario 1

Scenario I	Discount Rate	Sensitivity Analysis		
	6%	10%	3%	0%
Average NPV	€ 14,660,997	-€ 21,746,017	€ 68,375,437	€ 166,653,946
Min	-€ 157,066,237	-€ 147,137,514	-€ 159,367,222	-€ 149,708,592
Max	€ 181,421,305	€ 99,200,294	€ 290,647,865	€ 476,905,304

Table 10: PV of fuel saved for scenario1

Scenario 1	6%	10%	3%	0%
Average PV	€ 195,040,651	€ 127,841,497	€ 280,360,358	€ 420,892,142

Table 11: NPV of total benefits for scenario 1 including fuel saved

Scenario 1	6%	10%	3%	0%
Average NPV	€ 209,701,648	€ 106,095,480	€ 348,735,795	€ 587,546,088
Min	€ 37,974,414	-€ 19,296,017	€ 120,993,136	€ 271,183,549
Max	€ 376,461,956	€ 227,041,791	€ 571,008,224	€ 897,797,446

Table 12 shows that the average BCR at 6% is above 1 indicating the benefits outweighs the costs. This figure is even higher at 2.40 when the benefits of fuel saved are included.

Table 12: Summary of benefit-cost-ratio for scenario 1

Scenario 1	Benefit-Cost Ratio	Sensitivity Analysis	
	6%	10%	3%
Average	1.22	0.97	1.48
Min	0.39	0.31	0.47
Max	2.53	2.02	3.07
Including Fuel Saved			
Average	2.40	1.91	2.92
Min	1.15	0.91	1.40
Max	4.18	3.33	5.07

Scenario 2

Under scenario 2 a more aggressive purging strategy is expected to be implemented and the diurnal test is extended to 48 hours. Table 13 shows that at a 6% discount rate the average NPV is negative. This is the same at discount rates of 10%, 3% and 0%. Table 16 shows that the BCR is less than 1 for the average NPV at all discounts rates. However, when fuel saved is included in the benefits the BCR is above 1.

Table 13: Summary of net benefit for scenario 2

Scenario 2	Discount Rate	Sensitivity Analysis		
	6%	10%	3%	0%
Average NPV	-€ 361,242,407	-€ 400,965,703	-€ 272,240,408	-€ 75,284,931
Min	-€ 971,366,334	-€ 856,106,949	-€ 1,066,869,250	-€ 1,157,894,624
Max	€ 229,013,819	€ 36,394,798	€ 500,507,510	€ 982,880,037

Table 14: PV of fuel Saved for scenario 2

Scenario 2	6%	10%	3%	0%
Average PV	€ 611,179,816	€ 403,577,411	€ 873,415,674	€ 1,303,463,704

Table 15: NPV of total benefits under scenario 2 including fuel saved

Scenario 2	6%	10%	3%	0%
Average NPV	**€ 249,937,409**	**€ 2,611,707**	**€ 601,175,266**	**€ 1,228,178,773**
Min	-€ 360,186,518)	-€ 452,529,539	-€ 193,453,577	€ 145,569,080
Max	€ 840,193,635	€ 439,972,209	€ 1,373,923,183	€ 2,286,343,741

Table 16: Summary of benefit-cost ratio for scenario 2

Scenario 2	Benefit-Cost Ratio	Sensitivity Analysis	
	6%	10%	3%
Average	0.68	0.54	0.82
Min	0.24	0.19	0.29
Max	1.32	1.06	1.59
Including Fuel Saved			
Average	1.34	1.07	1.62
Min	0.72	0.57	0.87
Max	2.18	1.75	2.63

Scenario 2+

Under scenario 2+ a more aggressive purging strategy is implemented, the diurnal test is extended to 48 hours and canister durability requirements are introduced. At a 6%, 3% and 0% discount rate the average NPV is positive for (see Table 17) and is much higher when fuel saved is included (see (Table 19). The BCR is above 1 for the average NPV at both 6% and 10% discount rates and is much higher when total fuel saved is included in the total benefits (see Table 20).

Table 17: Summary of net benefit for scenario 2+

Scenario 2+	Discount Rate	Sensitivity Analysis		
	6%	10%	3%	0%
Average NPV	€ 146,709,441	-€ 89,133,323	€ 492,692,426	€ 1,123,801,185
Min	-€ 717,918,315	-€ 700,514,840	-€ 685,197,813	-€ 559,597,752
Max	€ 991,469,495	€ 504,467,450	€ 1,648,701,739	€ 2,782,755,399

Table 18: PV of fuel saved for scenario 2+

Scenario 2+	6%	10%	3%	0%
Average PV	€ 1,107,113,078	€ 708,031,564	€ 1,620,249,526	€ 2,474,178,392

Table 19: NPV of total net benefits for scenario 2+ including fuel saved

Scenario 2+	6%	10%	3%	0%
Average NPV	**€ 1,253,822,519**	**€ 618,898,241**	**€ 2,112,941,951**	**€ 3,597,979,577**
Min	€ 389,194,763	€ 7,516,723	€ 935,051,712	€ 1,914,580,640
Max	€ 2,098,582,572	€ 1,212,499,013	€ 3,268,951,265	€ 5,256,933,790

Table 20: Summary of benefit-cost ratio

Scenario 2+	Benefit-Cost Ratio	Sensitivity Analysis	
	6%	10%	3%
Average	1.23	0.95	1.52
Min	0.44	0.34	0.55
Max	2.40	1.86	2.96
Including Fuel Saved			
Average	2.43	1.88	3.00
Min	1.30	1.01	1.62
Max	3.95	3.08	4.88

Scenario 3

Under scenario 3 a more aggressive purging strategy is expected to be implemented, the diurnal test is extended to 48 hours and tank and canister durability requirements are introduced. The average NPV is negative at 6% and 10% discount rates but is positive at lower discount rates (3% and 0%) (see Table 21). The BCR is below 1 for the average NPV at a 6% discount rate and is above 1 when fuel saved is included in the total benefits (see Table 24).

Scenario 3 is also sensitive to the implementation date of the requirement for all new vehicles to be equipped with multilayer fuel tanks. It is clear that the sooner this requirement is implemented, the higher the benefit for society due to the reduction of NMVOC emissions. If the requirement on permeation is implemented later (e.g. in 2021), there will be lower benefits for society. However, late implementation will mean reduced or no additional cost for vehicle manufacturers associated with the introduction of the proposed test procedure, as far as fuel tanks are concerned. This is because monolayer tanks will be naturally phased-out.

Table 21: Summary of the net benefit for scenario 3

Scenario 3	Discount Rate	Sensitivity Analysis		
	6%	10%	3%	0%
Average NPV	-€ 274,724,414	-€ 488,799,890	€ 52,797,092	€ 663,288,776
Min	-€ 1,215,024,337	-€ 1,171,824,833	-€ 1,204,181,548	-€ 1,103,012,722
Max	€ 640,567,974	€ 171,561,478	€ 1,282,538,011	€ 2,399,547,518

Table 22: PV of fuel saved for scenario 3

Scenario 3	6%	10%	3%	0%
Average PV	€ 1,117,868,595	€ 717,949,404	€ 1,631,724,396	€ 2,486,465,507

Table 23: Summary of total net benefits for scenario 3 including fuel saved

Scenario 3	6%	10%	3%	0%
Average NPV	**€ 843,144,182**	**€ 229,149,513**	**€ 1,684,521,488**	**€ 3,149,754,283**
Min	-€ 97,155,742	-€ 453,875,429	€ 427,542,848	€ 1,383,452,785
Max	€ 1,758,436,570	€ 889,510,882	€ 2,914,262,407	€ 4,886,013,025

Table 24: Summary of benefit -cost ratio for scenario3

	Benefit-Cost Ratio	Sensitivity Analysis	
	6%	10%	3%
Average	0.84	0.63	1.08
Min	0.32	0.24	0.41
Max	1.59	1.18	2.05
Including Fuel Saved			
Average	1.67	1.24	2.14
Min	0.95	0.71	1.21
Max	2.63	1.95	3.38

Figure 6 provides a summary of the average NPV due to emission reduction at a 6% discount with maximum and minimum range outlined. This clearly shows that scenario 2+ has the most positive NPV compared to the other scenarios. When fuel saved is considered the total benefits the NPV is even higher (see Figure 7).

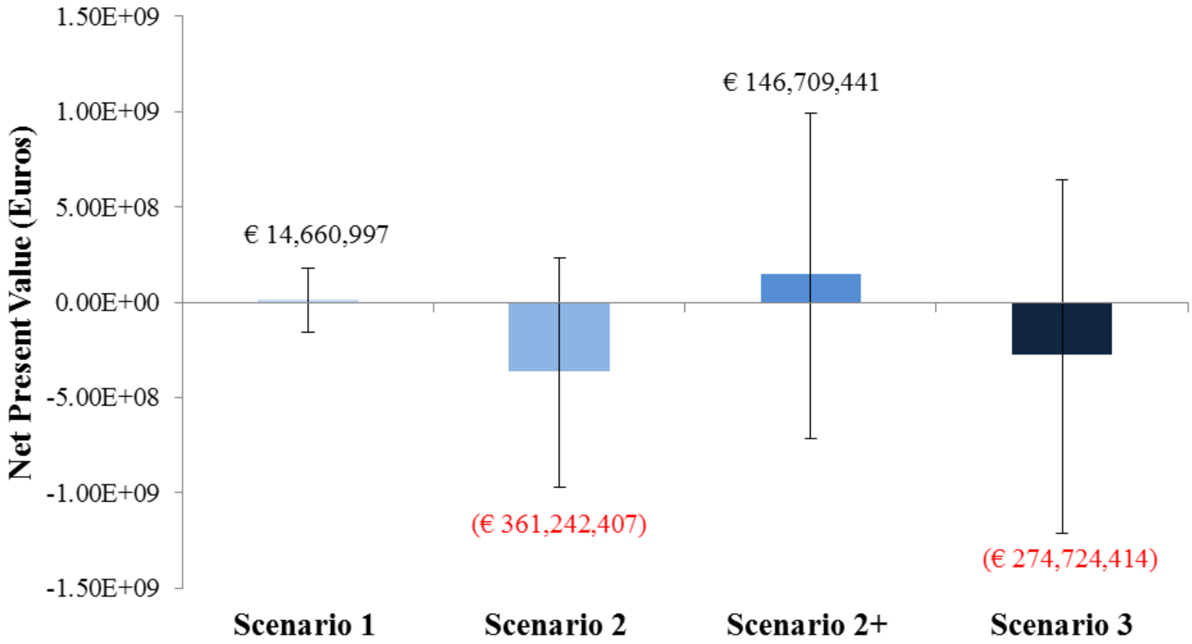


Figure 6: Average NPV Emission Reduction at 6% Discount Rate

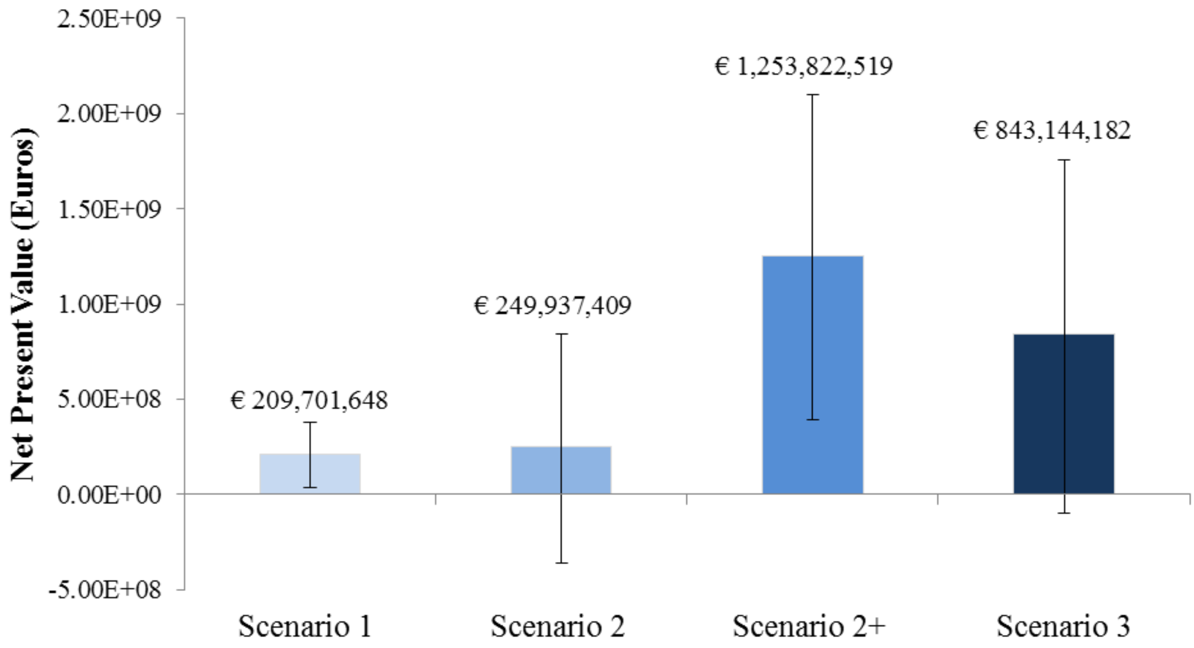


Figure 7: Average NPV Emission Reduction plus Fuel Savings at 6% Discount Rate

APPROACH 2: PER VEHICLE COSTS AND BENEFITS

Table 25 provides a summary of the costs and benefits per vehicle for each scenario over a 10 year useful life of the vehicle considering the intermediate discount rate at 6%. It also provides a summary of the average costs and benefits per vehicle for each scenario over a 15 year useful life of the vehicle.

Table 25: PV of benefits per vehicle at 6% discount rate (implementation date: 2015)

Useful life: *10 years*	Benefits/vehicle due to emission reduction only (euro)		Benefits/vehicle including value of fuel saved (euro)		Extra costs per vehicle 2015 (euro)	
	Low *damage/ton of VOC*	High *damage/ton of VOC*	Low *damage/ton of VOC*	High *damage/ton of VOC*	Low Cost Estimate	High Cost Estimate
Scenario 1	0.7	2.0	2.0	3.3	1.05	2.4
Scenario 2	2.2	6.5	6.4	10.8	6.3	12
Scenario 2+	3.2	9.6	9.4	15.9	6.3	12
Scenario 3	3.4	10.1	10.0	16.7	15.5	24.6
Useful life:15 years						
Scenario 1	0.9	2.7	2.7	4.5	1.05	2.4
Scenario 2	2.9	8.7	8.6	14.4	6.3	12
Scenario 2+	4.6	13.8	13.6	22.8	6.3	12
Scenario 3	4.8	14.3	14.1	23.7	15.5	24.6

Figure 8 and Figure 9 provide the average costs and benefits (at 6% discount rate) for each scenario considering a useful life of the vehicle respectively of 10 and 15 years. In Figure 8 and Figure 9 scenario 3 has an average additional cost of €20 per vehicle compared to €9 in scenarios 2 and 2+ (see also Table 25). This difference is due to the fact that in scenario 3 the additional cost for an early introduction of multi-layer tanks on all vehicles is taken into account. In the case of a useful life of 10 years, the average emission reduction benefit per vehicle in both scenario 2+ and 3 are similar at approximately €6-7. When the benefits of fuel saved are added to the emission reduction benefit, scenario 3 has a slightly higher average benefit per vehicle of approximately €13.3 compared to €12.7 in scenario 2+.

In Figure 9 (15 years useful life) the average per vehicle emission reduction benefit in scenario 2+ is €9.2 compared to €9.5 in scenario 3. When the benefits of fuel saved is added to the emission reduction, scenario 3 has a slightly higher average benefit per vehicle of approximately €19 compared to €18 in scenario 2+.

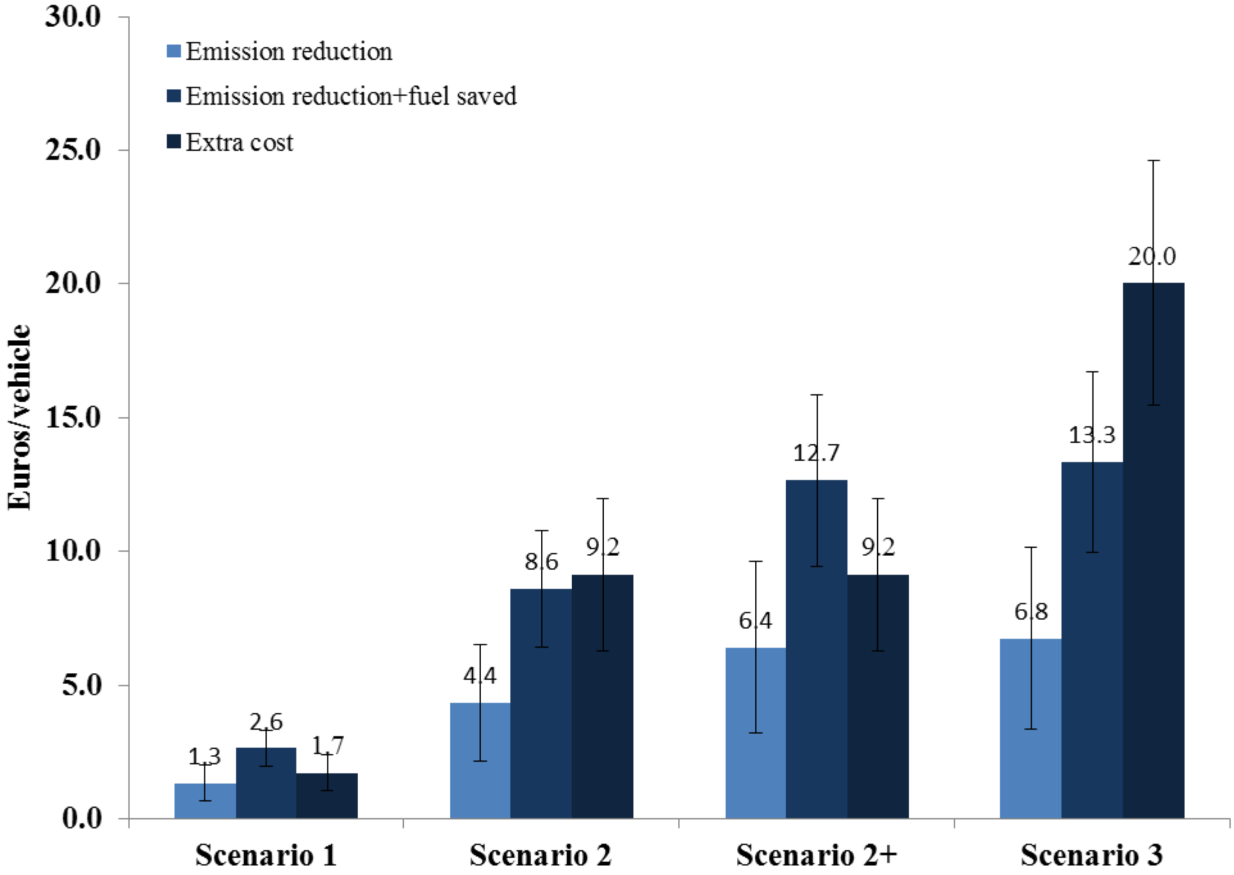


Figure 8: Average benefits and costs per vehicle at 6% discount rate assuming a 10 years useful life of the vehicle

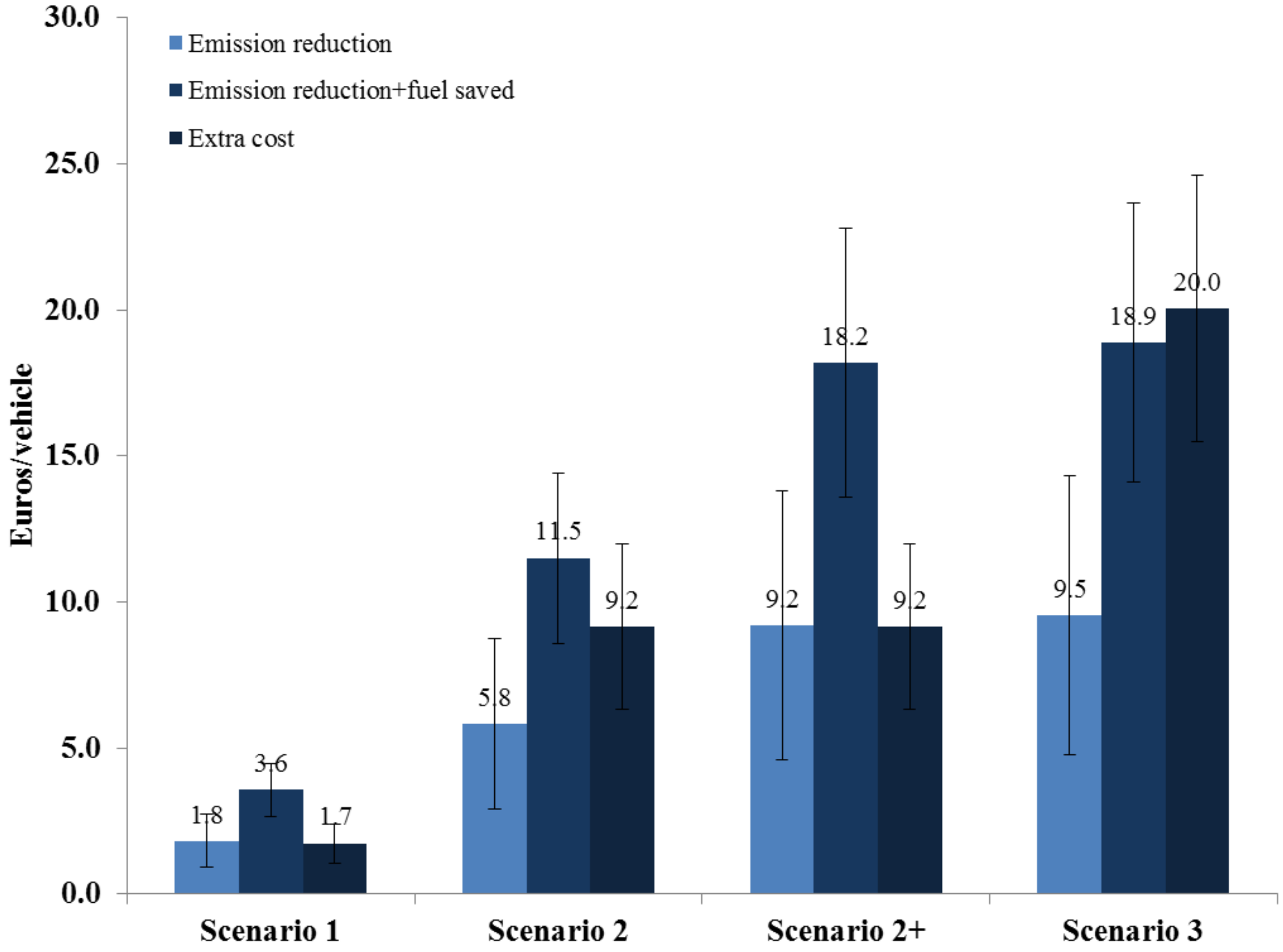


Figure 9: Average benefits and costs per vehicle at 6% discount rate assuming a 15 years useful life of the vehicle

A sensitivity analysis of average benefits and cost per vehicle at a 3% discount rate over a 10 and 15 year useful vehicle life was conducted for comparison. Figure 10 provides a summary of average per vehicle benefits and costs at 3% discount rate assuming a 10 years useful life of the vehicle. Scenario 3 has the highest average additional cost per vehicle of €20 compared to €9 for scenario 2+. The emission reduction benefit per vehicle under scenarios 3 and 2+ is approximately €7-8. For total benefits including emission reduction and fuel saved both scenarios have again similar average benefits of approximately €15.

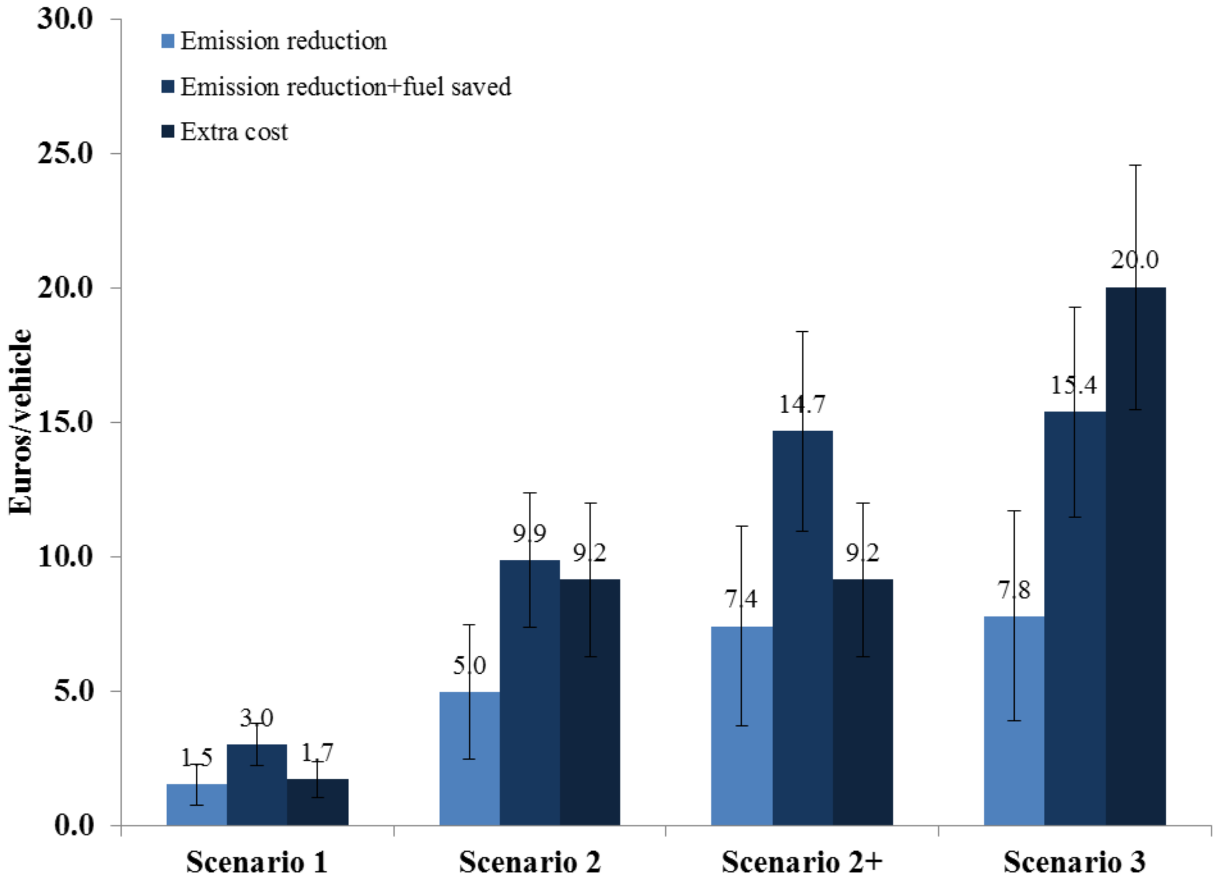


Figure 10: Average benefits and costs per vehicle at 3% discount rate assuming a 10 years useful life of the vehicle

Figure 11 presents the sensitivity analysis at 3% over a 15 year period. Again scenario 3 achieves the highest average additional vehicle cost at €20 compared to €9 for scenarios 2 and 2+. The average emission reduction benefit is similar for both scenarios 2+ and 3 at €11-12. The combined benefits including emission reductions and fuel saved are very close at about €23.

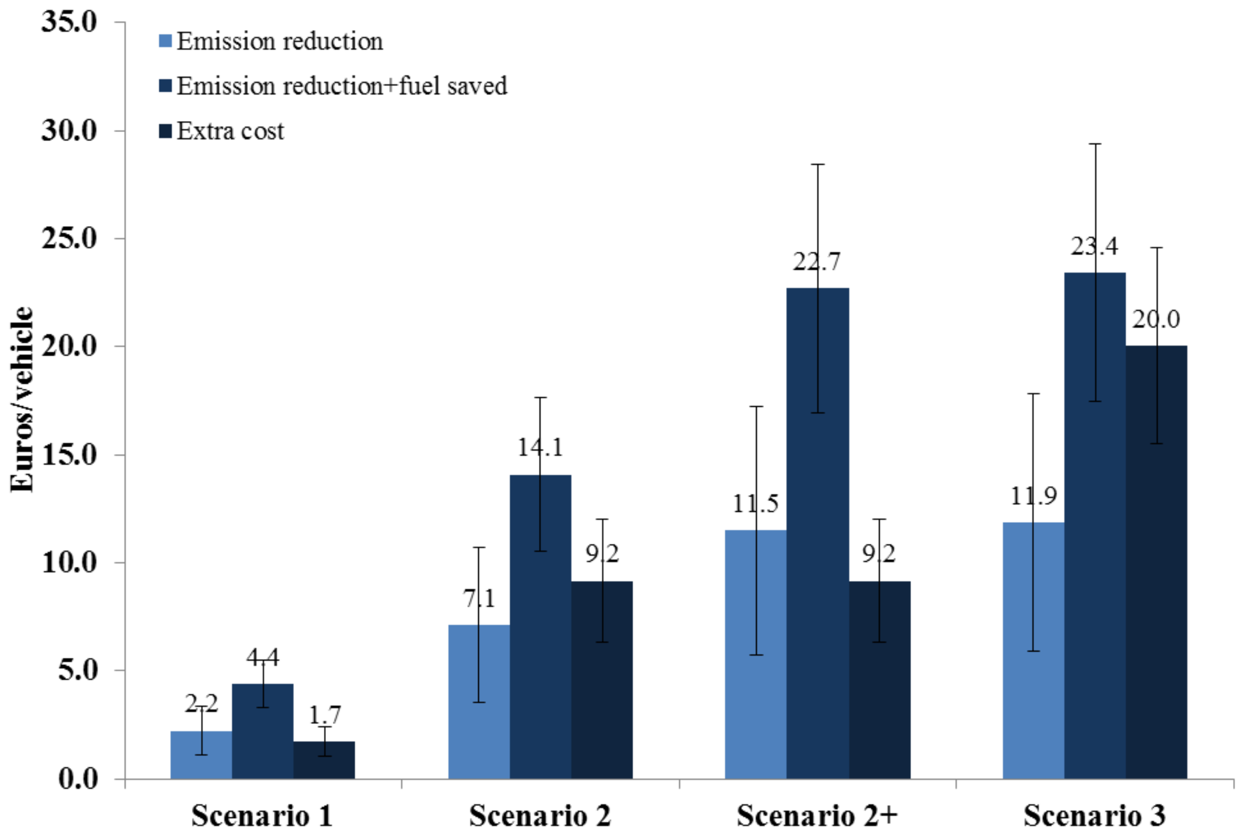


Figure 11: Average benefits and costs per vehicle at 3% discount rate assuming a 15 years useful life of the vehicle

Benefits and profits per vehicle have been also estimated in the case of a later implementation of the proposed measures (year 2017). The largest impact is on the estimated cost for scenario 3 since the number of vehicle to be fitted with a multilayer tank will decrease as a result of the natural phasing-out of monolayers tanks.

The estimated benefits and cost in case of a later implementation in 2017 are given in the Table 26.

Table 26: PV of benefits per vehicle at 6% discount rate (implementing date: 2017)

Useful life: *10 years*	Benefits/vehicle due to emission reduction only (euro)		Benefits/vehicle including value of fuel saved (euro)		Extra costs per vehicle 2017 (euro)	
	Low *damage/ton of VOC*	High *damage/ton of VOC*	Low *damage/ton of VOC*	High *damage/ton of VOC*	Low Cost Estimate	High Cost Estimate
Scenario 1	0.7	2.0	2.0	3.3	1.05	2.4
Scenario 2	2.2	6.5	6.4	10.8	6.3	12
Scenario 2+	3.2	9.6	9.4	15.9	6.3	12
Scenario 3	3.4	10.1	10.0	16.7	13.1	21.4
Useful life:15 years						
Scenario 1	0.9	2.7	2.7	4.5	1.05	2.4
Scenario 2	2.9	8.7	8.6	14.4	6.3	12
Scenario 2+	4.6	13.8	13.6	22.8	6.3	12
Scenario 3	4.8	14.3	14.1	23.7	13.1	21.4

9 VEHICLE MANUFACTURER'S PROFIT AND UNCERTAINTY

The ICMs used here do not include vehicle manufacturer's profit (Rogozhin *et al*., 2010). The National Research Centre (2011) has criticised the absence of manufacturer profit due to the automotive industry participating in a near monopolistic competitive market. This is a market where there is product differentiation but a high degree of competition among firms. In such a market, in the long-run costs are passed on to consumers. Since cost estimates assume long-run conditions, long-run supply assumptions should be used to ensure consistency. The ratio of profit to indirect cost is estimated to be 0.06 (Rogozhin *et al*., 2010). Table 27 presents the resulting ICMs.

Table 27: Amended ICMs including Manufacturer's profit

Manufacturer's profit	Short Run (first 5 years)	Medium Run (after 5 years)
ICM (Low complexity technology)	1.11	1.08
ICM (Medium complexity technology)	1.26	1.11

USEPA (2010) highlights the degree of uncertainty in ICM associated with individual technologies. They suggest ICM values range from 13 per cent lower to 13 per cent higher than the primary values. Taking into consideration this level of uncertainty the ICM values were further amended (see Table 28).

Table 28: Amended ICM including Manufacturer's profit and uncertainty

Manufacturer's profit and Uncertainty	Short Run (first 5 years)	Medium Run (after 5 years)
ICM (Low complexity technology)	1.10	1.07
ICM (Medium complexity technology)	1.29	1.12

Figure 12 presents NPV for each scenario using the amended ICM and taking into consideration uncertainty. The NPV for scenario 2+ is reduced compared to Figure 6. When fuel saved is added scenario 2+ has a positive NPV (see Figure 13).

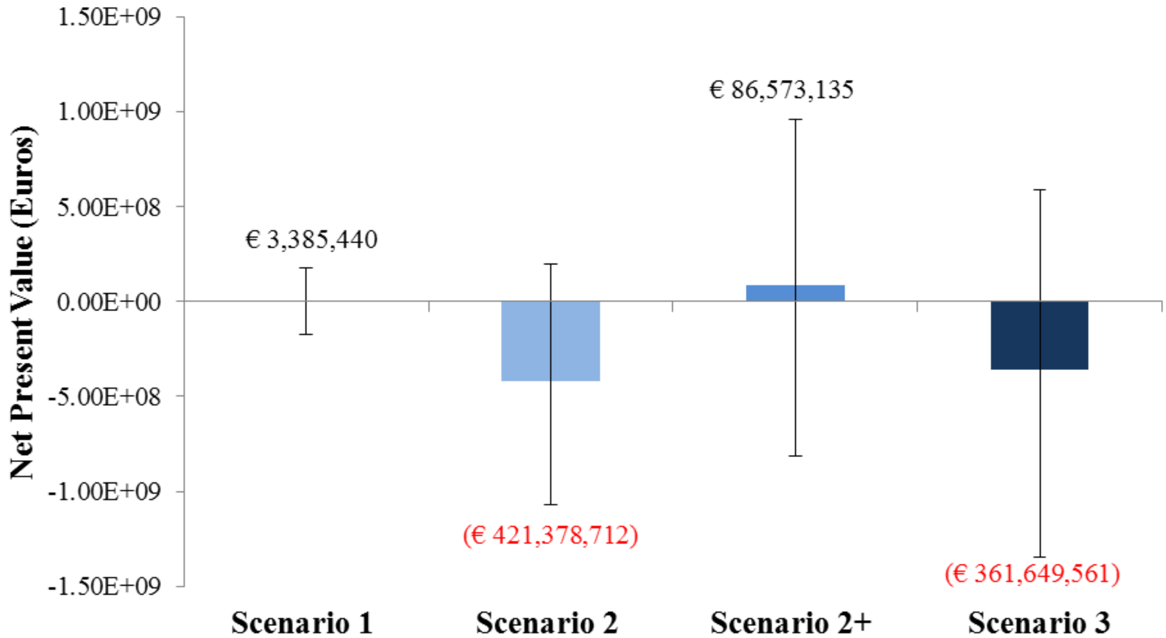


Figure 12: Average NPV Emission Reduction at 6% Discount Rate using Amended ICM

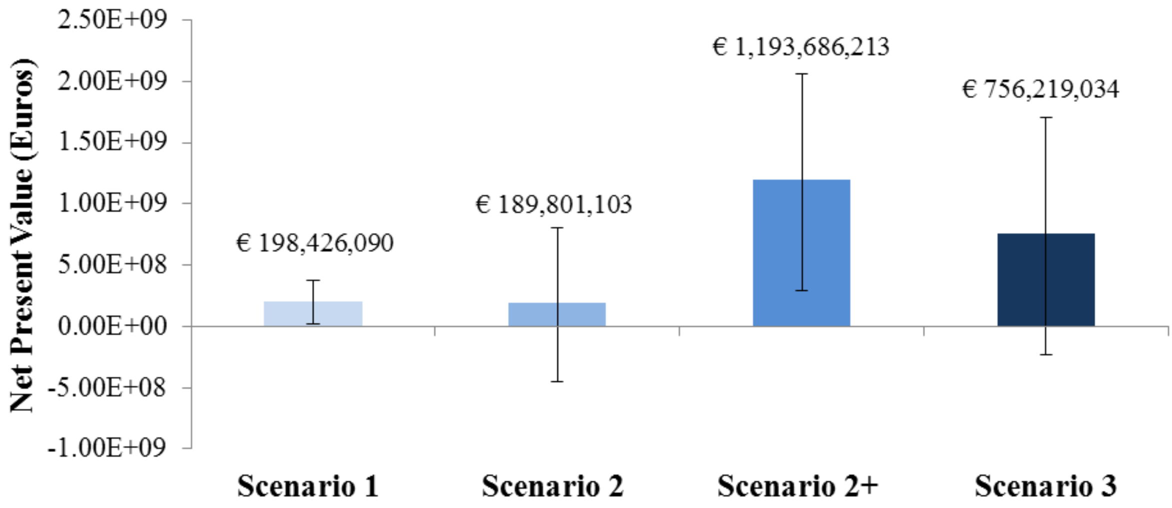


Figure 13: Average NPV Emission Reduction plus Fuel Saved at 6% Discount Rate using Amended ICM

It can therefore be concluded that even in more conservative estimates, the CBA does not lead to significantly different conclusions compared to those presented in Chapter 8. Scenario 2+ remains the most cost-effective policy option for the implementation of the proposed new test procedure for evaporative emissions.

10 CONCLUSION AND RECOMMENDATION

The analysis has attempted to determine the costs and benefits of adopting a modified test procedure for evaporative emissions under four scenarios. A CBA allows an estimate of the cost-effectiveness of evaporative emissions reduction achieved by the adoption of a new test procedure.

Scenario 2+ which involves the implementation of a more aggressive purging strategy over 48 hours and greater canister durability has a positive average NPV of €146,709,441 (see Table 17) and BCR of 1.2 at a 6% discount (see Table 20). A sensitivity analysis shows that average NPV for scenario 2+ is higher at discount rates of 3%. This is clearly due to the fact that benefits increase over time while costs remains more or less constant or decreases over time. A lower discount rate gives a higher value to future benefits.

When fuel saved is included in total benefits the NPV is €1,253,822,519 (Table 19) and has a BCR of 2.43. In fact all scenarios have a positive NPV when the value of fuel saved is added. This shows that the value of the fuel saved is similar to the monetary benefits linked to emission reduction. However, it has to be taken into account that the marginal damage costs for VOC emissions used in this study are likely to underestimate the actual damage and therefore the benefits associated with the reduction of NMVOC emissions.

This does not change significantly if a more conservative approach is taken to include manufacturer's profit and uncertainty. Scenario 2+ still has a positive NPV of €86,573,135. When fuel saved is included this is higher at €1,193,686,213 (see Table 29).

Table 29: Summary of NPV for each scenario at 6% discount rate taking into consideration different components

Scenarios	1	2	2+	3
NPV @ 6%	€ 14,660,997	-€ 361,242,407	**€ 146,709,411**	-€ 274,724,414
NPV @ 6% including fuel saved	€ 209,701,648	**€ 249,937,409**	**€ 1,253,822,519**	**€ 843,144,182**
Manufacturer Profit & Uncertainty				
NPV @ 6%	€ 3,385,440	-€ 421,378,712	€ 86,573,135	-€ 361,649,561
NPV @ 6% including fuel saved	€ 198,426,090	€ 189,801,103	€ 1,193,686,213	€ 756,219,034

A deeper analysis of the emission reduction achieved by the different proposed measures, clearly shows that the use of activated carbon with a lower degradation rates together with the installation of a larger canister deliver the highest benefits in the long-term. The impact of these measures on the cost of the vehicles is limited and explains the positive NPV, especially when the value of the fuel saved is also considered.

Scenario 3 delivers the highest benefits in terms of emissions avoided but the additional cost per vehicle of a fuel system with a low permeation rate (e.g. a multi-layer tank) is much higher compared to the extra costs associated with a larger canister and better activated carbon quality. This is seen more clearly when examined on a per vehicle basis. Scenario 2+ has an average additional cost of €9 compared to €20 in scenario 3 (see Table 30). There is instead less than one Euro/vehicle difference between scenario 2+ and scenario 3 in terms of average emission reduction benefits both considering 10 and 15 years useful life. The same applies for total benefits, including emission reduction and fuel saved.

A key question is whether the envisaged phasing-out rate of monolayer tanks, according to the forecast of relevant OEM suppliers, is realistic. Clearly, if a significant fraction of vehicles is still equipped with monolayer tanks after 2020, the total benefits associated with scenario 3 will be higher and the result of the analysis will change noticeably. In order to minimise the impact on vehicle's cost these measures could be introduced in 2020. This leads to another question: Will monolayer tanks no longer be in mass production after 2020 in the absence of measures forcing the car makers to adopt less permeable materials for the fuel system?

Table 30: Summary of average per vehicle costs and benefits

Useful life : 10 years	Average benefit (only emissions) €	Average benefit (including fuel)\ €	Average extra cost/vehicle €
Scenario 1	1.3	2.6	1.7
Scenario 2	4.4	8.6	9.2
Scenario 2+	6.4	12.7	9.2
Scenario 3	6.8	13.3	20.0
Useful life : 15 years			
Scenario 1	1.8	3.6	1.7
Scenario 2	5.8	11.5	9.2
Scenario 2+	9.2	18.2	9.2
Scenario 3	9.5	18.9	20.0

The CBA undertaken here has demonstrated a net benefit in implementing a modified test procedure for NMVOCs under all the scenarios when the value of fuel saved is taken into consideration. Both scenario 1 and scenario 2+ have a positive NPV if the fuel saved is not included in the analysis.

The average net benefit of implementing scenario 2+ is €146,709,441 at a 6% discount rate is considerably higher than €14,660,997 under scenario 1. Scenarios 2 and 3 and results in an average net cost. Scenario 2+ is most cost-effective. This involves the implementation of a more aggressive purging strategy over 48 hours and greater canister durability.

The additional costs in scenario 1 are lower (€1-2) but so are the total net benefits (€3-4). In contrast, the additional costs are much higher in scenario 3 (€20) although the total net benefits are slightly higher €13-19.

The analysis also found that on a per vehicle basis under scenario 2+ the benefits derived from a reduction in evaporative emissions range from €6-9. When the benefits from fuel savings are added, scenario 2+ total benefits range from €13-18. This is compared to average additional cost per vehicle of €9.

In conclusion, the CBA undertaken demonstrates a net benefit in implementing a modified test procedure for NMVOCs under scenario 2+. This involves the implementation of a more aggressive purging strategy over 48 hours and greater canister durability.

APPENDICES

Appendix 1

Scenario 1 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *Low Damage Cost/Medium Technology*		
Year	*Undiscounted* Benefit	*Undiscounted* Cost	Net benefit
2015	€ 952,704	€ 14,954,154	-€ 14,001,450
2016	€ 1,883,879	€ 14,473,889	-€ 12,590,010
2017	€ 2,831,712	€ 14,405,529	-€ 11,573,817
2018	€ 3,793,888	€ 14,377,931	-€ 10,584,043
2019	€ 4,761,164	€ 14,493,486	-€ 9,732,322
2020	€ 5,784,286	€ 13,268,921	-€ 7,484,635
2021	€ 6,568,324	€ 10,024,541	-€ 3,456,217
2022	€ 7,375,227	€ 10,086,726	-€ 2,711,499
2023	€ 8,175,430	€ 10,164,974	-€ 1,989,543
2024	€ 8,959,673	€ 10,548,678	-€ 1,589,006
2025	€ 9,759,905	€ 10,289,007	-€ 529,102
2026	€ 10,443,933	€ 9,151,814	€ 1,292,119
2027	€ 11,082,680	€ 9,106,593	€ 1,976,087
2028	€ 11,752,169	€ 9,087,239	€ 2,664,930
2029	€ 12,328,204	€ 9,057,051	€ 3,271,154
2030	€ 12,897,175	€ 8,912,792	€ 3,984,384
2031	€ 12,381,200	€ 0	€ 12,381,200
2032	€ 11,859,551	€ 0	€ 11,859,551
2033	€ 11,291,638	€ 0	€ 11,291,638
2034	€ 10,666,919	€ 0	€ 10,666,919
2035	€ 10,013,420	€ 0	€ 10,013,420
2036	€ 9,332,821	€ 0	€ 9,332,821
2037	€ 8,612,925	€ 0	€ 8,612,925
2038	€ 7,897,073	€ 0	€ 7,897,073
2039	€ 7,184,262	€ 0	€ 7,184,262
2040	€ 6,507,891	€ 0	€ 6,507,891
Discounted @ 6%	**€ 99,676,046**	**€ 128,371,141**	
Benefit-Cost Ratio =	0.78	NPV@6% =	-€ 28,695,095

Scenario 1 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *High Damage Cost/Medium Technology*		
	Undiscounted	*Undiscounted*	
Year	Benefit	Cost	Net benefit
2015	€ 2,866,050	€ 14,954,154	-12,088,105
2016	€ 5,667,333	€ 14,473,889	-€ 8,806,557
2017	€ 8,518,729	€ 14,405,529	-€ 5,886,800
2018	€ 11,413,273	€ 14,377,931	-€ 2,964,658
2019	€ 14,323,160	€ 14,493,486	-€ 170,326
2020	€ 17,401,049	€ 13,268,921	€ 4,132,128
2021	€ 19,759,697	€ 10,024,541	€ 9,735,156
2022	€ 22,187,128	€ 10,086,726	€ 12,100,402
2023	€ 24,594,405	€ 10,164,974	€ 14,429,431
2024	€ 26,953,666	€ 10,548,678	€ 16,404,988
2025	€ 29,361,030	€ 10,289,007	€ 19,072,023
2026	€ 31,418,814	€ 9,151,814	€ 22,267,000
2027	€ 33,340,375	€ 9,106,593	€ 24,233,783
2028	€ 35,354,420	€ 9,087,239	€ 26,267,181
2029	€ 37,087,326	€ 9,057,051	€ 28,030,275
2030	€ 38,798,980	€ 8,912,792	€ 29,886,188
2031	€ 37,246,755	€ 0	€ 37,246,755
2032	€ 35,677,461	€ 0	€ 35,677,461
2033	€ 33,968,992	€ 0	€ 33,968,992
2034	€ 32,089,630	€ 0	€ 32,089,630
2035	€ 30,123,689	€ 0	€ 30,123,689
2036	€ 28,076,221	€ 0	€ 28,076,221
2037	€ 25,910,534	€ 0	€ 25,910,534
2038	€ 23,757,014	€ 0	€ 23,757,014
2039	€ 21,612,641	€ 0	€ 21,612,641
2040	€ 19,577,894	€ 0	€ 19,577,894
Total Discounted @ 6%	**€ 299,858,595**	**€ 128,371,141**	
Benefit-Cost Ratio =	2.34	NPV@6% =	€ 171,487,454

Scenario 1 Year	Summary of Net Benefit of NMVOC Reductions *Low Damage Cost/Medium-High Technology* *Undiscounted* Benefit	*Undiscounted* Cost	Net benefit
2015	€ 952,704	€ 26,169,770	-€ 25,217,066
2016	€ 1,883,879	€ 25,329,307	-€ 23,445,428
2017	€ 2,831,712	€ 25,209,675	-€ 22,377,963
2018	€ 3,793,888	€ 25,161,379	-€ 21,367,491
2019	€ 4,761,164	€ 25,363,601	-€ 20,602,437
2020	€ 5,784,286	€ 25,779,617	-€ 19,995,332
2021	€ 6,568,324	€ 19,476,252	-€ 12,907,927
2022	€ 7,375,227	€ 19,597,068	-€ 12,221,841
2023	€ 8,175,430	€ 19,749,092	-€ 11,573,662
2024	€ 8,959,673	€ 20,494,575	-€ 11,534,902
2025	€ 9,759,905	€ 19,990,070	-€ 10,230,165
2026	€ 10,443,933	€ 17,780,667	-€ 7,336,734
2027	€ 11,082,680	€ 17,692,808	-€ 6,610,129
2028	€ 11,752,169	€ 17,655,206	-€ 5,903,038
2029	€ 12,328,204	€ 17,596,556	-€ 5,268,351
2030	€ 12,897,175	€ 17,316,281	-€ 4,419,105
2031	€ 12,381,200	€ 0	€ 12,381,200
2032	€ 11,859,551	€ 0	€ 11,859,551
2033	€ 11,291,638	€ 0	€ 11,291,638
2034	€ 10,666,919	€ 0	€ 10,666,919
2035	€ 10,013,420	€ 0	€ 10,013,420
2036	€ 9,332,821	€ 0	€ 9,332,821
2037	€ 8,612,925	€ 0	€ 8,612,925
2038	€ 7,897,073	€ 0	€ 7,897,073
2039	€ 7,184,262	€ 0	€ 7,184,262
2040	€ 6,507,891	€ 0	€ 6,507,891
Discounted @ 6%	**€ 99,676,046**	**€ 236,874,580**	
Benefit-Cost Ratio =	0.4	NPV@6% =	-€ 137,198,534

Scenario 2	Summary of Net Benefit of NMVOC Reductions *High Damage Cost/Medium Technology*		
Year	*Undiscounted* Benefit	*Undiscounted* Cost	Net benefit
2015	€ 2,866,050	€ 26,169,770	-€ 23,303,721
2016	€ 5,667,333	€ 25,329,307	-€ 19,661,974
2017	€ 8,518,729	€ 25,209,675	-€ 16,690,947
2018	€ 11,413,273	€ 25,161,379	-€ 13,748,106
2019	€ 14,323,160	€ 25,363,601	-€ 11,040,441
2020	€ 17,401,049	€ 25,779,617	-€ 8,378,568
2021	€ 19,759,697	€ 19,476,252	€ 283,446
2022	€ 22,187,128	€ 19,597,068	€ 2,590,060
2023	€ 24,594,405	€ 19,749,092	€ 4,845,313
2024	€ 26,953,666	€ 20,494,575	€ 6,459,091
2025	€ 29,361,030	€ 19,990,070	€ 9,370,960
2026	€ 31,418,814	€ 17,780,667	€ 13,638,147
2027	€ 33,340,375	€ 17,692,808	€ 15,647,567
2028	€ 35,354,420	€ 17,655,206	€ 17,699,213
2029	€ 37,087,326	€ 17,596,556	€ 19,490,770
2030	€ 38,798,980	€ 17,316,281	€ 21,482,699
2031	€ 37,246,755	€ 0	€ 37,246,755
2032	€ 35,677,461	€ 0	€ 35,677,461
2033	€ 33,968,992	€ 0	€ 33,968,992
2034	€ 32,089,630	€ 0	€ 32,089,630
2035	€ 30,123,689	€ 0	€ 30,123,689
2036	€ 28,076,221	€ 0	€ 28,076,221
2037	€ 25,910,534	€ 0	€ 25,910,534
2038	€ 23,757,014	€ 0	€ 23,757,014
2039	€ 21,612,641	€ 0	€ 21,612,641
2040	€ 19,577,894	€ 0	€ 19,577,894
Discounted @ 6%	**€ 299,858,595**	**€ 236,874,580**	
Benefit-Cost Ratio =	1.3	NPV@6% =	€ 62,984,015

Scenario 2 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *Low Damage Cost/Medium Technology*		
Year	*Undiscounted* Benefit	*Undiscounted* Cost	Net benefit
2015	€ 3,171,809	€ 89,724,927	-€ 86,553,118
2016	€ 6,259,918	€ 86,843,337	-€ 80,583,419
2017	€ 9,355,987	€ 86,433,173	-€ 77,077,186
2018	€ 12,466,957	€ 86,267,584	-€ 73,800,626
2019	€ 15,596,538	€ 86,960,918	-€ 71,364,380
2020	€ 18,803,420	€ 79,613,523	-€ 60,810,103
2021	€ 21,325,091	€ 60,147,247	-€ 38,822,157
2022	€ 23,815,154	€ 60,520,357	-€ 36,705,203
2023	€ 26,264,833	€ 60,989,843	-€ 34,725,011
2024	€ 28,671,989	€ 63,292,070	-€ 34,620,081
2025	€ 30,969,610	€ 61,734,039	-€ 30,764,430
2026	€ 32,906,477	€ 54,910,883	-€ 22,004,406
2027	€ 34,725,972	€ 54,639,555	-€ 19,913,583
2028	€ 36,459,611	€ 54,523,431	-€ 18,063,820
2029	€ 38,043,613	€ 54,342,304	-€ 16,298,691
2030	€ 39,495,213	€ 53,476,749	-€ 13,981,536
2031	€ 37,844,554	€ 0	€ 37,844,554
2032	€ 36,059,122	€ 0	€ 36,059,122
2033	€ 34,148,262	€ 0	€ 34,148,262
2034	€ 32,151,998	€ 0	€ 32,151,998
2035	€ 30,042,475	€ 0	€ 30,042,475
2036	€ 27,903,907	€ 0	€ 27,903,907
2037	€ 25,693,250	€ 0	€ 25,693,250
2038	€ 23,460,998	€ 0	€ 23,460,998
2039	€ 21,292,239	€ 0	€ 21,292,239
2040	€ 19,209,612	€ 0	€ 19,209,612
Discounted @ 6%	**€ 312,345,079**	**€ 770,226,848**	
Benefit-Cost Ratio =	0.4	NPV@6% =	-€ 457,881,769

Scenario 2 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *High Damage Cost/Medium Technology*		
Year	*Undiscounted* Benefit	*Undiscounted* Cost	Net benefit
2015	€ 9,541,853	€ 89,724,927	-80,183,074
2016	€ 18,831,909	€ 86,843,337	-€ 68,011,428
2017	€ 28,145,912	€ 86,433,173	-€ 58,287,261
2018	€ 37,504,740	€ 86,267,584	-€ 48,762,843
2019	€ 46,919,557	€ 86,960,918	-€ 40,041,361
2020	€ 56,566,922	€ 79,613,523	-€ 23,046,601
2021	€ 64,152,944	€ 60,147,247	€ 4,005,696
2022	€ 71,643,878	€ 60,520,357	€ 11,123,521
2023	€ 79,013,325	€ 60,989,843	€ 18,023,482
2024	€ 86,254,849	€ 63,292,070	€ 22,962,779
2025	€ 93,166,855	€ 61,734,039	€ 31,432,815
2026	€ 98,993,593	€ 54,910,883	€ 44,082,710
2027	€ 104,467,239	€ 54,639,555	€ 49,827,683
2028	€ 109,682,600	€ 54,523,431	€ 55,159,169
2029	€ 114,447,802	€ 54,342,304	€ 60,105,498
2030	€ 118,814,697	€ 53,476,749	€ 65,337,948
2031	€ 113,848,967	€ 0	€ 113,848,967
2032	€ 108,477,796	€ 0	€ 108,477,796
2033	€ 102,729,296	€ 0	€ 102,729,296
2034	€ 96,723,870	€ 0	€ 96,723,870
2035	€ 90,377,727	€ 0	€ 90,377,727
2036	€ 83,944,205	€ 0	€ 83,944,205
2037	€ 77,293,815	€ 0	€ 77,293,815
2038	€ 70,578,460	€ 0	€ 70,578,460
2039	€ 64,054,115	€ 0	€ 64,054,115
2040	€ 57,788,883	€ 0	€ 57,788,883
Total Discounted @ 6%	**€ 939,637,559**	**€ 770,226,848**	
Benefit-Cost Ratio =	1.2	NPV@6% =	€ 169,410,711

Scenario 2 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *Low Damage Cost/Medium-High Technology*		
Year	*Undiscounted* Benefit	*Undiscounted* Cost	Net benefit
2015	€ 3,171,809	€ 130,848,852	-€ 127,677,043
2016	€ 6,259,918	€ 126,646,533	-€ 120,386,615
2017	€ 9,355,987	€ 126,048,377	-€ 116,692,390
2018	€ 12,466,957	€ 125,806,893	-€ 113,339,936
2019	€ 15,596,538	€ 126,818,006	-€ 111,221,468
2020	€ 18,803,420	€ 128,898,086	-€ 110,094,665
2021	€ 21,325,091	€ 97,381,258	-€ 76,056,167
2022	€ 23,815,154	€ 97,985,339	-€ 74,170,186
2023	€ 26,264,833	€ 98,745,460	-€ 72,480,628
2024	€ 28,671,989	€ 102,472,875	-€ 73,800,886
2025	€ 30,969,610	€ 99,950,350	-€ 68,980,740
2026	€ 32,906,477	€ 88,903,335	-€ 55,996,858
2027	€ 34,725,972	€ 88,464,042	-€ 53,738,070
2028	€ 36,459,611	€ 88,276,031	-€ 51,816,420
2029	€ 38,043,613	€ 87,982,778	-€ 49,939,165
2030	€ 39,495,213	€ 86,581,404	-€ 47,086,190
2031	€ 37,844,554	€ 0	€ 37,844,554
2032	€ 36,059,122	€ 0	€ 36,059,122
2033	€ 34,148,262	€ 0	€ 34,148,262
2034	€ 32,151,998	€ 0	€ 32,151,998
2035	€ 30,042,475	€ 0	€ 30,042,475
2036	€ 27,903,907	€ 0	€ 27,903,907
2037	€ 25,693,250	€ 0	€ 25,693,250
2038	€ 23,460,998	€ 0	€ 23,460,998
2039	€ 21,292,239	€ 0	€ 21,292,239
2040	€ 19,209,612	€ 0	€ 19,209,612
Discounted @ 6%	**€ 312,345,079**	**€ 1,184,372,901**	
Benefit-Cost Ratio =	0.3	NPV@6% =	-€ 872,027,822

Scenario 2 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *High Damage Cost/Medium Technology*		
	Undiscounted	***Undiscounted***	
Year	**Benefit**	**Cost**	**Net benefit**
2015	€ 9,541,853	€ 130,848,852	-€ 121,306,999
2016	€ 18,831,909	€ 126,646,533	-€ 107,814,624
2017	€ 28,145,912	€ 126,048,377	-€ 97,902,465
2018	€ 37,504,740	€ 125,806,893	-€ 88,302,152
2019	€ 46,919,557	€ 126,818,006	-€ 79,898,449
2020	€ 56,566,922	€ 128,898,086	-€ 72,331,163
2021	€ 64,152,944	€ 97,381,258	-€ 33,228,314
2022	€ 71,643,878	€ 97,985,339	-€ 26,341,461
2023	€ 79,013,325	€ 98,745,460	-€ 19,732,136
2024	€ 86,254,849	€ 102,472,875	-€ 16,218,026
2025	€ 93,166,855	€ 99,950,350	-€ 6,783,495
2026	€ 98,993,593	€ 88,903,335	€ 10,090,259
2027	€ 104,467,239	€ 88,464,042	€ 16,003,197
2028	€ 109,682,600	€ 88,276,031	€ 21,406,569
2029	€ 114,447,802	€ 87,982,778	€ 26,465,025
2030	€ 118,814,697	€ 86,581,404	€ 32,233,293
2031	€ 113,848,967	€ 0	€ 113,848,967
2032	€ 108,477,796	€ 0	€ 108,477,796
2033	€ 102,729,296	€ 0	€ 102,729,296
2034	€ 96,723,870	€ 0	€ 96,723,870
2035	€ 90,377,727	€ 0	€ 90,377,727
2036	€ 83,944,205	€ 0	€ 83,944,205
2037	€ 77,293,815	€ 0	€ 77,293,815
2038	€ 70,578,460	€ 0	€ 70,578,460
2039	€ 64,054,115	€ 0	€ 64,054,115
2040	€ 57,788,883	€ 0	€ 57,788,883
Discounted @ 6%	**€ 939,637,559**	**€ 1,184,372,901**	
Benefit-Cost Ratio =	0.8	NPV@6% =	-€ 244,735,342

Scenario 2+ 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *Low Damage Cost/Medium Technology*		
	Undiscounted	*Undiscounted*	
Year	**Benefit**	**Cost**	**Net benefit**
2015	€ 3,700,702	€ 89,724,927	-€ 86,024,224
2016	€ 7,784,396	€ 86,843,337	-€ 79,058,941
2017	€ 12,311,872	€ 86,433,173	-€ 74,121,301
2018	€ 17,235,955	€ 86,267,584	-€ 69,031,628
2019	€ 22,535,844	€ 86,960,918	-€ 64,425,074
2020	€ 28,211,926	€ 79,613,523	-€ 51,401,597
2021	€ 33,468,714	€ 60,147,247	-€ 26,678,534
2022	€ 38,826,285	€ 60,520,357	-€ 21,694,071
2023	€ 44,243,343	€ 60,989,843	-€ 16,746,500
2024	€ 49,644,723	€ 63,292,070	-€ 13,647,347
2025	€ 54,911,300	€ 61,734,039	-€ 6,822,739
2026	€ 60,026,947	€ 54,910,883	€ 5,116,064
2027	€ 64,929,863	€ 54,639,555	€ 10,290,307
2028	€ 69,629,342	€ 54,523,431	€ 15,105,911
2029	€ 74,037,051	€ 54,342,304	€ 19,694,747
2030	€ 78,172,936	€ 53,476,749	€ 24,696,186
2031	€ 76,082,039	€ 0	€ 76,082,039
2032	€ 73,409,934	€ 0	€ 73,409,934
2033	€ 70,347,180	€ 0	€ 70,347,180
2034	€ 66,972,691	€ 0	€ 66,972,691
2035	€ 63,252,797	€ 0	€ 63,252,797
2036	€ 59,369,707	€ 0	€ 59,369,707
2037	€ 55,202,881	€ 0	€ 55,202,881
2038	€ 50,907,965	€ 0	€ 50,907,965
2039	€ 46,678,504	€ 0	€ 46,678,504
2040	€ 42,540,588	€ 0	€ 42,540,588
Discounted @ 6%	**€ 565,793,099**	**€ 770,226,848**	
Benefit-Cost Ratio =	0.7	NPV@6% =	-€ 204,433,749

Scenario 2+ 35% equipped with multilayered tanks	**Summary of Net Benefit of NMVOC Reductions** *High Damage Cost/Medium Technology*		
	Undiscounted	***Undiscounted***	
Year	**Benefit**	**Cost**	**Net benefit**
2015	€ 11,132,940	€ 89,724,927	-78,591,987
2016	€ 23,418,043	€ 86,843,337	-€ 63,425,293
2017	€ 37,038,193	€ 86,433,173	-€ 49,394,980
2018	€ 51,851,468	€ 86,267,584	-€ 34,416,116
2019	€ 67,795,291	€ 86,960,918	-€ 19,165,627
2020	€ 84,870,827	€ 79,613,523	€ 5,257,304
2021	€ 100,684,988	€ 60,147,247	€ 40,537,740
2022	€ 116,802,339	€ 60,520,357	€ 56,281,983
2023	€ 133,098,646	€ 60,989,843	€ 72,108,803
2024	€ 149,347,786	€ 63,292,070	€ 86,055,716
2025	€ 165,191,397	€ 61,734,039	€ 103,457,358
2026	€ 180,580,959	€ 54,910,883	€ 125,670,076
2027	€ 195,330,555	€ 54,639,555	€ 140,691,000
2028	€ 209,468,146	€ 54,523,431	€ 154,944,715
2029	€ 222,727,996	€ 54,342,304	€ 168,385,692
2030	€ 235,170,110	€ 53,476,749	€ 181,693,360
2031	€ 228,880,000	€ 0	€ 228,880,000
2032	€ 220,841,421	€ 0	€ 220,841,421
2033	€ 211,627,640	€ 0	€ 211,627,640
2034	€ 201,476,060	€ 0	€ 201,476,060
2035	€ 190,285,387	€ 0	€ 190,285,387
2036	€ 178,603,762	€ 0	€ 178,603,762
2037	€ 166,068,569	€ 0	€ 166,068,569
2038	€ 153,148,037	€ 0	€ 153,148,037
2039	€ 140,424,416	€ 0	€ 140,424,416
2040	€ 127,976,193	€ 0	€ 127,976,193
Total Discounted @ 6%	**€ 1,702,093,235**	**€ 770,226,848**	
Benefit-Cost Ratio =	2.2	NPV@6% =	€ 931,866,387

Scenario 2+ 35% equipped with multilayered tanks	**Summary of Net Benefit of NMVOC Reductions** *Low Damage Cost/Medium-High Technology*		
Year	***Undiscounted* Benefit**	***Undiscounted* Cost**	**Net benefit**
2015	€ 3,700,702	€ 130,848,852	-€ 127,148,149
2016	€ 7,784,396	€ 126,646,533	-€ 118,862,137
2017	€ 12,311,872	€ 126,048,377	-€ 113,736,505
2018	€ 17,235,955	€ 125,806,893	-€ 108,570,938
2019	€ 22,535,844	€ 126,818,006	-€ 104,282,162
2020	€ 28,211,926	€ 128,898,086	-€ 100,686,160
2021	€ 33,468,714	€ 97,381,258	-€ 63,912,544
2022	€ 38,826,285	€ 97,985,339	-€ 59,159,054
2023	€ 44,243,343	€ 98,745,460	-€ 54,502,117
2024	€ 49,644,723	€ 102,472,875	-€ 52,828,153
2025	€ 54,911,300	€ 99,950,350	-€ 45,039,050
2026	€ 60,026,947	€ 88,903,335	-€ 28,876,388
2027	€ 64,929,863	€ 88,464,042	-€ 23,534,179
2028	€ 69,629,342	€ 88,276,031	-€ 18,646,689
2029	€ 74,037,051	€ 87,982,778	-€ 13,945,727
2030	€ 78,172,936	€ 86,581,404	-€ 8,408,468
2031	€ 76,082,039	€ 0	€ 76,082,039
2032	€ 73,409,934	€ 0	€ 73,409,934
2033	€ 70,347,180	€ 0	€ 70,347,180
2034	€ 66,972,691	€ 0	€ 66,972,691
2035	€ 63,252,797	€ 0	€ 63,252,797
2036	€ 59,369,707	€ 0	€ 59,369,707
2037	€ 55,202,881	€ 0	€ 55,202,881
2038	€ 50,907,965	€ 0	€ 50,907,965
2039	€ 46,678,504	€ 0	€ 46,678,504
2040	€ 42,540,588	€ 0	€ 42,540,588
Discounted @ 6%	**€ 565,793,099**	**€ 1,184,372,901**	
Benefit-Cost Ratio =	0.5	NPV@6% =	-€ 618,579,802

Scenario 2+ 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *High Damage Cost/Medium Technology*		
	Undiscounted	***Undiscounted***	
Year	**Benefit**	**Cost**	**Net benefit**
2015	€ 11,132,940	€ 130,848,852	-€ 119,715,912
2016	€ 23,418,043	€ 126,646,533	-€ 103,228,489
2017	€ 37,038,193	€ 126,048,377	-€ 89,010,184
2018	€ 51,851,468	€ 125,806,893	-€ 73,955,425
2019	€ 67,795,291	€ 126,818,006	-€ 59,022,715
2020	€ 84,870,827	€ 128,898,086	-€ 44,027,258
2021	€ 100,684,988	€ 97,381,258	€ 3,303,730
2022	€ 116,802,339	€ 97,985,339	€ 18,817,000
2023	€ 133,098,646	€ 98,745,460	€ 34,353,186
2024	€ 149,347,786	€ 102,472,875	€ 46,874,911
2025	€ 165,191,397	€ 99,950,350	€ 65,241,047
2026	€ 180,580,959	€ 88,903,335	€ 91,677,624
2027	€ 195,330,555	€ 88,464,042	€ 106,866,513
2028	€ 209,468,146	€ 88,276,031	€ 121,192,115
2029	€ 222,727,996	€ 87,982,778	€ 134,745,218
2030	€ 235,170,110	€ 86,581,404	€ 148,588,706
2031	€ 228,880,000	€ 0	€ 228,880,000
2032	€ 220,841,421	€ 0	€ 220,841,421
2033	€ 211,627,640	€ 0	€ 211,627,640
2034	€ 201,476,060	€ 0	€ 201,476,060
2035	€ 190,285,387	€ 0	€ 190,285,387
2036	€ 178,603,762	€ 0	€ 178,603,762
2037	€ 166,068,569	€ 0	€ 166,068,569
2038	€ 153,148,037	€ 0	€ 153,148,037
2039	€ 140,424,416	€ 0	€ 140,424,416
2040	€ 127,976,193	€ 0	€ 127,976,193
Discounted @ 6%	**€ 1,702,093,235**	**€ 1,184,372,901**	
Benefit-Cost Ratio =	1.4	NPV@6% =	€ 517,720,334

Scenario 3 35% equipped with multilayered tanks	***Summary of Net Benefit of NMVOC Reductions*** *Low Damage Cost/Medium Technology*		
Year	***Undiscounted*** **Benefit**	***Undiscounted*** **Cost**	**Net benefit**
2015	€ 4,403,733	€ 220,573,779	-€ 216,170,045
2016	€ 8,992,569	€ 199,015,980	-€ 190,023,411
2017	€ 13,801,056	€ 180,069,110	-€ 166,268,054
2018	€ 18,660,875	€ 154,562,754	-€ 135,901,879
2019	€ 23,550,798	€ 126,818,006	-€ 103,267,208
2020	€ 28,651,028	€ 92,882,444	-€ 64,231,416
2021	€ 33,468,714	€ 60,147,247	-€ 26,678,534
2022	€ 38,826,285	€ 60,520,357	-€ 21,694,071
2023	€ 44,243,343	€ 60,989,843	-€ 16,746,500
2024	€ 49,644,723	€ 63,292,070	-€ 13,647,347
2025	€ 54,911,300	€ 61,734,039	-€ 6,822,739
2026	€ 60,026,947	€ 54,910,883	€ 5,116,064
2027	€ 64,929,863	€ 54,639,555	€ 10,290,307
2028	€ 69,629,342	€ 54,523,431	€ 15,105,911
2029	€ 74,037,051	€ 54,342,304	€ 19,694,747
2030	€ 78,172,936	€ 53,476,749	€ 24,696,186
2031	€ 76,082,039	€ 0	€ 76,082,039
2032	€ 73,409,934	€ 0	€ 73,409,934
2033	€ 70,347,180	€ 0	€ 70,347,180
2034	€ 66,972,691	€ 0	€ 66,972,691
2035	€ 63,252,797	€ 0	€ 63,252,797
2036	€ 59,369,707	€ 0	€ 59,369,707
2037	€ 55,202,881	€ 0	€ 55,202,881
2038	€ 50,907,965	€ 0	€ 50,907,965
2039	€ 46,678,504	€ 0	€ 46,678,504
2040	€ 42,540,588	€ 0	€ 42,540,588
Discounted @ 6%	**€ 571,289,735**	**€ 1,189,062,397**	
Benefit-Cost Ratio =	0.5	NPV@6% =	-€ 617,772,662

Scenario 3 35% equipped with multilayered tanks	**Summary of Net Benefit of NMVOC Reductions** *High Damage Cost/Medium Technology*		
Year	***Undiscounted*** **Benefit**	***Undiscounted*** **Cost**	**Net benefit**
2015	€ 13,247,890	€ 220,573,779	-207,325,888
2016	€ 27,052,628	€ 199,015,980	-€ 171,963,352
2017	€ 41,518,152	€ 180,069,110	-€ 138,550,958
2018	€ 56,138,098	€ 154,562,754	-€ 98,424,656
2019	€ 70,848,609	€ 126,818,006	-€ 55,969,397
2020	€ 86,191,791	€ 92,882,444	-€ 6,690,653
2021	€ 100,684,988	€ 60,147,247	€ 40,537,740
2022	€ 116,802,339	€ 60,520,357	€ 56,281,983
2023	€ 133,098,646	€ 60,989,843	€ 72,108,803
2024	€ 149,347,786	€ 63,292,070	€ 86,055,716
2025	€ 165,191,397	€ 61,734,039	€ 103,457,358
2026	€ 180,580,959	€ 54,910,883	€ 125,670,076
2027	€ 195,330,555	€ 54,639,555	€ 140,691,000
2028	€ 209,468,146	€ 54,523,431	€ 154,944,715
2029	€ 222,727,996	€ 54,342,304	€ 168,385,692
2030	€ 235,170,110	€ 53,476,749	€ 181,693,360
2031	€ 228,880,000	€ 0	€ 228,880,000
2032	€ 220,841,421	€ 0	€ 220,841,421
2033	€ 211,627,640	€ 0	€ 211,627,640
2034	€ 201,476,060	€ 0	€ 201,476,060
2035	€ 190,285,387	€ 0	€ 190,285,387
2036	€ 178,603,762	€ 0	€ 178,603,762
2037	€ 166,068,569	€ 0	€ 166,068,569
2038	€ 153,148,037	€ 0	€ 153,148,037
2039	€ 140,424,416	€ 0	€ 140,424,416
2040	€ 127,976,193	€ 0	€ 127,976,193
Total Discounted @ 6%	**€ 1,718,628,939**	**€ 1,189,062,397**	
Benefit-Cost Ratio =	1.4	NPV@6% =	€ 529,566,542

Scenario 3 35% equipped with multilayered tanks	Summary of Net Benefit of NMVOC Reductions *Low Damage Cost/Medium-High Technology*		
Year	***Undiscounted* Benefit**	***Undiscounted* Cost**	**Net benefit**
2015	€ 4,403,733	€ 268,240,146	-€ 263,836,412
2016	€ 8,992,569	€ 244,427,808	-€ 235,435,240
2017	€ 13,801,056	€ 224,366,111	-€ 210,565,055
2018	€ 18,660,875	€ 197,516,821	-€ 178,855,947
2019	€ 23,550,798	€ 168,667,948	-€ 145,117,150
2020	€ 28,651,028	€ 144,365,856	-€ 115,714,828
2021	€ 33,468,714	€ 97,381,258	-€ 63,912,544
2022	€ 38,826,285	€ 97,985,339	-€ 59,159,054
2023	€ 44,243,343	€ 98,745,460	-€ 54,502,117
2024	€ 49,644,723	€ 102,472,875	-€ 52,828,153
2025	€ 54,911,300	€ 99,950,350	-€ 45,039,050
2026	€ 60,026,947	€ 88,903,335	-€ 28,876,388
2027	€ 64,929,863	€ 88,464,042	-€ 23,534,179
2028	€ 69,629,342	€ 88,276,031	-€ 18,646,689
2029	€ 74,037,051	€ 87,982,778	-€ 13,945,727
2030	€ 78,172,936	€ 86,581,404	-€ 8,408,468
2031	€ 76,082,039	€ 0	€ 76,082,039
2032	€ 73,409,934	€ 0	€ 73,409,934
2033	€ 70,347,180	€ 0	€ 70,347,180
2034	€ 66,972,691	€ 0	€ 66,972,691
2035	€ 63,252,797	€ 0	€ 63,252,797
2036	€ 59,369,707	€ 0	€ 59,369,707
2037	€ 55,202,881	€ 0	€ 55,202,881
2038	€ 50,907,965	€ 0	€ 50,907,965
2039	€ 46,678,504	€ 0	€ 46,678,504
2040	€ 42,540,588	€ 0	€ 42,540,588
Discounted @ 6%	**€ 571,289,735**	**€ 1,625,297,570**	
Benefit-Cost Ratio =	0.4	NPV@6% =	-€ 1,054,007,835

REFERENCES

1. AEA Technology (2005) *Damages per tonne emission of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas, Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme*. AEA Technology Environment, Didcot.
2. CRC (2006) *Fuel Permeation from Automotive Systems: E0, E6, E10 and E85*, Interim Report. Coordinating Research Council, Georgia, Atlanta. Available: http://www.crcao.com/reports/recentstudies2006/E-65-3/CRC%20E-65-3%20Final%20Report.pdf accessed 25 March 2012.
3. CRC (2010) Enhanced Evaporative Emission Vehicles. Coordinating Research Council, CRC Report No. E-77-2., Georgia, Atlanta. Available: http://www.crcao.com/reports/recentstudies2010/E-77-2/E-77-2_Final_Report__March_2010.pdf accessed 25 March 2013.
4. De Gennaro, M., Paffumi, E., Scholz, H. and Martini, G. (2013 *Submitted*) Analysis of vehicles mobility behavioral databases and assessment of the impact of the electrification of urban road transport.
5. EC4MACS (2013) *European Consortium for Modelling of Air Pollution and Climate Strategies*, EU-LIFE project. Online: www.ec4macs.eu accessed 5 March 2013.
6. EEA (2010) *Impact of selected policy measures on Europe's air quality*. European Environmental Agency, Copenhagen.
7. EEA (2012) *Environmental Indicator Report 2012*. European Environmental Agency, Copenhagen.
8. Geiss, O., Barrero-Moreno, J., Kotzias, D., 2011. Measurements of volatile organic compounds in car showrooms in the province of Varese (Northern Italy*). Indoor Air* 21, 45-52.
9. Hanley, N. and Barbier, E. B. (2009) *Pricing Nature: Cost-Benefit Analysis and Environmental Policy*. Edward Elgar, Cheltenham.
10. Haung, H., He, Z., Yuan, H., Chen, Y., Kobayashi, N., (2011). Evaluation of n-butane Gas Absorption Performance of Composite Adsorbents Used for Carbon Canister. *Procedia Engineering* 18, 78-85.
11. Johansson, H. and Schmidt, H. (2009) *Lack of legislation causes large problems with evaporative emissions*. SAE Technical Paper 2009-24-0141, doi:10.4271/2009-24-0141.
12. Mellios, G., Samaras, Z., (2007). An empirical model for estimating evaporative hydrocarbon emissions from canister-equipped vehicles. *Fuel* 86, 2254-2261.
13. Ntziachristos, L., Gkatzofliasb, D., Kouridis C., and Samaras, Z. (2009) COPERT: A European Road Transport Emission Inventory Model. *Information Technologies in Environmental Engineering*, 491-504. DOI 10.1007/978-3-540-88351-7_37
14. National Research Centre (2011). Assessment of Technologies for Improving Light Duty Vehicles Fuel Economy. National Research Council. Available http://www.nap.edu/catalog.php?record_id=12924#toc (Accessed 21 February 2013).
15. Parrish, D.D., Kuster, W.C., Shao, M., Yokouchi, Y., Kondo, Y., Goldan, P.D., de Gouw, J.A., Koike, M., Shirai, T., 2009. Comparison of air pollutant emissions among mega-cities. *Atmospheric Environment* 43, 6435-6441.
16. Pearce, D., (1998). *Cost-Benefit Analysis and Environmental Policy*. Oxford Review of Economic Policy, 14:4, 84-100.
17. Rogozhin, A., Gallaher, M., Helfand, G., McManus, W. (2010).Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry, *Int. J. Production Economics*, 124, pp. 360-368.
18. Smith, K. R., Jerrett, M., Anderson, H.R., Burnett, R.T., Stone, V., Derwent, R., Atkinson, R.W., Cohen, A., Shonkoff, S.B., Krewski, D., Pope, C. A., Thun, M.J., Thurston, G., (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants. *The Lancet* 374 19/26, 2091-2103.
19. von Schneidemesser, E., Monks, P.S., Plass-Duelmer, C., 2010. Global comparison of VOC and CO observations in urban areas. *Atmospheric Environment* 44, 5053-5064.
20. USEPA (1993) *Control of Vehicular Evaporative Emissions: Final Regulatory Impact Analysis and Summary of Analysis of Comments*. United States Environmental Protection Agency, Washington.

21. USEPA, NHTS and California EPA (2010) *Interim Joint Technical Assessment Report: Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 1017-2015*. United States Environmental Protection Agency, Washington.

European Commission
EUR 26057 – Joint Research Centre – Institute for Energy and Transport

Title: Estimating the Costs and Benefits of Introducing a New European Evaporative Emissions Test Procedure

Author(s): Anwar Gary Haq, Giorgio Martini and Giorgos Mellios

Luxembourg: Publications Office of the European Union

2013 – 64 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (pdf), 1018-5593 (print),

ISBN 978-92-79-32364-5 (pdf)
ISBN 978-92-79-32365-2 (print)

doi: 10.2788/59642

Abstract

Evaporative emissions of non-methane volatile organic compounds (NMVOCs) arise from the vehicle's fuel system under changes in ambient and vehicle temperature and as a consequence of fuel permeation through plastic material. NMVOCs contribute to ground-level ozone and urban smog and pose a threat to human health. A revised test procedure for evaporative emissions and its possible implementation is currently under discussion by the European Commission. This study undertakes a cost-benefit analysis of four possible scenarios for the implementation of a revised test procedure for the period 2015-2040. Indirect cost multipliers (ICM) were used to estimate short- and long-run costs to the manufacturer. The COPERT model used to estimate EU evaporative emissions from the Euro 6 petrol vehicle population over time. Low and high marginal damage costs for NMVOC emissions from the CAFE Programme were used to calculate the economic value of the damage avoided. The study concludes that the most beneficial strategy is the implementation of a more aggressive purging strategy over 48 hours and greater canister durability (scenario 2+). The average net benefit of implementing scenario 2+ is €146,709,441 at a 6% discount rate is considerably higher than the other scenarios considered. Under scenario2+, the per vehicle benefits range from €6-9 but when fuel savings benefits are added, total benefits range from €13-18. This is compared to average additional cost per vehicle of €9..

LB-NA-26057-EN-N

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

ISBN 978-92-79-32364-5

Publications Office