Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars

Final Report

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Executive Summary

Introduction

This is the Final Report of the project *“Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars”* (contract nr. SI2.408212), which has been carried out by TNO, IEEP and LAT on behalf of the European Commission (DG-ENTR). The project is Task A of a set of two studies which are supporting the Impact Assessment, to be prepared by the European Commission in the preparation of a new strategy aimed at reducing the CO_2-emissions of light-duty vehicles to a level of 120 g/km in 2012.

Task B is the project *“Service contract in support of the extended impact assessment of various policy scenarios to reduce to reduce CO_2 emissions from passenger cars”,* carried out by ZEW and B&DForecast. This project assesses the macro-economic impacts as well as the impacts in the automotive industry of scenarios consisting of various technical and non-technical measures which are reviewed in Task A. In addition to these two Tasks, TML is performing TREMOVE calculations to assess impacts on the transport system and the environment.

The main objectives of Task A are:

1. to review the potential and related costs of various options for reducing the CO_2 emissions from passenger cars beyond the results reached in 2008/2009 based on the existing Community strategy;
2. to identify and design post 2008/9 CO_2 reduction scenarios, and to provide input to TML and Task B (*Service contract in support of the extended impact assessment of various policy scenarios to reduce to reduce CO_2 emissions from passenger cars*) so that these scenarios can be run in the partial and general equilibrium models;
3. to assist TML and the contractors for Task B in the interpretation of the results of their assessment of the likely economic, environmental and social effects of the scenarios studied.

In Task A a number of technical and non-technical measures is reviewed in terms of their potential contribution to CO_2-reduction in passenger cars and their costs. These measures have been identified by the European Commission and can be regarded as complementary options in the context of a so-called Integrated Approach, and include the following technical and non-technical measures:

Technical measures
- technical options to reduce fuel consumption at the vehicle level
- application of fuel efficient air conditioning systems
- options to reduce vehicle and engine resistance factors
- options for application of alternative fuels based on fossil energy
- increased application of biofuels
- possibilities to include N_1 vehicles into the Commitments

Non-technical measures
- fuel efficient driving
- CO_2 based taxation schemes for passenger cars
- options for improved energy or CO_2 labelling
- public procurement proposals

Technical options to reduce fuel consumption at the vehicle level

Using the methodology as developed in [IEEP 2004] an assessment has been made of the costs for reaching various possible targets for the sales averaged type approval CO_2-emissions of newly sold vehicles in 2012, reaching from maintaining the 140 g/km level of 2008 to 120 g/km. For this assessment a new review has been made of available data from literature on costs and CO_2-reduction potential of a wide range of technical options that can be applied to passenger cars. Also data have been collected from industry associations by means of a questionnaire and meetings. Based on these data and expert judgement by the consultants a new data set has been drawn up for CO_2-reduction measures to be applied to passenger cars. Based on these data the assessment of technology costs and CO_2-abatement costs has provided the following results:

- The costs of reaching an average CO_2-emission of new vehicles of 140 g/km in 2008 will involve additional manufacturer costs of €832 per vehicle compared to the 2002 baseline. This translates into an additional retail price of €1200 per vehicle.
- For most target-measure combinations the manufacturer costs for reaching a 2012 target of 120 g/km are around €1700 per vehicle compared to average costs of the 2008/9 baseline vehicle emitting 140 g/km. This translates into an additional retail price of €2450 per vehicle.
- The results of the new assess costs are significantly higher than the value calculated in [IEEP 2004]. The reasons for this significant difference are the following:
  - The translation from retail price data obtained from literature to manufacturer costs has been done with a different factor (1.44 instead of 2.0), resulting in higher input on the manufacturer costs;
  - The effects of autonomous weight increase have been modelled with a different formula resulting in a higher amount of additional CO_2-emissions to be compensated;
  - Cost and CO_2-reduction data for individual options have been newly estimated taking into account new literature data, information from industry and evolved expert judgement;
  - The resulting overall CO_2-reduction of packages of measures that target engine and powertrain efficiency has been assessed more conservatively;
- The abatement costs of reducing CO_2-emissions with technical measures applied to passenger cars depend on the reduction target and the oil price / fuel costs. For an oil price of 25 €/bbl the CO_2-abatement costs range from 166 to 233 €/tonne for 2012 target values between 135 and 120 g/km. For an oil price of 50 €/bbl the abatement costs range from 114 to 181 €/tonne for 2012 target values between 135 and 120 g/km. Abatement costs in this assessment are based on real-world fuel consumption and CO_2-emissions and include the Well-to-Tank greenhouse gas emissions.
- In general it can be concluded that, regardless of the type of policy measure that is chosen, reaching a new vehicle sales average TA CO_2-emission of 120 g/km requires the introduction of hybrid vehicles in the segments of small, medium ad large petrol cars and of large diesel cars. For small diesel cars the necessity for hybridisation depends on the policy measure, while for medium size diesel cars hybridisation is necessary for none of the policy measures.
- A first assessment of the overall GHG reduction potential associated with reducing the TA CO_2-emissions of new M_1-vehicles from 140 g/km in 2008/9 to 120 g/km in 2012 shows that for EU-15 a total reduction of 14.4 Mtonne/y would be achieved in 2012 growing to 54 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

Application of fuel efficient air conditioning systems

The EC has proposed several measures to reduce greenhouse gas emissions from passenger cars in the next decade. The EC aims at reducing greenhouse gas emissions from mobile air-conditioning systems (MACs) by a ban on the high GWP R134a as a refrigerant for all mobile air conditioner systems as from 2011. As a result of this legislation, the auto industry is challenged to develop new systems which use low GWP refrigerants as an alternative to R134a. Parallel to these developments, the industry investigates possibilities to improve existing systems, as such legislation is not proposed for other parts of the world and as for the EU still some time has to be bridged before switching to alternatives. It is expected that CO_2-based systems (R744) will be the dominant alternative and that in response to existing policy these systems will gradually enter the market after 2008, reaching near 100% of new sales by 2014 or 2015.

Both the existing R134a systems and the future R744 systems have room for improvement with respect to energy efficiency and the resulting indirect CO_2-emissions associated with use of these aircos. In response to a possible EU policy promoting energy efficiency of MACs it is expected that improved systems will come to the market which have significantly lower energy consumption. The additional manufacturer costs for improved systems are estimated at €40 for R134a systems and €60 for R744 systems. Besides that further improvement of the average efficiency of R134a systems is expected to be achieved by an increased share of systems variable displacement compressors.

Cost effectiveness of a policy promoting the introduction of more efficient MACs is assessed by estimating the total annual indirect CO_2-emissions, investment and fuel costs for a baseline scenario (describing the response to existing policy) and a constructed policy scenario sketching a possible response to a not yet defined EU policy aimed at the efficiency of MACs. At low oil prices (25 to 35 €/bbl) the CO_2-abatement costs of reducing CO_2-emissions by means of energy efficient MACs vary between 40 and 90 €/tonne. At 50 €/bbl the CO_2-abatement costs vary between 15 and 40 €/tonne, becoming even negative for an oil price of 74 €/bbl. Compared to other technical options fuel efficient MACs therefore are a relatively cost-effective measure to reduce CO_2-emissions from passenger cars.

For the moment there are no means for including the indirect fuel consumption of MACs in the type approval test. In [TNO 2004] a simplified test procedure has been developed to this end, but this procedure was found not to yield sufficiently reproducible and accurate results. The impossibility to include MACs in the TA test procedure for the moment seems to exclude legislative measures aimed at promoting airco efficiency. The existing procedure can be used as a monitoring tool accompanying a voluntary agreement with the automotive industry on airco efficiency.

A first assessment of the overall reduction potential associated with promotion of the use of fuel-efficient air conditioner systems shows that for EU-15 a total GHG reduction of 1.0 Mtonne/y could be achieved in 2012 growing to 2.7 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

Options to reduce vehicle and engine resistance factors

In chapter 8 the technology options of low rolling resistance tyres (LRRT), tyre pressure monitoring systems (TPMS) and low viscosity lubricants (LVL) are analysed based on data retrieved from literature and the industry. Low rolling resistance tyres and tyre pressure monitoring systems showed an important CO_2 reduction potential which was approximated at 3% and 2.5% respectively. In addition the CO_2-abatement costs of low rolling resistance tyres remain limited compared to other solutions and was estimated to be 140 €/tonne CO_2 reduced for low oil prices and 15 €/tonne for high oil prices in the case of LRRT. For TPMS CO_2-abatement costs were found negative in most cases.

Important issues that are presented regarding these technologies are the absence of the necessary standardisation and legislative framework that will support their introduction in the market and possible inconsistencies in relation to the vehicle type approval test. As for the last the potential of these technologies has either zero impact on the vehicle type approval test (TPMS) or can be incorporated without necessarily reaching the market (LRRT).

Low viscosity lubricants present similar characteristics with LRRT and TPMS. Their CO_2 reduction potential was found at 2.5% and their CO_2-abatement costs were estimated at approximately 180 €/tonne for low oil prices and 50 €/tonne for higher oil prices. Certain problems were revealed in the case of LVL regarding standardisation and vehicle warrantee issues when applying LVL.

Various measures are proposed for supporting and accelerating the introduction of the aforementioned technologies in the market. Amongst them are the application of labelling schemes, creation of consumer support tools such as product databases, adoption of relevant standards for each technology and purchase incentive programs. All of these should be combined with a necessary update of the relevant legislative framework.

Assuming a constructed scenario quantifying the effectiveness of policy measures promoting the application of low rolling resistance tyres, the total reduction potential associated with the increased use of low rolling resistance tyres is estimated for EU-15 at 2.4 Mtonne/y in 2012 growing to 5.3 Mtonne/y in 2020. Similarly for tyre pressure monitoring systems the overall potential is estimated at 2.0 resp. 9.6 Mtonne/y for 2012 and 202. The application of low-viscosity lubricants is estimated to result in an overall GHG reduction at EU-15 level of 2.0 Mtonne/y in 2012 increasing to 9.6 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

Application of alternative fuels based on fossil energy

Under this heading initially an assessment of LPG and CNG was foreseen. In the course of the project it was decided to focus on CNG only.

The additional manufacturer costs of medium sized natural gas vehicles (NGVs) compared to equivalent petrol vehicles is estimated at around €1750 per vehicle. Compared to equivalent petrol vehicles the direct (exhaust or Tank-to-Wheel (TTW)) CO_2-emissions of NGVs are about 22% lower. Based on these data it is found that even at a petrol price of 0.60 €/l (oil price = 74 €/bbl) NGVs are not a cost effective solution for reducing CO_2-emissions. CO_2-abatement costs range from around 350 €/tonne at an oil price of 25 €/bbl to 190 €/tonne at 74 €/bbl.

The abatement costs of reducing CO_2-emissions from passenger cars by means of natural gas depend strongly on the price of oil and the costs of natural gas at the filling station, as well as on the origin of the natural gas. Longer transport distances incur relatively high Well-to-Tank (WTT) emissions that counteract the TTW benefits to some extent. For this study it is assumed that most of the additional natural gas consumed between 2008 and 2012 by NGVs will be imported from outside Europe with an average transport distance of 4000 km. Using the WTW-assessment made in [Concawe 2006] for this fuel chain the net WTW CO_2-emission reduction compared to petrol vehicles is about 17% for this case. Including the benefits of NGVs (and possibly also other alternative fuels, specifically biofuels) in a monitoring scheme accompanying legislative or other policy measures aimed at reaching a defined CO_2-emissions reduction would thus preferably include a methodology for dealing with the WTT greenhouse gases for all fuels;

Compared to technical measures that can be applied to conventional vehicles, NGVs are a less cost effective option for reaching a 2012 target of e.g. 120 g/km, mainly due to the higher fuel price excluding taxes per unit energy for natural gas. As a result of that NGVs have higher fuel costs (excl. taxes) than baseline petrol vehicles to which the natural gas technology is applied, while more efficient petrol vehicles have a net fuel cost reduction compared to the same baseline. As natural gas can also be applied to petrol vehicles to which technical measures are applied in order to reach an overall 2012 goal between 140 and 120 g/km, NGVs may play a role in extending the potential for CO_2-reduction beyond 120 g/km or as an alternative for the expensive technologies that need to be applied for reaching targets beyond 120 g/km. This could be further explored on the basis of a comparison of marginal costs.

Assuming a linear increase of the additional share of NGVs in new vehicle sales[1] from 0% in 2007 to 10% in 2012 and a constant share of 10% after 2012, the total GHG reduction potential for EU-15 is estimated at 2.1 – 2.4 Mtonnes/y in 2012 growing to 6.4 – 7.3 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

Options to promote application of biofuels

Currently the biofuels most commonly available as transport fuels are biodiesel and bioethanol (with the latter often converted to bio-ETBE to be used as an additive in petrol). The main feedstocks are crops grown for oil (such as rape, soya and sunflower) for biodiesel, and crops high in sugar or starch (including sugar beet and cane, various grain crops, etc) for ethanol. In future, ‘second generation’ processes should be able to produce a range of synthetic fuels from a wider range of biomass sources, including bio-wastes, woody crops and grasses, but these are unlikely to contribute significantly up to 2012.

Biofuels offer CO_2 reduction benefits relative to mineral fuels because their carbon was absorbed from the atmosphere as the source plants grew, rather than being released from underground storage as with fossil fuels. However few if any biofuels are truly ‘carbon neutral’; those grown in Europe typically offer around a 50% greenhouse gas reduction, although the benefits of ethanol imported from Brazil are typically much greater (around 80% reduction).

Current biofuels are produced at a cost premium relative to conventional fuels, but this is reduced significantly if oil prices remain high. For the cheaper biofuel options (particularly Brazilian ethanol) the cost of CO_2 avoided falls to around zero on the assumption of a high oil price (€50/bbl), but more expensive European sources continue to have a cost premium, although this varies substantially according to both the cost and greenhouse gas reduction of the biofuel in question, and the anticipated price of oil.

The current biofuels policy framework sets indicative targets for biofuel percentages to the year 2010; it is proposed to model the greenhouse gas benefits of a linear extrapolation of the agreed trend for the years 2011 and 2012.

The additional replacement of 1% of fossil fuel use (in energy terms) by the use of biofuels (over and above the share already achieved as a consequence of the Biofuels Directive) is estimated to result in

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[1] Additional sales of NGVs in response to an assumed new policy promoting the use of NGVs, on top of the autonomous development of the market share of NGVs resulting from existing market drives and policies.

an overall GHG emission reduction for EU-15 of 3.1 to 4.0 Mtonne/y. A more in-depth assessment of the overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

Possibilities to include N_1 vehicles into the Commitments

The possibilities for and cost effectiveness of CO_2-reduction in light commercial vehicles has been assessed based on a methodology developed in a previous study on this subject by TNO, IEEP and LAT. Cost and CO_2-reduction potentials of options to reduce CO_2-emissions form N_1-vehicles have been based on the results of Task 1.1 on passenger cars. For each fuel data from the M_1 categories small, medium and large have been used for the N_1 categories Class I, II and III. For some technical options the data for M_1-vehicles have been modified to account for characteristics of the application in M1-vehicls that influence CO_2-reduction potential or system costs. For each of the classes a business-as-usual package (BAU) has been defined of CO_2-reducing options that are assumed to be applied in the period 2002 – 2012 even in the absence of policy aimed at the CO_2-emissions of N_1-vehicles, as well as four packages with increasing levels of CO_2-reduction and technical complexity that may be applied by manufacturers in response to policy. For each of these packages the overall costs and CO_2-emission reductions have been assessed.

The CO_2-abatement costs are found to depend strongly on the desired level of CO_2-reduction and on fuel costs. Small levels of CO_2-reduction compared to the BAU baseline (up to 15 g/km) are found to yield cost benefits for almost all levels of fuel costs. Average emission reductions between 30 and 60 g/km can be reached at vehicles cost ranging from €350 to €6200 and abatement cost levels varying, depending on fuel price, between about 65 and -30 €/tonne for a reduction of 30 g/km and between -205 and 110 €/tonne for a reduction of 60 g/km.

Achieving an average 60 g/km TA CO_2-emission reduction in N_1-vehicles has about equal CO_2-abatement costs as reducing the average TA CO_2-emission from M_1-vehicles with 20 g/km form 140 to 120 g/km. Given the non-linear dependence of abatement costs on the reduction target, an average 20 g/km TA CO_2-emission reduction in N_1-vehicles can thus be reached at significantly lower costs per ton than the same reduction in M_1-vehicles. CO_2-emission reduction in N_1-vehicles therefore is an interesting option to consider in the context of the Integrated Approach. Obviously this advantage of N_1-vehicles compared to M_1-vehicles is largely due to the fact that M_1-vehicles are subject to CO2-reducing policy until 2008, while such a policy does not exist for N_1-vehicles.

A first assessment of the overall GHG reduction potential associated with reducing the TA CO_2-emissions of new N_1-vehicles compared to the business-as-usual baseline has been made for EU-15. For a 2012 reduction target of 15 g/km the overall GHG reduction potential grows from 1.2 Mtonne/y in 2012 to 2.2 Mtonne/y in 2020. These values increase with higher reduction targets reaching 4.9 Mtonne/y in 2012 and 16.5 Mtonne/y in 2020 for a reduction target of 60 g/km. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

Fuel efficient driving

Assessment of the CO_2-abatement costs of eco-driving is found to be extremely sensitive to the methodology that is used and to variations in the values of the input parameters The initial effect of eco-driving is reasonably well measured and documented. The long term effect on the other hand is less well known, but is expected to be significantly smaller. As both the level of effect and the duration strongly affect the outcome of the abatement costs calculation the assessment presented here has significant uncertainty margins.

The effective use of a gear shift indicators (GSI) in itself only captures part of the total reduction potential of eco-driving. On the other hand GSI can be an effective tool to assist drivers in maintaining a correct and effective fuel efficient driving style. In this way the use of GSI in combination with eco-driving is expected to increase the long-term effectiveness of eco-driving. In this study it is assumed that the long term effect of applying eco-driving is a fuel consumption reduction of 3%. With the aid of GSI this can be improved to 4.5%. The effect of only using GSI is 1.5%. The duration of the effect of eco-driving is assumed to be 40 years for new drivers to whom has been taught during the regular driver training for their drivers licence. For existing drivers, e.g. following a dedicate course on eco-driving, an average duration of the effect of 25 years is assumed. The costs of lessons are set at €100 (no costs for new drivers). The additional manufacturer costs of GSI are €15 (€22 additional retail price).

Under the assumptions made in this analysis with regard to costs of lessons, GSI and government campaigns the application of eco-driving is a very cost effective means of reducing CO_2-emissions of passenger cars for oil prices ranging from 25 €/bbl upwards.

Incorporation of eco-driving in an EU-policy aimed at reducing CO_2-emissions from passenger cars is hindered by the limited monitorability of the effects of ecodriving.

The total GHG reduction potential of fuel-efficient driving depends strongly on the way the measure is implemented or promoted and on the assumed effectiveness of such promotion measures. Indicative calculations for EU-15 show the following results:

- If eco-driving is included in the lessons for new drivers, then a total reduction of 1.8 Mtonne/y could be achieved in 2012, increasing to 5.5 Mtonne/y in 2020;
- The total effect of mounting GSI systems on new vehicles is estimated at 1.5 Mtonne/y in 2012 and 4.4 Mtonne/y in 2020;
- For a combination of measures promoting the application of eco-driving by existing drivers the overall reduction potential is estimated at 4.0 Mtonne/y in 2012 growing to 9.1 Mtonne/y in 2020. If GSI is used to assist these drivers in maintaining a fuel-efficient driving style these values increase to 6.0 Mtonne/y in 2012 and 13.7 Mtonne/y in 2020.

A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

CO_2 based taxation schemes for passenger cars

As a policy instrument, taxation can be used to complement other measures in order to encourage the wider take up of more fuel efficient vehicles in the market through the use of a strong fiscal signal. Of the various taxation instruments available to the policy maker, this project focused on the use of taxes to encourage the purchase and use of low emission vehicles, i.e. taxes on registration and annual circulation; hence, other instruments, such as fuel taxes and road user chargers, were not considered. Within certain boundary conditions, i.e. no vehicle downsizing, no change to the proportion of diesel vehicles sold, and revenue neutrality, restructuring vehicle tax systems so they are based on CO_2 emissions has the potential to produce, on average, a 5% reduction across the EU-15 in emissions from new vehicles[2]. However, if these boundary conditions were relaxed, particularly the one concerning revenue neutrality, then different levels of CO_2 reduction might be achievable.

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[2] *Fiscal measures to reduce CO_2 emissions from new passenger cars*, COWI 2002

The achievement of the proposed harmonisation in the tax system (COM(2005)264) across Europe is likely to prove politically difficult. This need not adversely effect potential CO_2 reductions through restructuring of taxation, but it will necessitate individual concerted action by Member States. The evidence from the Member States indicates that a realignment of vehicle taxes to reflect CO_2 and other emissions is currently being considered in a number of countries.

Options for improved energy or CO_2-labelling

Labelling has a role to play in increasing awareness. However, evidence to date suggests that awareness of the impact of cars on climate change is only growing at a slow rate. There is a rationale, therefore, in improving the label. Several Member States are already improving their respective labels, but the current approach is leading to diverse and disparate responses. The Commission should consider the harmonization of the approach to labelling. However, the assessment of the label introduced under Directive 1999/94 suggests that labels have not yet significantly contributed to actual emission reductions. However, there are potential synergies if the label is used as part of a package of measures, e.g. linking vehicle taxation directly to the label's categories. In addition, the further dissemination of vehicle energy efficiency information to the public could be accomplished through an EU-based, or coordinated, 'Consumer Guide to Cleaner Vehicles' website.

It also appears that manufacturers' marketing strategies are often at odds with, and overshadowing, the message that the label is projecting. More attention needs to be given to influencing the manufacturer's message. At a minimum, the consideration of a code of conduct for advertising on environment and sustainability grounds should be considered. To ensure that potential car buyers are more aware of the impact of the climate impact of their purchasing decision, consideration should be given to ensuring that information on CO_2 emissions and fuel efficiency is given wherever and whenever cars are promoted. Thought should therefore be given to expanding the scope of Directive 1999/94 to cover car advertising in all media, i.e. including TV and radio, as well as newspapers and magazines.

Public procurement proposals

Public procurement provides the opportunity to stimulate the market in alternative more fuel efficient vehicle technologies and fuels by creating economies of scale for manufacturers and thereby reducing the costs of production. A 25% quota for public procurement of more fuel efficient vehicles could result in substantial savings in terms of CO_2 for both M_1 and N_1 vehicles. A net cost of €5 million for passenger cars and a net benefit of €253 million for N_1s and internal rates of return of 3.7% and 37.6% respectively have been estimated (SEC(2005)1588). The overall market share for publicly procured light duty vehicles is small and therefore the implementation of the quota is unlikely to achieve economies of scale. However, a number of Member States already have existing environmental vehicle public procurement policies at various tiers of government based on environmental or technologically driven criteria. The current public procurement proposal is of limited relevance to this study, as it does not propose action on either M_1 or N_1 vehicles and focuses on environmentally enhanced vehicles (EEVs), which do not have a criterion relating to CO_2 emissions. However, if the proposed public procurement Directive does come into force, and a CO_2-criterion is included in the EEV definition, then it might provide a model for a future public procurement proposal on N_1 vehicles.

Comparison of options

A comparison of all options with respect to abatement costs for CO_2-reduction and overall reduction potential is presented in the table on the next page. CO_2-abatement costs are calculated taking into account:

- additional costs (retail price excl. taxes) of technical measures applied;
- fuel cost savings based on real-world fuel consumption and fuel cost excluding taxes;
- avoided CO_2-emissions based on real-world fuel consumption and including Well-to-Wheel emissions of the fuel chain.

The cost effectiveness for consumers (net value of investment minus fuel cost savings) is generally different as for consumers fuel taxes, vehicle taxes and VAT have to be included. Given the fact that the share of taxes in the fuel price is higher than in the vehicle or product price, some options may actually have a net cost benefit to consumers while CO_2-abatement costs from a societal point of view are positive.

With regard to the table the following notes should be made:

- The overview table does not take into account the fact that the various measures are not directly comparable based on abatement costs and overall reduction potential alone for the following reasons:
  - The abatement costs and overall reduction potential calculated in this study are a preliminary calculation, with the CO_2 reductions being calculated ex-ante without considering market reactions by using models such as TREMOVE;
  - Not all measures are measurable, monitorable and/or accountable in terms of their effect and the influence of stakeholder actions on those effects, and despite their apparent attractiveness in terms of abatement costs it may therefore not be possible to use some measures in a policy aiming to reach the Commission's 120 g CO_2/km objective;
- For blending percentages up to around 10% the (abatement) costs and CO_2-reduction potential per unit of fuel of biofuels are assumed independent of the applied blending percentage. In the table below the overall CO_2-reduction potential is calculated for an additional use of 1%, which is irrespective of the percentage that is reached as a consequence of the Biofuels Directive. If the targeted 5.75% is not met in 2010 then making this target mandatory could be part of the Integrated Approach. The (abatement) costs associated with increasing the biofuels share from the level reached in response to the Biofuels Directive to 5.75% or another target set in a new CO_2-policy for passenger cars should be attributed to this new policy, and can be calculated by multiplying the increase in biofuel share with the costs for increasing the share by 1% as calculated in this report.
- The overall CO_2 reduction potential of the various measures, taking into account market dynamics in response to cost changes, will be calculated using TREMOVE;
- Macro-economic impacts of various measures as well as impacts on industry, global competition and promotion of innovation will be assessed in Task B. These aspects should also be taken in to account in a full comparison of options.

Overall conclusions

For the options that have been quantitatively assessed in this report the following overall conclusions can be drawn:

- The abatement costs for reducing CO_2-emissions in M_1-vehicles through technical measures that improve fuel efficiency on the type approval test are a benchmark for the other measures studied in this report. The abatement costs for reaching a new vehicle sales average of 120 g/km in 2012 range from 233 €/tonne at an oil price of 25 €/bbl to 132 €/tonne at an oil price of 74 €/bbl. The results for M_1-vehicles are sensitive to the assumptions made on the autonomous weight increase and to various assumptions made in relation to uncertainties in the cost assessment. Costs have been estimated based on data that are valid for large scale production of the applied technologies, but further assessment may be carried out to gain more insight in possible cost reductions as a function of time and production volume;

- Fuel efficient air conditioning systems reduce the real-world CO_2-emissions of passenger cars more cost effectively that technical measures to improve powertrain efficiency. However, inclusion of the energy use of air conditioning systems into the Type Approval test is not possible at this stage. This is due to the fact that a testing procedure that is consistent with the general approach of type approval testing does not yield sufficiently accurate results, while available more accurate procedures are considered too complex and costly for this purpose. The available TA-type test procedure for MACs can, however, be used in monitoring schemes e.g. accompanying a voluntary agreement with the industry to reduce indirect CO_2-emissions from airco systems;
- Retrofitting of low rolling resistance tyres has positive costs per avoided tonne CO_2-eq., but these abatement costs are somewhat lower than for efficiency improvement of conventional, new cars.
- Tyre pressure monitoring systems can be a very cost effective means of achieving a few percent reduction of the CO_2-emissions of the European passenger car fleet, with negative CO_2-abatement costs for oil prices above 30 €/bbl;
- Low-viscosity lubricants used in existing vehicles have higher CO_2-abatement costs than retrofitting of low rolling resistance tyres;
- Natural gas is a relatively expensive option for reducing CO_2-emissions from passenger cars. Abatement costs are generally higher than for efficiency improvement of conventional cars. If cost reductions would be possible beyond the cost value used for the assessment in this report, then conversion to natural gas could compete with the expensive technologies that need to be applied to passenger cars for reaching 2012 targets of 125 or 120 g/km in scenarios with a high oil price;
- For biofuels the CO_2-abatement costs depend highly on the assumed values for fuel costs and WTW CO_2-emission reduction. Brazilian ethanol is cost-effective for most oil price values. The CO_2-abatement costs of 1st generation European biofuels are in the same range as that of technical measures that can be applied to improve the fuel efficiency of passenger cars. Measures to increase the share of biofuels beyond the existing 5.75% target of the EU Biofuels Directive need to be critically reviewed. Additional policy aiming at increased use of biofuels should include a system to monitor the Well-to-Wheel GHG emission reduction of fuels (incl. conventional fuels), as reducing WTW emissions of biofuels may in some cases be more effective than increasing the share of biofuels.
- The abatement costs of reducing CO_2-emissions in light-duty commercial vehicles (N_1) are generally lower than those of technical measures applied to passenger cars. This is not so much due to lower costs for N1-vehicles, but to the fact that for passenger cars CO_2-abatement costs are calculated compared to a baseline that already incorporates policy measures to reduce CO_2-emissions (i.e. only the costs and effects of going beyond the 2008/9 target of the manufacturers' self commitments is assessed), while for N_1-vehicles such policy is not yet in place.
- Fuel efficient driving, based on lessons and with or without the aid of GSI, is a very cost effective means of achieving one or two percent reduction of the CO_2-emissions of the European passenger car fleet. This option, however, has a problem with regard to measurability, monitorability and accountability.

Comparison of options with respect to abatement costs (€ per tonne of CO_2-eq. avoided) and total reduction potential

		Retail price excl. tax per vehicle [€][1]	GHG abatement costs in [€/tonne CO_2-eq.]				Total annual reduction in [Mtonne/y]	
Oil price			**25 €/bbl**	**36 €/bbl**	**50 €/bbl**	**74 €/bbl**	**2012**	**2020**
Technical options at the vehicle level[2]	- 140 g/km in 2012	245	--	--	--	--	--	--
	- 135 g/km in 2012	570	166	143	114	65	3.0	5.1
	- 130 g/km in 2012	960	187	164	135	86	6.8	21.4
	- 125 g/km in 2012	1410	209	186	157	108	10.6	37.7
	- 120 g/km in 2012	1940	233	210	181	132	14.4	54.1
Fuel efficient air conditioning systems[3]		33 / 19	68 / 90	48 / 66	24 / 37	1.5	1.0	2.7
Options reducing vehicle resistance	- Low rolling resistance tyres	49	139	109	73	15	2.4	5.3
	- TPMS	58	5	-20	-50	-98	2.0	9.6
	- Low viscosity lubricants	20	181	150	113	53	2.0	9.6
CNG[4]	- compared to 2008 petrol	2030	400	356	302	208	2.4	7.3
	- compared to average 2008 vehicle	1450	347	312	268	193	2.1	6.4
Biofuels[5]	- Brazilian ethanol	12 ± 2 €/GJ	52 / 136	16 / 90	-28 / 34	-103 / -63	3.1 - 4.0	3.1 - 4.0
	- European ethanol	19 ± 6 €/GJ	196 / 656	137 / 564	65 / 451	-58 / 257		
	- Biodiesel	18 ± 3 €/GJ	158 / 426	111 / 355	53 / 268	-47 / 118		
N_1-vehicles[6]	- 15 g/km reduction	410	6	-16	-44	-91	1.2	2.2
	- 30 g/km reduction	1620	63	41	14	-34	2.4	7.0
	- 45 g/km reduction	3850	131	108	88	34	3.7	11.7
	- 60 g/km reduction	7240	206	184	156	109	4.9	16.5
Fuel efficient driving	- new drivers	0	-35	-50	-69	-100	1.8	5.5
	- GSI	17	-26	-50	-78	-128	1.5	4.4
	- existing drivers (lessons)	100	-2	-21	-45	-85	4.0	9.1
	- existing drivers (lessons + GSI)	135	-7	-26	-49	-89	6.0	13.7

[1]) Retail price excl. tax is input for abatement cost calculation.

[2]) Average results for the scenarios where various targets are applied per manufacturer without trading

[3]) Policy scenario compared to baseline, data for 2010 and 2012.

[4]) For natural gas imported from outside Europe with 4000 km transport distance. Abatement costs for scenario assuming additional market share growing to 10% in 2012 and beyond.

[5]) Abatement costs assessed for high reduction % / low fuel cost assumption resp. low reduction % / high fuel cost assumption, based on fuel production costs, for additional 1% replacement of fossil fuels.

[6]) Costs compared to 2012 business as usual baseline.

Table of Contents

1 Introduction

This is the Final Report of the project *"Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars"* (contract nr. SI2.408212), which has been carried out by TNO, IEEP and LAT on behalf of the European Commission (DG-ENTR). The project is Task A of a set of two studies which are supporting the Impact Assessment, to be prepared by the European Commission in the preparation of a new strategy aimed at reducing the CO_2-emissions of light-duty vehicles to a level of 120 g/km in 2012.

Task B is the project *"Service contract in support of the extended impact assessment of various policy scenarios to reduce to reduce CO_2 emissions from passenger cars",* carried out by ZEW and B&DForecast. This project assesses the macro-economic impacts as well as the impacts in the automotive industry of scenarios consisting of various technical and non-technical measures which are reviewed in Task A. In addition to these two Tasks, TML is performing TREMOVE calculations to assess impacts on the transport system and the environment.

1.1 Objectives

The main objectives of this project are:

4. to review the potential and related costs of various options for reducing the CO_2 emissions from passenger cars beyond the results reached in 2008/2009 based on the existing Community strategy;
5. to identify and design post 2008/9 CO_2 reduction scenarios, and to provide input to TML and Task B (*Service contract in support of the extended impact assessment of various policy scenarios to reduce to reduce CO_2 emissions from passenger cars*) so that these scenarios can be run in the partial and general equilibrium models;
6. to assist TML and the contractors for Task B in the interpretation of the results of their assessment of the likely economic, environmental and social effects of the scenarios studied.

1.2 Activities under objective 1: review of options

In Task A a number of technical and non-technical measures is reviewed in terms of their potential contribution to CO_2-reduction in passenger cars and their costs. These measures have been identified by the European Commission and can be regarded as complementary options in the context of a so-called Integrated Approach. In this project the review of these different measures, as part of Objective 1, is organised in the Tasks specified below:

Task 1.1	Review of technical options to reduce fuel consumption at the vehicle level	(TNO / LAT)
Task 1.2	Review of options for application of alternative fuels based on fossil energy	(TNO)
Task 1.3	Review of CO_2 based taxation schemes for passenger cars	(IEEP)
Task 1.4	Review of options for improved energy or CO_2 labelling	(IEEP)
Task 1.5	Review of options for promoting fuel efficient driving	(TNO)
Task 1.6	Review of options to promote application of fuel efficient air conditioning systems	(TNO)
Task 1.7	Review of options to reduce vehicle and engine resistance factors	(LAT)
Task 1.8	Review of public procurement proposals	(IEEP)

Task 1.9 Review of options to promote application of biofuels (IEEP)

Task 1.10 Review of the possibilities to include N_1 vehicles into the Commitments (TNO / IEEP)

The numbering of the Tasks relates to the original list of options to be studied as included in the Technical Specifications for this project. For a clearer presentation these options can been grouped into two sets of technical resp. non-technical measures. The listing below is maintained for the chapters in this report:

Technical measures
- technical options to reduce fuel consumption at the vehicle level
- application of fuel efficient air conditioning systems
- options to reduce vehicle and engine resistance factors
- options for application of alternative fuels based on fossil energy
- increased application of biofuels
- possibilities to include N_1 vehicles into the Commitments

Non-technical measures
- fuel efficient driving
- CO_2 based taxation schemes for passenger cars
- options for improved energy or CO_2 labelling
- public procurement proposals

1.3 Activities under objective 2: Scenario development

Work under Objective 2 of Task A contains the following elements:

- Review of the CO_2 data currently used in TREMOVE, and possible fine tuning;
- Collaboration with the contractors of Task B and TML to define appropriate formats for the input data to be delivered for use in TREMOVE and the general equilibrium model of Task B
- Cooperation with the European Commission, TML, the contractors of Task B and various stakeholders to define the scenarios to be analysed by TREMOVE and Task B;

Scenarios in this context are consistent packages of technical and non-technical measures aimed to achieve the overall targets of 120 gCO_2/km. For comparing scenarios the target of 120 g/km will be translated into an overall CO_2-reduction target in Mtonnes/year[3] on the basis of a reference scenario in which the 120 g/km target is reached solely by technical measures at the vehicle level.

As a starting point for building scenarios the options will be evaluated and ranked in terms of abatement costs (expressed in €/tonne CO_2 costs to society) and potential impact (contribution to reaching the overall CO_2-target)[4]. Complementary options will be combined to create robustness. These include technical and market-oriented measures. Measures and targets will be differentiated towards the various responsible stakeholders:

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[3] The result of this calculation will be a preliminary assumption since overall CO_2 savings will in fact be calculated with TREMOVE, taking into account the overall transports system evolution

[4] Other parameters (sensitivity to global competition, promotion of innovation, political feasibility/acceptability) will be taken into account by task B.

- Car industry: efficient vehicles;
- Fuel industry: alternative fuels;
- Consumers: purchasing & driving behaviour;
- Public authorities: taxation policies, information campaigns on ecodriving, public procurement.

Targets should be defined in such a way that the success of one stakeholder does not reduce the required effort by other stakeholders.

1.4 Activities under objective 3: Contribution to the assessments by TML and Task B

Work under Objective 3 of Task A mainly concerns providing assistance to TML and the contractors of Task B in the analysis of results from model calculations with TREMOVE and the models of Task B. These results of these model runs may require some iterative adjustments of the input data provided by Task A.

1.5 General approach of Task A

For the Tasks as listed above the general approach is as follows:

- Review of available literature / studies
- Limited effort in collection or generation of new data
- Interaction with stakeholders through:
    - Inter-service Coordination Group of the Commission
    - Steering Group
    - questionnaires and, if necessary, interviews
    - ECCP II Working Group on “the Integrated Approach to CO_2-reduction from light duty vehicles”
- Quantitative assessment of reduction potential, costs & abatement costs of various options
- Qualitative evaluation of options for implementation of policy measures
- Generation of input data which can be used in TREMOVE and Task B

Confidentiality of input data provided by industry stakeholders

For several of the tasks as listed in section 1.2 detailed input data on CO_2-reduction potentials and costs of components have been collected from industrial stakeholders (automotive manufacturer associations, supply industry associations, individual manufacturers) by means of questionnaires and meetings. Several of these stakeholders have expressed a strong preference that their data are treated as confidential. For this reason it has been decided not to include details of the input data provided by any of the industrial stakeholders in this report. In the assessments of the various topics, however, the data provided by the industry has been an important and valuable source of information.

1.6 Relation between Task A and the “Integrated Approach”

The original pillars of the EU passenger car CO_2 strategy – the so-called car industry's ‘voluntary commitments’, the CO_2 emissions label and taxation measures – focused on the emissions performance of new vehicles, and specifically cars, as this was arguably the main area of EU competence in relation to addressing transport’s greenhouse gas emissions. In particular, in the Recommendations from the Commission that form part of the self-commitments with the carmakers’ associations, the main source of progress is envisaged to be through technical improvements by the carmakers, possibly accompanied by a degree of downsizing. Supplementary efforts by Member States in the fields of taxation and labelling were also foreseen under the agreements, but where these occur, they are to be viewed as additional to and distinct from the improvements to be made by manufacturers themselves in meeting their 140g/km targets. Vehicle improvements were also expected to make 'the major contribution' towards the subsequent achievement of the Community's 2012 target of 120g/km.

1.6.1 CARS21 working group on the Integrated Approach

More recently, there has been discussion (launched by ACEA) of the adoption of an 'Integrated Approach' at EU level in the context of the Passenger Car CO_2 Strategy to reducing transport's greenhouse gas emissions. The Integrated Approach was also the subject of a CARS21 Working Group, which has given additional impetus to this approach. The essence of the Integrated Approach is that:

- a 2012 CO_2-target may be reached more cost-effectively by a combination of technical and non-technical measures to be carried out by the car industry and the other stakeholders (fuels & lubricants industry, tyre industry, consumers, authorities, etcetera);
- from an environmental perspective, there is a greater potential for CO_2 reductions when more elements of the system are subject to reduction measures;
- greater policy coherence could give more scope for synergism and avoidance of perverse effects;
- adjustment costs can if appropriate be shared between a broader range of stakeholders.

The options listed in section 1.2 reflect that in the definition of the contents of Task A by mid 2004 the European Commission already anticipated such an approach.

However, some options, which were discussed in the context of CARS21, are not included in Task A. These are:

- traffic measures:
  - in CARS21 especially synchronisation or traffic lights was mentioned
  - speed limitation
  - town planning
  - infrastructural measures, incl. infrastructure charging
- public transport
  - higher levels of provision
  - modal shift from road to rail
- utilisation of longer trucks
  - to reduce number of trucks on the road (decreases congestion) and decrease energy consumption per tonne-km.
- responsible marketing & advertising

The total list of options discussed in CARS21 is probably not even exhaustive. Additional options would e.g. be the promotion of the use of niche fuels (pure biofuels, biogas, etc.) or the accelerated implementation of fuel cell vehicles and sustainable hydrogen.

Especially the option of traffic measures may have a significant potential. Besides synchronisation or traffic lights in urban areas this would also include (enforced) speed limits on highways and various measures to curb congestion by means of traffic flow management. These measures are currently under study in the context of solving local air quality problems (esp. related to PM_{10} and NO_2) and of the European Common transport policy. In our view the subject can not yet be included in the Impact Assessment for a new European CO_2-policy, as a new generation of emission factor models to assess the impacts of changing traffic dynamics on emissions is only now being developed. As a consequence these models are not yet mature and for the time being lack European consensus.

1.6.2 ECCP II Working Group on "the Integrated Approach to CO_2-reduction from light duty vehicles"

In December 2005 the ECCP II Working Group on "the Integrated Approach to CO_2-reduction from light duty vehicles" was started. This working group is intended as a stakeholder consultation forum for including the Integrated Approach in the European Commission's Impact Assessment in the preparation of a new strategy aimed at reducing the CO_2-emissions of light-duty vehicles to a level of 120 g/km in 2012. Task A will present its results to this Working Group and –in consultation with the Commission– will deal with the feedback provided by the stakeholders represented in the Working Group.

1.6.3 Methodological issues of the "Integrated Approach"

When the present Community policy, aiming at reducing the CO_2-emissions of new vehicles as measured on the type approval, is replaced by a policy that strives to accomplish a CO_2-reduction through a combination of technical and non-technical means (i.e. the Integrated Approach) a number of methodological issues arise. These issues, which are discussed below, need to be explored further in the process of evaluating options and making scenarios in Task A and B.

1.6.3.1 Metric in which the target is expressed

The present Community target of 120 g/km refers to the sales-weighted average of the CO_2-emissions (as measured on the type approval test (NEDC-cycle)) of newly sold vehicles in Europe in a given year, expressed in gCO_2/km. CO_2 in this context is direct CO_2-emissions in the exhaust gases as measured in the lab. Various measures proposed under the Integrated Approach do not affect CO_2-emissions on the type approval test, but do reduce the real-world CO_2-emissions of vehicles (e.g. efficient air conditioners and ecodriving). For the Integrated approach, therefore, a new target definition is necessary, related to the real-world CO_2-emission expressed e.g. in fleet average gCO_2/km on the road or total fleet emissions in Mtonne/y, either for the fleet of newly sold vehicles or for the entire fleet. In principle a translation can be made on the basis of the estimated impact in Mtonne/y of the original 120 g/km target related to technical measures on new vehicles only, although this is a preliminary assumption and the overall CO_2 savings will be calculated using the TREMOVE model.

1.6.3.2 Scope of application

Some measures (e.g. ecodriving or biofuels) not only affect the CO_2-emissions of new vehicles but also the emissions of the entire fleet. Options such as retrofitting of low rolling resistance tyres specifically target the existing fleet. Furthermore in Task A also the inclusion of N_1-vehicles in the Commitments is considered.

1.6.3.3 Baseline scenario for biofuels

The EU Biofuels Directive encourages Member States to replace 2% resp. 5.75% of their transport fuel consumption by biofuels in 2005 resp. 2010. The target, however, is not binding. It should therefore be envisaged that this target may not be met by the European Community as a whole. For this reason the costs and CO_2-reduction potential of biofuels are not studied in relation to an absolute target in this report, but rather per unit of additional biofuel share in the total fuel use irrespective of the baseline share to which a new biofuels policy is applied.

1.6.3.4 Well-to-wheel aspects

When natural gas or biofuels are considered as candidate measures for the Integrated Approach then not only the direct, tailpipe CO_2-emissions should be taken into account but rather the total (= upstream + direct) CO_2-emissions or even total greenhouse gas emissions in the entire Well-to-Wheel (WTW) energy chain. If all greenhouse emissions were included in the approach, as they should be in principle, then the total emissions would need to be calculated in terms of total CO_2-equivalent emissions (where emissions of the different greenhouse gases would be weighted on the basis of their respective GWP). For an assessment as carried out in Task A sufficient general data are available from existing WTW-analyses. When alternative fuels are used in practice, however, it is very difficult to certify what the WTW greenhouse gas emissions of a specific fuel are. One needs to know the origin of the fuel, the transportation distances, efficiencies and emissions of refineries, etcetera.

1.6.3.5 Measurability, monitorability and accountability

Policies with quantitative targets require quantitative means to monitor progress in relation to those targets. This means in this case that the achieved CO_2-emission reductions need to be measurable in some way. If various stakeholders are involved in achieving the overall target their individual contributions must be measurable in order to be able to make these stakeholders accountable for their contributions. This poses severe demands on the definition of the target and the policy measures, which need to be discussed in the context of the process of arriving at a new Community policy on cars and CO_2. Measurability of real-world CO_2-emissions is not a trivial issue. Overall effects may be monitored based on total sales of different fuels (and their CO_2 conversion factors), but decomposition of these effects into various origins requires a measure of the real-world CO_2-emissions of individual cars and transport performances. The former can be done (by approximation) in different ways. Given the present TA test procedure this measure might be derived from Type Approval data using a conversion factor. This factor may depend on technology and may develop over time and thus needs to be monitored in some way by itself in order for it to be acceptable to all stakeholders. Another way could be to adapt the TA test procedure to make its results more representative of real-world driving. A starting point would be the definition of a new driving cycle. Similarly, the monitorability of ecodriving is considered problematic.

2 Methodological aspects

2.1 Cost definitions

In the context of this study three main cost definitions are discerned:
- manufacturer costs = ex-factory costs
- costs to society, to be used in the calculation of CO_2-abatement costs
- consumer costs = retail price

Basic data from different sources on the costs of technological options in this report are compared on the basis of manufacturer costs. Manufacturer costs include all direct costs to produce a vehicle (purchase costs of materials and components, tooling costs, labour costs, etc.) as well as a proportional share of company overheads (R&D, management, marketing, etc.). The analysis presented in Annex A indicates that manufacturer costs of an average vehicle amount about 60% of the vehicle retail price in Europe.

In this study cost to society for use in the calculation of CO_2-abatement costs are defined in a first order approximation as retail price minus taxes, applied to the additional vehicle costs as well as to the fuel cost savings (or possibly increases in the case of alternative fuels). It can be argued whether profits should or should not be a part of the costs to society. However, profits can to a large share be interpreted as mark-up for entrepreneurial risks (e.g. to cover losses in case of bankruptcy) and can thus be considered as real economical costs to be included in the calculation of CO_2-abatement costs as perceived by society. In contrast to what was assumed in [IEEP 2004] dealer costs should be included in these costs as these are real economic costs of bringing the product to the user. Based on this reasoning the investment costs to be used in the calculation of CO_2-abatement costs of vehicle-related measures to reduce CO_2-emissions are equal to 81% of the additional retail price (see Annex A). It should be noted that this definition of cost to society is a limited definition which is not including all aspects usually included in a formal definition of societal costs. The net societal costs corresponding to CO_2 reduction should include various aspects of economic welfare such as the change in consumer surplus, i.e. increased investment costs minus fuel savings, the change in business profits, and the change in government surplus. In a complete approach they should also include potential environmental co-benefits and effects on safety. Furthermore second order effects of changes in price on the demand for transport, the demand for cars and the sales distribution over fuel types and vehicle classes can be taken into account in assessing societal costs.

Using a broad definition of societal costs, however, is considered beyond the scope of Task A. Relevant other studies also use a limited definition of societal costs. E.g. [Blok 2001] includes additional investment costs, changes in operation and maintenance costs, changes in fuel costs and secondary benefits. For the options under study in Task A, however, possible changes in operation and maintenance costs are assumed negligible (except for e.g. recurring replacement costs of low rolling resistance tyres or low viscosity lubricants which are included as investment costs). With regard to secondary benefits [Blok 2001] includes changes in external costs related to changes in the emissions of air pollutants or noise associated with applying the CO_2-reducing technology. For the options considered in Task A, however, the secondary effects on emissions are negligible or already accounted for in the assessment of investment costs by subtracting part of the technology costs that may be attributed to meeting other goals than CO_2-reduction (which is the case for some engine technologies assessed in chapter 3). Reduction of the external costs of CO_2-emissions should not be included in the calculation of CO_2-abatement costs. In the absence of present damage costs, the external costs of CO_2-emissions are generally estimated based on avoidance costs, so that including these in the CO_2-abatement cost formula would lead to inappropriate double-counting. [AEA 2001] uses the same definition of costs to society as the one used in this study. At a more aggregate level a broader definition of societal costs may be taken into account in the TREMOVE calculations and the assessments carried out in Task B.

In this study we are dealing with the marginal, i.e. additional costs of applying CO_2-reducing technologies to a baseline vehicle. If a car becomes more expensive to build due to CO_2-saving technologies this does not mean that all costs in bringing the car to the consumer (dealer costs) increase with the same percentage. Based on the first table in Annex A the average dealer mark-up equals 27% of the manufacturer costs (both excl. profits). It is proposed to assume that for additional manufacturer costs related to CO_2-reduction the additional dealer costs are only 10% of the manufacturer costs. Including profit margins[5] this yields a factor of 1.16 between manufacturer costs and the additional retail price excluding taxes, which then also is the new definition to use for the additional investment costs. Including a 19% share of tax in the retail price (which is the sum of additional manufacturer costs and profits, additional dealer costs and profits, and tax), the factor between additional manufacturer costs and additional retail price becomes 1.44. This is also presented in the table below (see also Annex A).

Table 2.1 Relation between marginal manufacturer costs and marginal investment costs to society (for use in calculation of CO_2-abatement costs)

add. manufacturer costs		1.00	
manufacturer profit / manuf. costs	0.05		
marginal dealer costs / manuf. costs	0.10		*assumed marginal value for additional technology*
dealer profit / manuf. costs	0.01		
add. retail price excl. tax		1.16	*= factor between retail price excl. tax a and additional manufacturer costs*
tax (19% of retail price)	0.27		
retail price incl. tax		1.44	*= factor between retail price incl. tax and additional manufacturer costs*

For the calculations presented in this report this means the following:

- Literature data on additional retail price are translated into manufacturer costs using the factor 1.44, unless a different known factor is used by the source[6]. Obviously for various sources it is not known what definition they used so this introduces a level of uncertainty. However, as the manufacturer associations and various suppliers and supplier organisations have been asked to provide data on manufacturer costs, this uncertainty has a limited influence on the final cost assessment.
- For the calculation of CO_2-abatement costs the additional manufacturer costs of the option under consideration are multiplied by a factor of 1.16.

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[5] One might argue that new technologies at their early stage of market introduction are sold without a profit or even with a loss, but the starting point of our assessment is that we analyse whether technologies are cost effective in the situation in which they are technically and economically mature. Whether that can be reached by 2012 for some of the options, is another issue and should be dealt with in the discussion on the time horizon for the policy measures.

[6] Various US sources appear to be using a factor of 1.4. This value is consistent with the price breakdown analysed in [ANL 2000] (also analysed in Annex A). In [ANL 2000], however the value is derived for the whole vehicle price. As argued in section 2.1 and Annex A, a different factor should be applied to relate additional manufacturer costs of applied CO_2-reduction technologies to retail price increase. Given the difference in tax regimes the whole vehicle factor of 1.4 for the US seems roughly consistent with the whole vehicle translation factor of 1.67 as derived in Annex A for Europe).

2.2 Calculation of CO_2-abatement costs

In this report various technical and non-technical options for reducing the CO_2-emissions of passenger cars and vans are compared on the basis of CO_2-abatement costs, i.e. the net costs to society per unit of CO_2 avoided. For this purpose the following formula is used:

$$\text{CO}_2\text{-abatement costs} = \frac{\text{investment} - \text{NPV (lifetime fuel cost savings)}}{\text{lifetime CO}_2\text{-reduction}}$$

The net costs equal the investment costs (manufacturer costs * 1.16 = retail price excl. tax) minus the net present value of the lifetime fuel savings (based on fuel price excluding taxes). For calculating the net present value an interest rate of 4% is used in line with the prescribed procedures for impact assessments performed by the European Commission. For vehicle technologies a constant average annual mileage of 16,000 km and an average vehicle lifetime of 13 years. For other options the lifetime may be different. It could be argued that in the calculation of net present value of the lifetime fuel savings the annual mileage should be differentiated over time to reflect that new cars generally drive more kilometres per year than older cars. However, since this is a first order assessment of CO_2-abatement costs, and since the above formula with constant yearly fuel savings is applied equally to all options under study, the proposed simplified approach is deemed sufficient.

Fuel cost savings are based on the real-world fuel consumption which is assumed to be 1.195 times the TA value (see section 2.3). The CO_2-reduction is also based on the real-world CO_2-emission, calculated from the TA value using a factor of 1.195, and furthermore includes the avoided WTT CO_2-emissions (see section 2.4).

This definition is different from the one used in [IEEP 2004]. Besides the new definition of investment costs in relation to additional manufacturer cost, real-world driving and WTW-aspects are included to make the abatement cost calculation comparable to the assessments for e.g. eco-driving (chapter 9) and biofuels (chapter 7).

Lifetime fuel cost savings are dependent on the fuel cost (fuel price excl. taxes). In this report CO_2-abatement costs are generally calculated for 4 different scenarios assuming different values for the oil price and related costs of fuels. Data on oil price and costs of petrol/diesel are given in Table 2.2. The values for oil prices of 25 and 50 €/bbl are based [Concawe 2006], which uses the same two oil price scenarios. Gas costs in this table are price at the filling station excluding taxes and including the amortised costs of infrastructure. The values printed in italic have been calculated from these values assuming a linear relation between fuel costs and oil price. The value of 0.30 €/l for the costs of petrol/diesel (price excl. taxes) was used in [IEEP 2004]. The value of 0.60 €/l for the costs of petrol/diesel is added as an extreme scenario.

Table 2.2 Oil price and fuel cost values assumed for CO_2-abatement costs calculations

oil price [€/bbl]	petrol/diesel cost [€/l]	gas cost [€/m^3]
25	0.21	0.32
36	*0.30*	*0.40*
50	0.41	0.49
74	*0.60*	*0.65*

It should be noted here that the CO_2-abatement costs as calculated in this study are only a first indication of the cost effectiveness of the measures under study. The CO_2 reductions are calculated ex-ante without considering market reactions. A more definitive assessment of cost-effectiveness will be performed using the TREMOVE-model.

2.3 Translation from Type Approval to real-world CO_2-emission

The real-world (RW) emissions and fuel consumption of vehicles generally differs significantly from the values measured on the Type Approval (TA) test using the NEDC driving cycle and the prescribed test conditions. A description of the physical aspects that determine this difference and an assessment of the average quantitative relation between RW and TA fuel consumption and CO_2-emissions is presented in Annex B. In this study an average factor of 1.195 is used. Obviously this factor may change as a result of CO_2-reducing technologies that e.g. affect the ratio between part-load and full-load efficiency of the powertrain but this aspect is difficult to quantify within the aggregated approach of this study and is therefore neglected. The issue may require further study in a future project. The limited availability of hybrids and other advanced powertrains does not yet allow a statistically sound identification of a possible difference in the translation factor from type approval to real-world between these vehicles and vehicles with more conventional power trains.

2.4 Calculating Well-to-Wheel CO_2-emissions

Besides the direct CO_2-emissions from the exhaust the use of a vehicle also causes indirect CO_2- and other greenhouse gas emissions emanating from the fuel chain. Direct emissions are referred to as tank-to-wheel (TTW) emission, while the emissions from the fuel chain are called well-to-tank (WTT) emissions. The sum of the two are the well-to-wheel (WTW) emissions resulting from the mining and transport of raw energy carriers, the production and distribution of fuels and the consumption of fuel in the vehicle. Emissions of different greenhouse gases (CO_2, CH_4, N_2O as well as e.g. CFCs and HFCs used as airco refrigerants) are expressed and added in CO_2-equivalents by multiplication with a Greenhouse Warming Potential (GWP).

For calculating WTW greenhouse gas emissions this study generally uses factors based on [Concawe 2006]. The factors for translating TTW CO_2-emissions into WTW CO_2 emissions are given in Table 2.3. In various analyses on “average” vehicles an sales-weighted average WTW/TTW factor of 1.183 is used, based on a 50%/50% share of petrol and diesel in the fleet.

Table 2.3 Data on the WTW greenhouse gas emissions from petrol and diesel derived from [Concawe 2006].

	TTW		WTT			WTW
	CO_2-content [gCO_2/MJ_fuel]	lower heating value (LHV) [MJ/l_fuel]	WTT energy consumption [MJ/MJ_fuel]	WTT CO_2-emission [gCO_2/MJ_fuel]	WTT CO_2-emission [gCO_2/gCO_2_TTW]	WTW CO_2-emission [gCO_2/gCO_2_TTW]
petrol	73.40	32.2	0.14	12.5	0.170	1.170
diesel	72.80	35.8	0.16	14.2	0.195	1.195

2.5 Calculation of overall CO_2-reduction

The essence of the Integrated Approach is to identify a package of measures that achieves a certain level of CO_2-emission reduction for the lowest costs. As the idea of the Integrated Approach originates from discussions on the feasibility of reaching the Community target of 120 g/km by means of technical measures at the vehicle level, an reference case can be defined by means of a translation of the 120 g/km TA-based target to an equivalent target for the Integrated Approach expressed in Mtonnes/y for the EU-25.

In order to be consistent with the TREMOVE calculations to be performed on the basis of the output of this study it was decided to calculate the overall CO_2-reduction potential of various measures using a fleet spreadsheet on the basis of output data on vehicle stock, annual mileage and baseline CO_2-emission from TREMOVE (see [TREMOVE]). At the time of these calculations TREMOVE 2.42 baseline data were available for EU-15 only. All CO_2-reduction potential assessments presented in this report therefore relate to EU-15.

The fleet spreadsheet used contains for the years 1995, 2000, 2002, 2005, 2008, 2009, 2010, 2011, 2012, 2015 and 2020 data on the vehicle stock specified in:

- number of vehicles of different ages
    - for some calculations (e.g. NGVs) also a distinction between petrol and diesel vehicles was used;
- annual mileage for vehicles of different ages;
- real-world CO_2-emission for vehicles of different ages (in TREMOVE based on COPERT III).

Such a spreadsheet allows modelling of the effect of the gradual penetration of new technologies into the fleet through the sales of new vehicles, taking account of the fact that new vehicles drive more kilometres per year than older vehicles, but also allows the assessment of effect of measures that target the entire fleet. CO_2-emission reduction potentials are calculated for the different years in Mtonnes/y by subtracting the emissions produced under certain scenario assumptions from the emissions produced in the baseline situation. Overall emissions are calculated by means of the sumproduct of the number of vehicles, the annual mileage and the CO_2-emission in g/km of vehicles of different ages in the fleet.

It should be noted here that the CO_2-reduction potential as calculated in this study is only a first indication of the overall CO_2-reduction potential of the measures under study. The CO_2 reductions are calculated ex-ante without considering market reactions. A more definitive assessment of CO_2-reduction potentials for the various measures will be performed using the TREMOVE-model.

As stated above CO_2-reduction potentials are only assessed for EU-15. However, the objective of the EU policy is to reach an EU-25 average of 120 g CO_2/km. Based on 2004 monitoring results, EU10 average emissions are at 156 gCO_2/km, compared to an EU-15 average of 163 gCO_2/km, leading to an EU-25 average of 162 g CO_2/km. Including the new countries into the assessment would thus result in somewhat smaller average values for the EU-25 new vehicle sales averaged CO_2-emission. This effect can not be taken into account, not even in an indicative way. The car market in the new EU countries is a growing market in contrast to the rather saturated market in EU-15. As a consequence the optimal solution for reaching a 2012 target may be different for the EU-25 than for EU-15. Projections on the development of this growing market should be made in order to properly assess the future average new vehicle CO_2-emissions for EU-25. Given the lack of readily available data on this market such an analysis was considered beyond the scope of this study.

2.6 Literature

[AEA 2001] *Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change, Economic Evaluations of Emissions Reductions in the Transport Sector of the EU, Bottom-up Analysis*, J. Bates, C. Brand, P. Davidson and N. Hill, AEA Technology for DG Environment, March 2001

[ANL 2000]	*Comparison of indirect cost multipliers for vehicle manufacturing*, Anant Vyas, Dan Santini and Roy Cuenca, Centre for Transportation Research, Argonne National Laboratory, April 2000
[Blok 2001]	*Economic evaluation of sectoral emission reduction objectives for climate change, bottom up analysis of emission reduction potentials and costs for GHG in the EU*, ECOFYS Utrecht the Netherlands, 2001. See also: *Economic evaluation of sectoral emission reduction objectives for climate change; Summary Report for Policy Makers*, updated March 2001
[Concawe 2006]	*Well-to-Wheels analysis of future automotive fuels and powertrains in the European context*, Concawe / Eucar / JRC, update of the 2003 study, January 2006.
[IEEP 2004]	*Service contract to carry out economic analysis and business impact assessment of CO_2 emissions reduction measures in the automotive sector*, contract nr. B4-3040/2003/366487/MAR/C2, carried out by IEEP, TNO and CAIR on behalf of DG-ENV, 2004.
[TREMOVE]	http://www.tremove.org/

3 Technical options to reduce fuel consumption at the vehicle level

3.1 Goal of Task 1.1

Task 1.1 covers a detailed assessment of the technical feasibility, CO_2 reduction potential and costs of technical measures at the vehicle level which can be implemented by manufacturers in support of achieving a 120 g/km goal. These measures include technical options to improve engine and powertrain efficiency and to reduce vehicle weight and resistance factors. Alternative fuels such as CNG or biofuels are covered separately in Task 1.2 (Chapter 6) and Task 1.9 (Chapter 7). Options to improve the energy efficiency of air conditioners are discussed in Task 1.6 (Chapter 4). An overview will be given of policy measures that can be employed to promote the application of technical options to reduce fuel consumption at the vehicle level.

3.2 Approach

Starting point for the analysis are the methodology and results of a previous study by IEEP/TNO/CAIR for DG-ENV [IEEP 2004]. This study will updated using data from more recent reports, e.g. issued in relation to the CARB CO_2-legislation, and information obtained from consultation of stakeholders and independent experts.

A table has been drawn up listing a wide range of relevant individual technical measures at the engine, powertrain or vehicle level as a starting point for discussions with industry and independent experts.

As agreed at the Steering Group meeting on July 20, 2005, consultation of the industry was co-ordinated through the associations ACEA/JAMA/KAMA. A questionnaire, with clear specification of the requested data and useful explanations, has been drawn up on the basis of the above-mentioned table. In September 2005 the European Commission has sent this questionnaire to ACEA, JAMA and KAMA. ACEA, JAMA and KAMA have submitted responses to this questionnaire between December 2005 and May 2006. Especially with ACEA intensive interaction has taken place on the interpretation of the submitted data and their application to this study.

In the questionnaire Tasks 1.1 (technical options at the vehicle level) and 1.7 (tyres and lubes) have been combined. Furthermore some questions were added concerning Task 1.2 (alternative fuels based on fossil energy).

Based on literature data and results from the industry and expert consultation with a table is drawn up with cost and CO_2-reduction data of the technologies evaluated under this subtask. Using the cost curve approach and the cost assessment model developed in [IEEP 2004] additional costs at the vehicle level are assessed for packages of technical measures reaching various levels of CO_2-emission reduction. These are expressed as continuous cost curves for small, medium-sized and large vehicle running on petrol resp. diesel. Using these cost curves new runs are performed with the cost assessment model from [IEEP 2004] for selected target / instrument combinations. Cost are expressed as additional costs compared to vehicles sold in 2008/9, assuming that these on average meet the 140 g/km target set by the voluntary agreement. Also overall cost curves (car fleet average for all market segments combined) and marginal cost curves are drawn up to create insight in the costs of reaching various target levels between 140 and 120 g/km or less.

This yields the required output data for TREMOVE and Task B for a reference scenario in which it is assumed that the 120 g/km target is solely met by technical measures at the vehicle level and for other scenarios in which a smaller CO_2-reduction at the vehicle level is augmented by one or more of the other measures under study. One or more iterations with TREMOVE may be necessary to assess first order effects of price changes on the sales distribution over different segments, which influence the division of required reduction efforts per segment leading to an overall least cost solution for the manufacturers.

Cost are expressed as additional costs compared to vehicles sold in 2008/9, assuming that these on average meet the 140 g/km target set by the voluntary agreement. Also overall cost curves (car fleet average for all market segments combined) and marginal cost curves are drawn up to create insight in the costs of reaching various target levels between 140 and 120 g/km or less.

The output data of Task 1.1 will be used to compare the CO_2-abatement costs of technical measures at the vehicle level to that of other measures studied in this project.

3.3 General considerations

- The previous study undertaken by IEEP/TNO/CAIR [IEEP 2004] and the study undertaken by ADL for ACEA [ADL 2003 a,b] both confirmed that this is possible to achieve the 120g/km target solely by means of technical efficiency improvements at the vehicle level, though the two studies produced significantly different estimates as to the cost of reducing emissions to this extent. Where [ADL 2003 a,b] estimated the average retail price increase per vehicle to be around € 4000, [IEEP 2004] arrived at an estimate of around € 1200. One of the purposes of this task thus is to explore the reasons behind the wide difference in the costs identified by the two previous studies, as a starting point for comparing these costs with the costs of reducing emissions through other means.
- Through economies of scale and learning effects production volumes influence production costs. Generally new technologies become cheaper as more are produced. The Euro V/VI work has suggested that there can even be step changes in the cost of production as the amount produced increases, which can have a significant impact on cost estimates. Due to the large number of options and packages of various options this issue can not be accounted for in detail in the CO_2-study. Instead literature data have been used that are derived under the assumption of mass volume production, and also in the questionnaires industrial stakeholders were explicitly asked to provide data that are valid for the situation of a mature technology and mass production (> 100,000 p.a. per manufacturer). For some complex technologies, such as hybrid powertrains, it may not be realistic to assume that all manufacturers are able to reach this level of market and product maturity in 2012 in response to a possible new EC CO_2-policy to be effected between 2008 and 2012. This should be analysed at a later stage in relation to the concrete formulation of policy instruments, target levels and associated target years.
- Cost definitions and associated assumptions in cost calculations can have a significant impact on end results, as already identified in [IEEP 2004]. An update of the assessment of the relation between manufacturer costs and retail price is presented in section 2.1 and Annex A.
- Experience from [IEEP 2004] has taught that it was quite difficult to know whether or to what extent considerations on cost definitions and on the relation between costs and production volume had already been taken into account in available cost estimates. This is generally also the case for the new information collected for this study.
- Attention is paid to identification of and accounting for the effect on CO_2 emissions of new or upcoming emission legislation, specifically the draft Euro 5 emission standards. Impacts of

legislation concerning safety aspects and the end-of-life vehicle Directive are not taken into account.

- The model developed in [IEEP 2004] calculates results (CO_2 reduction to be implemented per segment and associated costs) per manufacturer and takes account of the differences between manufacturers in terms of sales volumes and average CO_2 emission value per market size segment (2 fuels, 3 size segments). This functionality of the model may be used here to assess impacts of target-measure combinations in function of the market positioning of individual manufacturers. The analysis as presented in this Final Report, however, does not refer to individual companies' achievements.
- The previous study for DG ENV [IEEP 2004] looked at a matrix of combinations of different target definitions and implementation measures for reaching 120gCO_2/km:
    - target: uniform / percentage reduction / utility based;
    - implementation measure: each car / per manufacturer / per manufacturer incl. trading.

  The target/measure combinations that include trading yield the lowest costs, independent of the target definition. Calculations are made for all these scenarios. Overviews of the results for all target/measure combinations are summarized in this chapter, but in an in-depth analysis of the pros and cons of the various target-measure combinations, as carried out in [IEEP 2004], will not be performed in this report.
- In [IEEP 2004] various levels of hybridisation were included in the continuous cost curves. TREMOVE has a separate category for hybrids. In interaction with TML it has been decided not to model hybrids as a separate category in this study. An important issue is that hybrid technology can also be combined with other measures at the vehicle level. At the end of this chapter a brief analysis is made of the role of hybrids in achieving various levels of the 2012 target.

3.4 Technological options for reducing TA CO_2-emissions of passenger cars

In [IEEP 2004] a list of technical options was identified which could be used to improve the fuel economy and reduce CO_2-emissions of passenger cars on petrol and diesel in the period between 2002 and 2012. For the purpose of the current project this list has been updated. Table 3.1 shows the various options. This list was also used in the questionnaire sent out to the car manufacturer associations.

Notes:
- The options marked with an asterisk were not included in the original questionnaire sent to the various stakeholders, but were included at a later stage in response to input from stakeholders and information obtained from literature. See also section 3.4.1;
- The exhaust gas aftertreatment technologies at the end of the list obviously are not intended to improve fuel economy. These options may need to be applied to certain (packages of) engine improvement options in order to meet Euro 5/6 emission limits. They are listed here as they have an impact on the overall CO_2-benefit of these options which needs to be taken into account in the calculations.

As can be seen from the list, the number of options for petrol cars is larger than for diesel vehicles. The reason for this is that through the introduction of DI engines diesel vehicles have already made a significant step in fuel efficiency improvement in the period before 2002.

Table 3.1 Technical options to improve fuel economy and reduce CO_2-emissions of passenger cars on petrol and diesel in the period between 2002 and 2012

	Petrol vehicles	**Diesel vehicles**
Engine	Reduced engine friction losses	Reduced engine friction losses
	DI / homogeneous charge (stoichiometric)	4 valves per cylinder
	DI / Stratified charge (stoichiometric)	Piezo injectors
	DI / Stratified charge (lean burn / complex strategies)	
	Mild downsizing with turbocharging	Mild downsizing
	Medium downsizing with turbocharging	Medium downsizing
	Strong downsizing with turbocharging	Strong downsizing
	Variable Valve Timing	
	Variable valve control	
	Cylinder deactivation	Cylinder deactivation
	Variable Compression Ratio	
	Optimised cooling circuit*	Optimised cooling circuit*
	Advanced cooling circuit + electric water pump*	Advanced cooling circuit + electric water pump*
		Exhaust heat recovery*
Trans-mission	Optimised gearbox ratios	6-speed manual/automatic gearbox
	Piloted gearbox	Piloted gearbox
	Continuous Variable Transmission	Continuous Variable Transmission
	Dual-Clutch	Dual-Clutch
Hybrid	Start-stop function	Start-stop function
	Regenerative braking	Regenerative braking
	Mild hybrid (motor assist)	Mild hybrid (motor assist)
	Full hybrid (electric drive)	Full hybrid (electric drive capability)
Body	Improved aerodynamic efficiency	Improved aerodynamic efficiency
	Mild weight reduction	Mild weight reduction
	Medium weight reduction	Medium weight reduction
	Strong weight reduction	Strong weight reduction
Other	Low rolling resistance tyres	Low rolling resistance tyres
	Electrically assisted steering (EPS, EPHS)*	Electrically assisted steering (EPS, EPHS)*
	Advanced aftertreatment	DeNOx catalyst
		Particulate trap / filter

Notes:

- Reduced engine friction losses: includes low friction engine and gearbox lubricants
- Mild downsizing with turbocharging: ≈ 10% cylinder content reduction
- Medium downsizing with turbocharging: ≈ 20% cylinder content reduction
- Strong downsizing with turbocharging: ≈ 30% cylinder content reduction
- Mild weight reduction: ≈ 5% reduction of weight on Body-In-White
- Medium weight reduction: ≈ 15% reduction of weight on Body-In-White
- Strong weight reduction: ≈ 30% reduction of weight on Body-In-White
- Advanced aftertreatment: e.g. NO_x-storage catalyst for DI petrol engines

3.4.1 Other technical options not included in the list

In the course of the project several other options have been identified which were not included in the list used for the questionnaire. E.g. [IEA 2005] lists the following options:

- electric water pumps
- efficient alternators
- heat batteries for accelerated engine warm-up
- dual cooling circuits

CLEPA in its response to the questionnaire has added information on:

- down-sizing in combination with e-boost (instead of turbocharging)
- optimised cooling circuit*
- advanced cooling circuit in combination with an electric water pump*
- electrically assisted steering (EPS, EPHS)*
- exhaust heat recovery (for diesel engines)*

The options marked with an asterisk in the above list have been taken into account in the cost curve evaluation and final cost assessment for Task 1.1 (see section 3.8). The options not marked with an asterisk were not included for various reasons. Electric water pumps are not included as a separate option but only in combination with an advanced cooling circuit. This option is also considered to cover the duel cooling circuits listed by [IEA 2005]. Efficient alternators are considered to have a minor impact. Heat batteries for accelerated engine warm-up are not regularly mentioned as options in industry papers on the subject of CO_2-reduction and are therefore considered too exotic. The option of down-sizing in combination with e-boost, mentioned by CLEPA, is considered to resemble mild hybridisation too much to be considered a separate option. Limitation of the number of options was furthermore necessary due to practical limitations of the spreadsheet model used to assess packages of measures (see section 3.8.2).

3.5 Review of recent literature

3.5.1 California

In 2004 the California Environmental Protection Agency and the Air Resources Board have announced regulations aimed at reducing the CO_2-emissions from motor vehicles. In support of these regulations also an inventory has been made of the costs of reducing CO_2-emissions in vehicles. The results of this inventory have been published in [CARB 2004a] and [CARB 2004d]. Data are based on in house expertise and consultation of external experts. The cost figures presented in [CARB 2004a] and [CARB 2004d] are expressed in US$ retail price increase. In Table 3.2 the results for small and large petrol cars[7] are displayed in the format as used in this study. The original retail price data have been translated to manufacturer costs in Euros. In deriving these numbers a factor of 1.4 is assumed between retail price and costs to manufacturers[8].

In the table below care should be taken in the interpretation of costs of options that relate to the transmission or the complete powertrain. For the US situation the reference vehicle is one with an automatic transmission, and the cost differential mentioned here therefore is in comparison to that.

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[7] US definition, roughly corresponding to the categories medium/petrol resp. large/petrol as used in [IEEP 2004] and this report.

[8] The factor 1.4 is used in various US literature sources including the CARB studies. For Europe this report uses a factor of 1.44 between additional manufacturer costs and retail price increase.

Table 3.2 CO_2-emissions reduction potential and manufacturer costs of various technologies. Data derived from [CARB 2004a] and [CARB 2004d]

		Petrol small		Petrol Large	
		CO2-red.	Costs	CO2-red.	Costs
Technology options		[%]	[Euro]	[%]	[Euro]
Engine	Reduced engine friction losses	0,4	3	0,4	9
	DI / homogeneous charge (stoichiometric)		115	0,7	157
	DI / Stratified charge (stoichiometric)				
	DI / Stratified charge (lean burn / complex strategies)	4,3	441	6,4	581
	Mild downsizing (≈ 10%) with turbocharging	4,3	339	5,7	127
	Medium downsizing (≈ 20%) with turbocharging				
	Strong downsizing (≥ 30%) with turbocharging				
	Variable Valve Timing	2,1	106	2,9	195
	Variable valve control	7,9	342	11,4	386
	Cylinder deactivation	2,1		4,3	68
	Variable Compression Ratio	5,0		5,0	
Trans-mission	Optimised gearbox ratios				
	Piloted gearbox				
	Continuous Variable Transmission	2,9	127	2,1	148
	Dual-Clutch				
Hybrid	Start-stop function		119		119
	Regenerative braking				
	Mild hybrid (motor assist)	20,7	1543	20,7	1543
	Full hybrid (electric drive)	38,6	2429	38,6	2429
Body	Improved aerodynamic efficiency	1,1	0 - 76	1,4	0 - 76
	Mild weight reduction (≈ 10%)				
	Medium weight reduction (≈ 25%)				
	Strong weight reduction (≈ 40%)				
Other	Low rolling resistance tyres	1,4	12 - 54	1,4	12 - 54
	Advanced aftertreatment				

3.5.2 The Ricardo “Carbon to Hydrogen” Roadmap for Passenger Cars

The study presented in [Ricardo 2003] is an update of a previous study completed in 2002. This study was also one of the sources used for costs and CO_2-reduction data in [IEEP 2004]. The main differences compared to the 2002 report are that all costs are calculated on the basis of a 2003 reference case, that a new scenario concerning Euro 5 emissions has been added and that some cost and CO_2-reduction data have been updated. Furthermore costs and CO_2-reduction data have been checked in interview with a large number of representatives from car manufacturers in Europe and Asia.

The base vehicle in the analysis is a 2003 C/D class (Ford Focus / Mondeo) DI diesel vehicle. Packages of a range of technological options are analysed in terms of costs and effects on fuel consumption and CO_2-emissions. Various packages involve the use of hydrogen and fuel cells. These are also in [Ricardo 2003] assumed to come to the market after 2020, and are thus clearly beyond the scope or Task A. The relevant packages can be plotted on a cost curve as depicted in Figure 3.1. Manufacturer costs are derived from the retail price data in [Ricardo 2003] using a translation factor of 1.44 (see section 2.1 and Annex A). [Ricardo 2003] does not provide information on how retail price increases have been estimated in that study, so using the factor of 1.44 introduces a level of uncertainty in the interpretation of data from [Ricardo 2003].

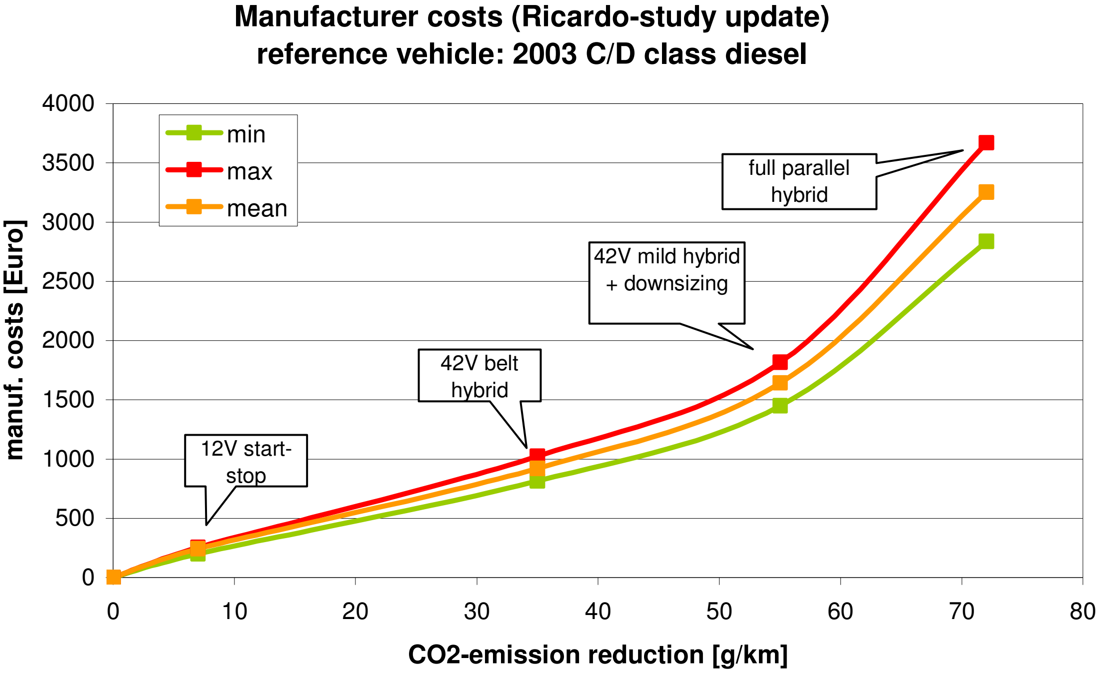

Figure 3.1 Cost curve for medium-size diesel vehicles based on [Ricardo 2005]

3.5.3 Update of the Concawe/Eucar/JRC WTW-study

In May 2006 Concawe, in co-operation with Eucar and JRC, has published an update of the Well-to-Wheel (WTW) study [Concawe 2003], which they first published end 2003 / beginning 2004. In this update [Concawe 2006] various new fuel chains have been added and some WTT and TTW data have been updated.

The data presented in [Concawe 2006] on costs and CO$_2$-emissions of vehicles with powertrains which are relevant to this study are summarized in Table 3.3.

All calculations are based on a lower mid-size reference vehicle (comparable to VW Golf). The original data in [Concawe 2006] are specified as retail price data. In Table 3.3 manufacturer cost data are derived from the retail price data using a translation factor of 1.44 (see section 2.1 and Annex A).

Table 3.3 Retail price and additional costs to manufacturers[9] and CO_2-emissions of lower mid-size vehicles with powertrains which are relevant to this study, as presented in [Concawe 2006]

manufacturer costs	CO_2-emission NEDC [g/km]	CO_2-reduction [g/km]	retail price [Euro]	retail price increase [Euro]	add. manufacturer costs [Euro]
PISI	166.2	0	18600	0	0
PISI+turbo+stop&go	139.4	26.8	19560	960	667
DISI	155.2	11	18890	290	201
DISI+turbo+stop&go	137.9	28.3	19850	1250	868
PISI-HEV	118.6	47.6	25780	7180	4986
DISI-HEV	119.6	46.6	26933	8333	5787
					0
DICI	134.6	0	20300	0	0
DICI+stop&go	126.1	8.5	20960	660	458
DICI-HEV	103.4	31.2	27190	6890	4785

In Figure 3.2 these data are graphically displayed in the form of cost curves.

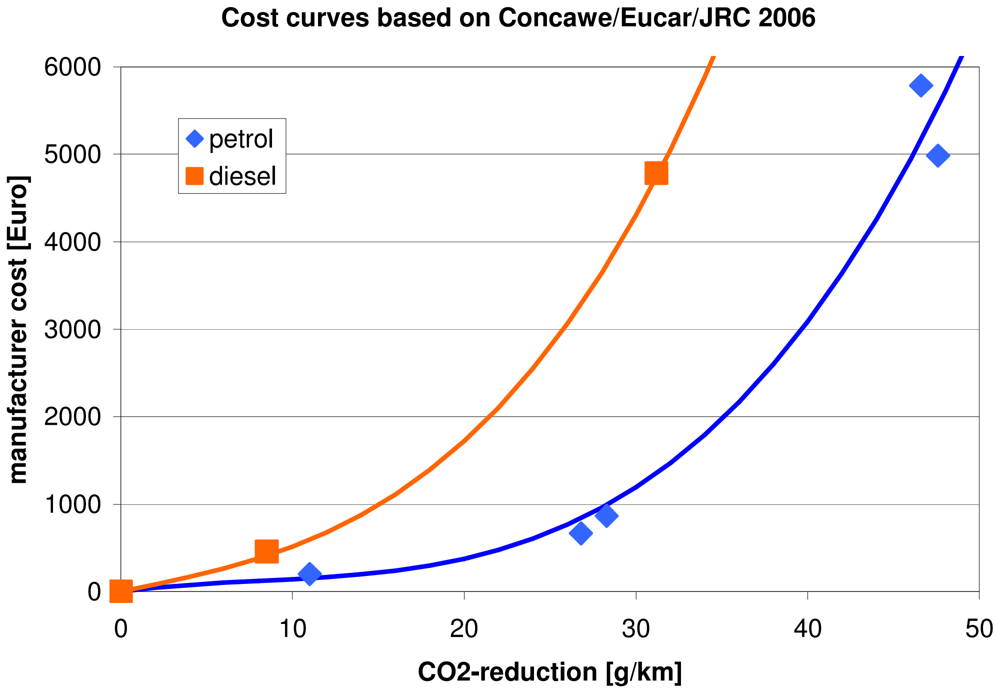

Figure 3.2 Cost curves (manufacturer costs) for lower mid-size passenger cars based on [Concawe 2006]

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[9] Derived from retail price information presented in [Concawe 2006] using a translation factor of 1.44.

3.5.4 IEA-study: Making cars more fuel efficient

Table 3.4 presents CO_2-reduction potentials as stated by [IEA 2005] for a list of technologies that provides a CO_2-emission reduction on the type approval test. For these technologies this study unfortunately does not present cost data. Also the sources, on which the provided data are based, are not specified. The figures listed are valid for petrol and diesel cars, except for the specific data on DI petrol engines. For many options the data are very much in line with those used in [IEEP 2004].

Table 3.4 Type approval CO_2-reduction data from [IEA 2005] for various technologies.

		petrol		
		CO2-red. [%]		Costs [Euro]
Technology options		min.	max.	
Engine	Reduced engine friction losses	2.0	4.0	
	DI / homogeneous charge (stoichiometric)	12.0	15.0	
	DI / Stratified charge (lean burn / complex strategies)			
	Mild downsizing (≈ 10%) with turbocharging	2.0	4.0	
	Medium downsizing (≈ 20%) with turbocharging			
	Variable Valve Timing	1.5	2.5	
	Variable valve control	5.0	7.0	
	Cylinder deactivation	6.0	8.0	
	Continuous Variable Transmission	5.0	7.0	
Hybrid	Start-stop function	3.0	5.0	150 - 200
	Mild hybrid (motor assist)	5.0	7.0	
	Full hybrid (electric drive)	30.0	50.0	
Body	Improved aerodynamic efficiency	2.0	4.0	
	Medium weight reduction	3.5	7.0	
Other	Low rolling resistance tyres	2.0	4.0	25 - 40
	Low friction engine lubricants	0.5	1.0	20 - 30

Table 3.5 summarises relevant cost and CO_2-reduction figures, also derived from [IEA 2005], for technologies that especially reduce the difference between Type Approval CO_2-emission and real-world CO_2-emission[10]. In [IEA 2005] all costs are expressed in retail price increase. The original data have been calculated into manufacturer costs by means of a translation factor 1.44 (see section 2.1 and Annex A). [IEA 2005] does not provide information on how retail price increases have been estimated in that study, so using the factor of 1.44 introduces a level of uncertainty in the interpretation of data from [IEA 2005].

Interesting about this list is that it includes options which are not included in the questionnaire for this project. These options are: electric water pumps, efficient alternators, heat batteries (for storing engine heat to speed up engine warm-up at cold start) and dual cooling circuits. [IEA 2005] expects the effects of these options on the TA CO_2-reduction to be around 0.5% each.

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[10] Reducing this “shortfall”, i.e. the difference between TA and real-world fuel consumption is the main focus of the [IEA 2005] report.

Table 3.5 Relevant cost and real-world CO_2-reduction data from [IEA 2005] for technologies that reduce the difference between Type Approval CO_2-emission and real-world CO_2-emission.

	petrol vehicle						diesel vehicle					
	manuf. cost [Euro]		CO_2-reduction [%]				manuf. cost [Euro]		CO_2-reduction [%]			
			cold climate		hot climate				cold climate		hot climate	
	min.	max.	dense traffic	light traffic	dense traffic	light traffic	min.	max.	dense traffic	light traffic	dense traffic	light traffic
Electric water pump	69	104	4	2	2	1	69	104	2	1	1	0.5
Efficient alternators	28	42	2	1	1	0.5	28	42	2	1	1	0.5
Heat battery	56	69	3	1	0	0	56	69	1.5	0.5	0	0
Dual cooling circuits	21	35	2	2	1	1	21	35	1	1	0.5	0.5
Idle stop/start	208	278	4	0	8	0	208	278	2	0	4	0
Low rolling resistance tyres	35	56	1	2	1	2	35	56	1	2	1	2
0W-5W/20 oils	28	42	2	1	0.5	0.5	28	42	1	0.5	0.5	0.5
Tyres inflation monitor	21	28	1	1	1	1	21	28	1	1	1	1

3.5.5 Data on hybrids from UC Davis

In [UCD 2003] the life cycle costs of hybrids are assessed. As a starting point the retail price increase of hybrids is determined based on the result of a survey of recent literature from the US. Converted into manufacturer costs (using a factor 1.4 as is applicable to the US situation) these data are summarized in Table 3.3.6**.**

Table 3.3.6 Additional manufacturer costs [Euro] of hybrid powertrains according to a survey made in [UCD 2003] [11].

manufacturer cost	ANL	ANL	ANL	EEA	EF	EPRI base	EPRI low	MIT	NRC min	NRC max	UCD
base ICEV											
ICEV w/42V ISG				1286	357				214	429	
mild HEV	2143	2286	2214	2000	2357			1214			1000
full HEV	2429	2857	3357	2857	3429	2857	1643				2429
HEV 20 miles el. range		5143	5714			4286					
HEV 60 miles el. range						7500	4929				

ANL:	Plotkin, S. et al., 2001, Hybrid vehicle Technology Assessment: Methodology, Analytical Issues, and Interim Results, Argonne National Laboratory Report ANL/ESD/02-2, Argonne IL
EEA:	Energy and Environmental Analysis, Inc. (EEA), 2002, Analysis and Forecast of the Performance and Costs of Conventional and Electric-Hybrid Vehicles, Prepared for the California Energy Commission, P600-02-013CR
EF:	De Cicco, J. et al. Technical Options for Improving the Fuel Economy of US Cars and Light Trucks by 2010-2015, American Council for an Energy-Efficient Economy, Washington D.C.
EPRI:	Graham, R. et al., 2001, Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options, Final Report, Electric Power Research Institute, Palo Alto, CA
MIT:	Weiss et al., 2000, On the Road in 2020: A Lifecycle Analysis of New Automobile Technologies, MIT Energy Laboratory Report No. MIT EL 00-003, Energy Laboratory, Massachusetts Inst. of Technology, Cambridge, MA
NRC:	National Research Council, 2002, Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, Washington D.C., National Academe Press
UCD:	Burke, A. et al., 2002, The Future of Hybrid-Electric ICE Vehicles and Fuels Implications, Inst. of Transportation Studies, UC Davis, UCD-RR-02-09

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[11] The same data are quoted in [IPTS 2005]. The conversion from US$ to € is taken from this report.

3.5.6 Evaluation of costs of existing hybrids

Besides the above data from available studies also the retail prices of current hybrids on the market can be compared to those of their conventional counterparts. The comparison, however, is not trivial. Only the Toyota Prius has been sold in significant quantities so that the current price may be assumed to be a regular commercial price, in terms of included margins. But exactly this vehicle does not have a direct conventional comparison. Furthermore care should be taken not to overstate the additional costs of the hybrid version as hybrid vehicles are often sold with a base model that is somewhat more luxurious than the conventional base model.

In US the Honda Civic hybrid is sold at a base price that is US$ 7400 more expensive than the conventional Civic. The hybrid Lexus RX 400h AWD is US$ 7300 more expensive than the conventional RX 350 with automatic 5 speed gear box. The Toyota Prius II costs US$ 7600 more than a roughly comparable conventional Corolla. Using a factor 1.4 (often used in US studies and reflecting lower tax levels in the US) to translate retail price into manufacturer costs and a factor 1.2 to translate dollars into Euros yields a value for the additional manufacturer costs of around € 4400 for these vehicles.

In Germany the Honda Civic IMA is € 8100 more expensive that the conventional Civic DX. The Toyota Prius II costs € 8650 more than a conventional Corolla. In France the price difference between Honda Civic IMA and the conventional Civic is € 6100, while the difference between the Prius and the Corolla is around € 8900. Using a factor of 1.67 (as assumed valid for the whole vehicle price of conventional vehicles) to translate retail price into manufacturer costs this comes down to additional manufacturer costs of € 3650 – 5180. Using a translation factor of 1.44 (as defined in this study for the marginal costs of additional technologies) yields additional manufacturer costs of € 4240 – 6000.

As the market for hybrid vehicles is a new and emerging market it is unclear to what extent the real additional costs of the hybrid technology as used in the above-mentioned vehicles are fully passed on to the consumer. Additional manufacturer costs may thus be higher than the values estimated above. On the other hand still significant cost reductions may be expected over the next years with increasing sales and production volumes.

The Type Approval CO$_2$-reduction obtained on the NEDC by the various vehicles is:

Honda Civic:	23%
Toyota Prius:	35%
Lexus 400h:	20%

Obviously the reduction obtained in the Prius is not only the result of the hybrid drive. On the other hand the additional fuel economy improvement is caused by additional measures such as weight reduction, improved aerodynamics, low rolling resistance tyres, etc., which also add to the additional costs of the Prius.

At the recent introduction of the diesel-electric hybrid concepts based on the Peugeot 307 and Citroën C4, PSA stated that at present status of technology the retail price of these vehicles would be € 4500 higher than of their conventional counterparts. Using the factor of 1.44 this would come down to additional manufacturer costs of around € 3100 per vehicle. PSA claims that further cost reductions are necessary but possible provided that sufficient investments can be made. The diesel-hybrid concept presented by PSA is claimed to deliver a CO$_2$-reduction of 28%.

3.6 Data provided by industrial stakeholders

By means of a detailed questionnaire industry stakeholders (manufacturer associations and supplier associations) have been consulted and requested to provide detailed input concerning the CO_2-reduction potential and costs of technical measures as listed in Table 3.1. Input on specific topic was also received from several individual companies.

ACEA has provided a detailed response to the questionnaire sent out to the manufacturer associations, in writing as well as through meetings and bilateral contacts to discuss and clarify various issues. The information provided by JAMA is to a large extent qualitative. The supplied document contains descriptive information on technical options that may be implemented to reduce fuel consumption of future vehicles. A rough indication is given of costs and effects of various more or less advanced levels of measures by means of a general categorisation scheme. Data provided by KAMA are specified at a more aggregated level than requested in the questionnaire, i.e. in terms of the average costs and CO_2-reduction of vehicles sold in various market segments as well as of the average KAMA new vehicle sales. CLEPA and a.o. Honeywell have provided input on behalf of the component supply industry.

All data inputs have been used in the assessment of costs and CO_2-reduction potentials and have contributed to the generation of the final data set as presented in section 3.8. In this process the input from industry has been compared to data from literature and in-house expertise of the consultants. However, as the input provided by the industry is confidential, neither the industry data nor the analysis and comparison with other sources have been included in this report.

3.7 Methodology for cost assessment

In the assessment presented in this chapter the same models and methodology as developed for [IEEP 2004] have been used. The models have been updated with new input data on cost and CO_2-reduction potentials and where appropriate adapted assumptions on e.g. autonomous trends. The methodology for cost assessment consists of the following two main steps:

- construction of cost curves;
- assessment of the overall costs to reach a given type approval CO_2-target.

In summary these two steps can be described as follows:

Construction of cost curves:

- identification of the average 2002 baseline vehicle (in terms of applied technology, mass, CO_2-emission, costs, etc.) for small / medium / large passenger cars on petrol and diesel;
- identification of technical options for CO_2-reduction to be applied after 2002;
- quantification of the CO_2-reduction potential and additional costs of each individual technical option;
- identification of (all) possible packages in which two or more of the above technical options can be combined in a vehicle;
- determination of the overall CO_2-reduction potential (in [%] compared to baseline) and additional costs (in [€]) of each possible package;
- determination per vehicle segment of a continuous cost curve describing additional costs as a function of CO_2-reduction (in [g/km]), based on the above assessment of the overall CO_2-reduction potential and additional costs of each possible package;

Assessment of the overall costs to reach a given type approval CO_2-target

- quantification of the 2002 situation per manufacturer in terms of the sales and average TA CO_2-emission per segment (for [IEEP 2004] and this study based on data from Polk Marketing Systems);
- quantification of assumptions on autonomous trends between 2002 and 2012:
  - sales increase
  - weight increase
  - shift from petrol to diesel
- assessment of the 2008/9 situation:
  - For calculating the required reductions per car per segment, it is assumed that the 2008 goal will be reached in such a way that the total costs for the members of an association (ACEA / JAMA /KAMA) are minimal and that per segment all manufacturers realise the same reduction per car. This way the costs per car in a given segment are the same for all manufacturers, so that the burden is shared in a fair way. The reductions per car for each segment are found using a solver-function which minimises the total costs (costs for realising 140g/km in 2008, starting from the base year 2002) for the association-“bubble” by varying the reductions per car for the six segments under the condition that the resulting average emission per car in 2008 is 140g/km. When this minimum is reached, the reductions per car per segment are such that the marginal costs are equal for all segments.
- assessment of the 2012 situation:
  - specification of a target-measure combination: Calculations are done for the following 18 (= 3 + 3 + 3*4) options of target-measure combinations:
    - car-based targets:
      - fixed target per car
      - percentage reduction target per car
      - four different versions of utility-based targets per car
    - manufacturer-based targets
      - fixed target per manufacturer
      - percentage reduction target per manufacturer
      - four different versions of utility-based targets per manufacturer
    - manufacturer based targets with allowing trading of CO_2-credits
      - fixed target per manufacturer including the possibility of emission trading
      - percentage reduction target per manufacturer including the possibility of emission trading
      - four different versions of utility-based targets per manufacturer including the possibility of emission trading
  - calculation of the costs for reaching the specified 2012 target:
    - For the car-based this is a straightforward calculation of the required reduction per segment and the associated costs on the basis of the cost curve, carried out for each manufacturer separately;
    - For the manufacturer-based targets (without and with trading) this involves a cost optimisation routine, applied to each manufacturer separately, using a solver function that finds the distribution of CO_2-reductions over the various vehicle segments that yields the lowest costs for reaching the target;
- In the assessment of the 2008 and 2012 situation the effects of sales trends, autonomous weight increase and the shift from petrol to diesel are accounted for.

A more elaborate description of the applied model and methodology can be found in Annex D.

The target-measure combinations in which trading of CO_2-credits is allowed among manufacturers are assessed under the assumption of a fully transparent market with a high number of participants. Whether these assumptions are justified and whether the costs of setting up a trading system outweigh the potential benefits needs to be analysed in a future project (i.e. in case trading is considered a promising ingredient of a future EU CO_2-policy for passenger cars).

3.7.1 The 2002 baseline vehicles

Using Polk Marketing Systems data from 2002 six 2002 baseline cars have been identified (see also [IEEP 2004]), as depicted in Table 3.7. The 2002 baseline technologies for these six baseline cars have been identified as presented in Table 3.8.

Table 3.7 Specifications of 2002 baseline cars

Averages	**SP**	**MP**	**LP**	**SD**	**MD**	**LD**	**Grand Total**
Total CO_2	148.5	183.7	237.5	123.2	152.9	200.7	166.4
vehicle mass	957.3	1260.7	1499.7	1028.5	1365.0	1689.5	1236.1
power	52.5	85.7	129.4	54.2	81.7	100.7	77.3
engine capacity	1238.2	1725.6	2439.0	1606.0	1949.6	2326.3	1732.5
length	3.7	4.3	4.5	3.8	4.4	4.6	4.2
width	1.6	1.7	1.8	1.7	1.8	1.8	1.7
height	1.5	1.5	1.5	1.4	1.5	1.7	1.5
volume (l*w*h)	8.9	11.0	12.4	9.1	11.4	14.1	10.7
consumer price	13442.9	28932.7	51039.6	14896.4	23643.6	34737.5	24162.6

Source: developed from Polk Marketing Systems data

Table 3.8 2002 baseline technologies

	Petrol, Small	**Petrol, Medium**	**Petrol, Large**	**Diesel, Small**	**Diesel, Medium**	**Diesel, Large**
Engine layout:	4 cylinder in-line	4 cylinder in-line	4/6 cylinder in-line	4 cylinder in-line	4 cylinder in-line	4/6 cylinder in-line
Fuel system:	Multi point injection	Multi point injection	Multi point injection	Common rail direct injection	Common rail direct injection	Common rail direct injection
Gearbox:	5 speed manual	5 speed manual	5 speed manual (automatic)	5 speed manual	5 speed manual	5 speed manual (automatic)

3.8 Generation of the final data set on CO_2-reduction potential and costs of various options used for the cost assessment

3.8.1 CO_2-reduction potential and costs of individual options

Based on an evaluation of the data obtained from literature and from various stakeholders, as described above, a final data set has been constructed, describing the assumed CO_2-reduction potential and additional costs of the various individual technologies studied in this chapter. These data, listed in Table 3.9 and Table 3.10, are used as input for the construction of cost curves and the assessment of the overall costs and CO_2-abatement costs of reaching the 2008/9 target of 140 g/km and various targets between 140 and 120 g/km in 2012.

The cost data presented in Table 3.9 and Table 3.10 are additional manufacturer costs compared to the 2002 baseline vehicle. CO_2-reduction percentages are relative to the CO_2-emission of the 2002 baseline vehicle in each segment. Obviously some of these technologies have already been introduced in 2006 for the purpose of achieving the 2008/9 target.

Table 3.9 CO_2-reduction potential and additional manufacturer costs of technical options to reduce CO_2-emissions of passenger cars on petrol

Technology options for petrol cars		Small					Medium					Large				
Description		CO2 reduction [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 reduction [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 reduction [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]
Engine	Reduced engine friction losses	3.0	40	100%	40		4.0	50	100%	50		5.0	60	100%	60	
	DI / homogeneous charge (stoichiometric)	3.0	125	100%	125		3.0	150	100%	150		3.0	175	100%	175	
	DI / Stratified charge (stoichiometric)															
	DI / Stratified charge (lean burn / complex strategies)	10.0	320	100%	320		10.0	400	100%	400		10.0	480	100%	480	
	Mild downsizing with turbocharging															
	Medium downsizing with turbocharging	8.5	225	100%	225		10.0	300	100%	300		10.0	375	100%	375	
	Strong downsizing with turbocharging	12.0	390	100%	390		12.0	450	100%	450		12.0	510	100%	510	
	Variable Valve Timing	3.0	100	75%	75		3.0	150	75%	113		3.0	200	75%	150	
	Variable valve control	7.0	300	75%	225		7.0	350	75%	263		7.0	400	75%	300	
	Cylinder deactivation															
	Variable Compression Ratio															
	Optimised cooling circuit	1.5	35	100%	35		1.5	35	100%	35		1.5	35	100%	35	
	Advanced cooling circuit+ electric water pump	3.0	120	100%	120		3.0	120	100%	120		3.0	120	100%	120	
Trans-mission	Optimised gearbox ratios	1.0	50	100%	50		1.5	60	100%	60		1.5	70	100%	70	
	Piloted gearbox	4.0	300	100%	300		4.0	350	100%	350		4.0	400	100%	400	
	Continuous Variable Transmission															
	Dual-Clutch	4.0	600	75%	450		5.0	700	75%	525		5.0	900	75%	675	
Hybrid	Start-stop function	4.0	220	100%	220		4.0	250	100%	250		4.0	280	100%	280	
	Start-stop + regenerative braking	7.0	515	100%	515		7.0	600	100%	600		7.0	685	100%	685	
	Mild hybrid (motor assist)	11.0	1200	75%	900		11.0	1600	75%	1200		11.0	2000	75%	1500	
	Full hybrid (electric drive)	22.0	2800	75%	2100		22.0	3500	75%	2625		22.0	4200	75%	3150	
Body	Improved aerodynamic efficiency	1.5	75	100%	75		1.5	75	100%	75		1.5	75	100%	75	
	Mild weight reduction (5% BIW = 1.5% veh. weight)	0.9	22	100%	22	-14	1.0	28	100%	28	-19	0.9	34	100%	34	-22
	Medium weight reduction (12% BIW = 3.6% veh. weight)	2.2	57	100%	57	-34	2.3	90	100%	90	-45	2.2	115	100%	115	-54
	Strong weight reduction (30% BIW = 9.0% veh. weight)	5.5	212	100%	212	-86	5.8	294	100%	294	-113	5.4	418	100%	418	-135
Other	Low rolling resistance tyres	2.0	25	100%	25		2.0	30	100%	30		2.0	35	100%	35	
	Electrically assisted steering (EPS, EPHS)	3.0	100	100%	100		2.5	100	100%	100		2.0	100	100%	100	
	Advanced aftertreatment	-1.0	0	100%	0		-1.0	0	100%	0		-1.0	0	100%	0	

Table 3.10 CO_2-reduction potential and additional manufacturer costs of technical options to reduce CO_2-emissions of passenger cars on diesel

Technology options for diesel cars		**Small**					**Medium**					**Large**				
Description		CO2 reduction [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 reduction [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 reduction [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]
Engine	Reduced engine friction losses	3.0	40	100%	40		4.0	50	100%	50		5.0	60	100%	60	
	4 valves per cylinder															
	Piezo injectors															
	Mild downsizing	3.0	120	100%	120		3.0	150	100%	150		3.0	180	100%	180	
	Medium downsizing	5.0	160	100%	160		5.0	200	100%	200		5.0	240	100%	240	
	Strong downsizing						7.0	300	100%	300		10.0	375	100%	375	
	Cylinder deactivation															
	Optimised cooling circuit	1.5	35	100%	35		1.5	35	100%	35		1.5	35	100%	35	
	Advanced cooling circuit+ electric water pump	3.0	120	100%	120		3.0	120	100%	120		3.0	120	100%	120	
	Exhaust heat recovery						1.5	45	100%	45		1.5	45	100%	45	
Trans-mission	6-speed manual/automatic gearbox															
	Piloted gearbox	4.0	300	100%	300		4.0	350	100%	350		4.0	400	100%	400	
	Continuous Variable Transmission															
	Dual-Clutch	5.0	600	75%	450		5.0	700	75%	525		5.0	900	75%	675	
Hybrid	Start-stop function	3.0	180	100%	180		3.0	200	100%	200		3.0	220	100%	220	
	Start-stop + regenerative braking	6.0	475	100%	475		6.0	550	100%	550		6.0	625	100%	625	
	Mild hybrid (motor assist)	10.0	1200	75%	900		10.0	1600	75%	1200		10.0	2000	75%	1500	
	Full hybrid (electric drive capability)	18.0	2800	75%	2100		18.0	3500	75%	2625		18.0	4200	75%	3150	
Body	Improved aerodynamic efficiency	1.5	75	100%	75		1.5	75	100%	75		1.5	75	100%	75	
	Mild weight reduction (5% BIW = 1.5% veh. weight)	1.0	23	100%	23	-15	1.0	31	100%	31	-20	1.0	38	100%	38	-25
	Medium weight reduction (12% BIW = 3.6% veh. weight)	2.4	65	100%	65	-37	2.5	101	100%	101	-49	2.4	136	100%	136	-61
	Strong weight reduction (30% BIW = 9.0% veh. weight)	5.9	231	100%	231	-93	6.3	333	100%	333	-123	5.9	538	100%	538	-152
Other	Low rolling resistance tyres	2.0	25	100%	25		2.0	30	100%	30		2.0	35	100%	35	
	Electrically assisted steering (EPS, EPHS)	3.0	100	100%	100		2.5	100	100%	100		2.0	100	100%	100	
	DeNOx catalyst	0.0	0	100%	0		0.0	0	100%	0		0.0	0	100%	0	
	Particulate trap / filter	-1.5	0	100%	0		-1.5	0	100%	0		-1.5	0	100%	0	

3.8.1.1 Notes on the assessment of costs and CO_2-reduction potential of individual options

Given the large number of options assessed in this study and the level of expert judgement that has gone into interpreting and comparing the data from different sources, not all numbers presented in Table 3.9 and Table 3.10 will be motivated in detail. Below some notes are give on general aspects of the cost assessment as well as on critical issues regarding the assessment of costs and CO_2-reduction potential of a limited number of important technologies:

- For down-sizing applied to petrol vehicles costs consist of engine adaptations and cost of a turbo. Costs for engine adaptations are assumed to be partly cancelled by cost reductions as a result of using a smaller engine. Although diesel engines already have a turbo, some additional costs of an advanced turbo design (variable geometry or dual stage) compared to a conventional turbo have been taken into account as well as demands set by the application of EGR.
- The costs for various levels of hybridization (from start/stop to full hybrid) have been assessed on the basis of input from literature and data provided by industry. The data in Table 3.9 and Table 3.10 are largely based on literature (estimates of costs at various production volumes) and TNO's own experience in purchase of HEV components. The € 3500 for the full hybrid powertrain in a medium-size petrol car is significantly smaller than estimates by the automotive industry, but is nevertheless at the conservative end of the range estimated by TNO in a cost breakdown assessment carried out in interaction with ACEA. It is chosen to be consistent with the input from [Ricardo 2003] and accounts for the fact that possibly not all integration aspects of hybrid powertrains are included in a simplified cost breakdown. Further cost reductions, however, do seem feasible in a longer timeframe than the period until 2012 as studied here. It should be mentioned that the overall manufacturer costs assumed here are only slightly higher than the [IEEP 2004] data recalculated using the new factor between manufacturer costs and retail price[12].
- Data on CO_2-reduction and costs of measures to reduce vehicle weight are taken over from results of the EU-funded "Super Light Car" project, which is looking into potential future body structures using new approaches in body designs by applying mixtures of light weight and composite materials. A 30% weight reduction target for the Body-in-White (BIW) over a conventional BIW has been identified for this project. This assumes a body structure that is capable of handling the load, torsion, reparability and noise requirements of a current vehicle. Data on costs and weight reduction have been discussed extensively with ACEA, and are considered scientifically sound.
- Table 3.9 and Table 3.10 also list the assumed share of technology costs that can be attributed to CO_2-reduction. In general the cost of a new technology can be attributed to various goals, such as reaching a next level emission limits (e.g. Euro 5), improving fuel efficiency, reducing noise, and improving performance, driveability, comfort or other quality aspects of the vehicle. For variable valve timing and variable valve control it is assumed that 25% of the costs can be attributed to the benefits of these technologies with respect to exhaust gas emission reduction. For dual clutch automatic gearboxes and for mild and full hybrid power trains it is assumed that these also present added value to the consumer besides fuel economy improvement. 25% of the additional costs of these technologies are attributed to improved performance and driveability.
- In the assessment of costs no analysis has been made of the effects of production volumes on costs through economies of scale. This aspect was taken into account in an implicit rather than

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[12] The retail price increase of € 4500 for a full hybrid powertrain in a medium-size petrol car as given in Table 3.4 of [IEEP 2004] translates into additional manufacturer costs of € 3125 using the factor of 1.44 instead of the factor of 2 as used in [IEEP 2004].

explicit way. In the questionnaire as sent out to the OEMs it was explicitly stated that we were looking for estimates of costs under the assumption of large scale production (order of magnitude > 100,000 p.a. per manufacturer). ACEA has stated that their data have been derived under that assumption, but they have not provided an explicit breakdown of these costs that allows verification of the assumptions. The various available studies (incl. [Ricardo 2003] and [Concawe 2006]) also present data for the situation of large scale production without giving insights in assumed cost developments as function of production volumes. Furthermore it should be noted that, given the constraints of the budget, the number of options to be evaluated and the general lack of hard data on cost developments as a function of product maturity or production volume, such an in-depth analysis was considered beyond the scope of this project.

- The assumed levels of production volumes and product maturity may not be reached in the 2008-2012 timeframe for all options considered and depends on a variety of complex factors. The approach of this study is that it should first of all be assessed whether certain targets beyond 2008 can be reached in a cost-effective way assuming availability of mature technology, an the dynamics of getting these technologies into the market in time should be discussed at a later stage in the context of preparing the actual policy measures. If industry and other experts at that stage can convincingly motivate why certain technologies can not be (made) available in time to reach a certain target in 2012 then the target year of the policy could be debated rather than the actual level of the target itself.

3.8.2 Generation of cost curves for packages of technical measures

Using the methodology as described in [IEEP 2004] and Annex D from the lists in Table 3.9 and Table 3.10 those options that are technically compatible can be combined into packages of measures. This yields a large number of possible packages, each with a different overall CO_2-reduction potential and different overall costs.

The overall CO_2-emission of a vehicle with a package of n CO_2-reducing options is estimated as:

$$CO_2^{package} = CO_2^{baseline} \times \prod_{i=1}^{n} (1 - \delta_i)$$

with δ_i the relative CO_2-emission reduction (in [%]) of technical option i.

The additional costs of a vehicle with a package of n CO_2-reducing options are calculated as:

$$cost^{package} = \sum_{i=1}^{n} cost_i$$

with $cost_i$ the additional cost of technical option i.

Obviously the above formula for assessing the overall CO_2-reduction potential is a rough estimation which may overestimate the overall reduction achieved by two measures that target the same losses. As an example, in a combination that includes both engine down-sizing and drivetrain hybridisation the first option improves the engine's part load efficiency while the second option aims to avoid the occurrence of part load operation. The overall efficiency improvement of the combination of the two options will this be smaller that the product of the efficiency improvements estimated for the individual options applied separately to a baseline vehicle. The estimation of the reduction potential of a package of options can be estimated correctly by means of dynamical computer simulation of a vehicle comprising the package of options over a driving cycle. This, however, is a time consuming and information intensive exercise which could only be performed for a limited number op packages. As there are several thousands of possible combinations of two or more of the options listed in Table 3.9 and Table 3.10 a more straightforward approach has been adopted in this study, in which the CO_2-reduction potential of each package is roughly estimated with the above formula, while the effect of overestimating the overall CO_2-reduction potential is compensated by the way in which the cost curve is determined on the basis of the costs and CO_2-reduction potentials of a large number of packages in a way as is described below.

In Figure 3.4 to Figure 3.9 the pink dots represent the costs vs. net CO_2-reduction of the various feasible packages, based on manufacturer cost estimates. The blue lines represent the constructed cost curves. Starting point for the x-axis in these figures is the TA CO_2-emissions value for the 2002 average baseline vehicle of a given class as indicated in Table 3.7. Starting point for the y-axis in these figures is 0.60 times the average consumer price[13] the consumer price value for the 2002 average baseline vehicle of a given class as indicated in Table 3.7. It should be noted that in the cost assessment model the cost curves are applied separately to the different manufacturers using the 2002 values for TA CO_2-emissions and vehicle costs for the individual manufacturers as starting points (based on Polk Marketing Data for 2002).

The cost curves (blue lines) are drawn to follow the curvature of the "cloud" of data points at a certain distance from the outer envelope. This distance serves as a safety margin to account for the fact that simply combining the CO_2-reduction potential of individual measures as defined above tends to overestimate overall CO_2-reduction potential of the complete package. The cheapest packages are also not necessarily the technical solutions that yield optimal driveability or meet other design goals besides CO_2-emission reduction, and may therefore not be the optimal solution from a broader design point of view or may be more difficult to market. For this assessment the cost curves are positioned in such a way that roughly 2/3 of the data points is on the left side of the curve and 1/3 on the right side. This margin is somewhat larger than was used in [IEEP 2004], in order to better account for possible overestimations when combining e.g. the CO_2-reductions of hybrid power trains with those of advanced engine technologies (petrol DI, downsizing).

Cost curves are defined as 3rd order polynomials expressed as:

$$y = a\,x^3 + b\,x^2 + c\,x$$

with x the CO_2-reduction in [g/km] and y the costs in [Euro]. The values for the coefficients a, b and c, as determined for the various vehicle classes are listed in Table 3.11.

An overview of the resulting cost curves for the six different vehicle segments is presented in Figure 3.3.

A sensitivity analysis exploring the impact of the construction of the cost curve and the size of the "safety margin" on the resulting costs for reaching the 2012 target is given in section 3.11.2.

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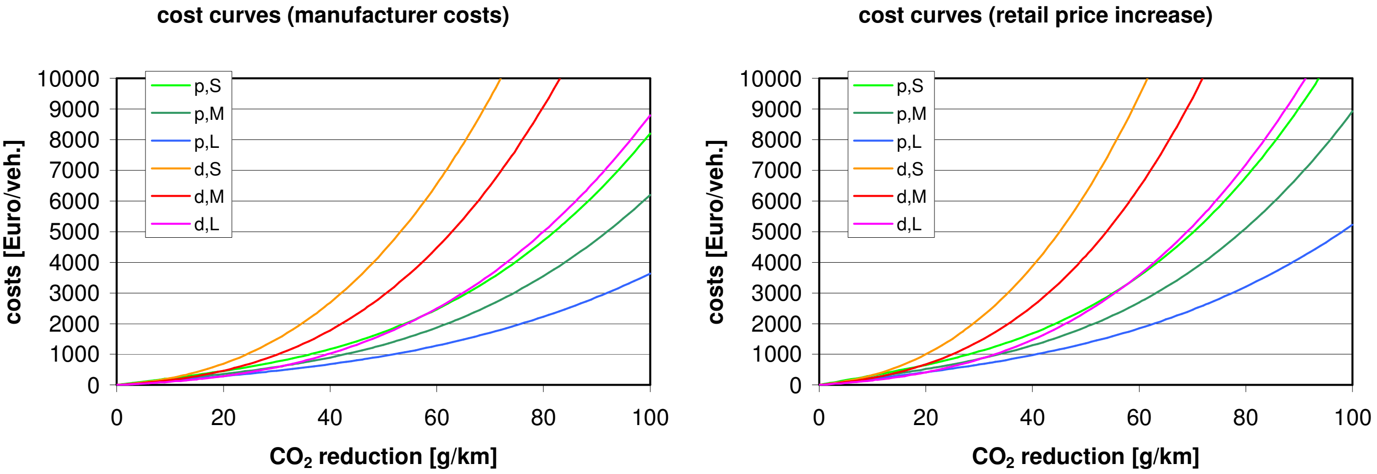
[13] See Annex A for the relation between retail price and manufacturer costs.

Table 3.11 Coefficient values for cost curves

	additional manufacturer costs					
	p,S	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**
a	0.0070	0.0055	0.0025	0.0120	0.0110	0.0060
b	-0.100	-0.110	-0.027	0.900	0.400	0.200
c	22.0	18.0	14.0	12.0	11.0	8.0

	retail price increase (manuf. costs * 1.44)					
	p,S	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**
a	0.0101	0.0079	0.0036	0.0173	0.0158	0.0086
b	-0.144	-0.158	-0.039	1.296	0.576	0.288
c	31.7	25.9	20.2	17.3	15.8	11.5


cost curves (manufacturer costs)

cost curves (retail price increase)

Figure 3.3 Cost curves based on manufacturer costs (left) and retail price (right) for reaching CO_2-reductions in the various vehicle segments. Starting points of the cost curves are the TA CO_2-emission values and vehicle costs of the 2002 average baseline vehicles for the different segments as given in Table 3.7.

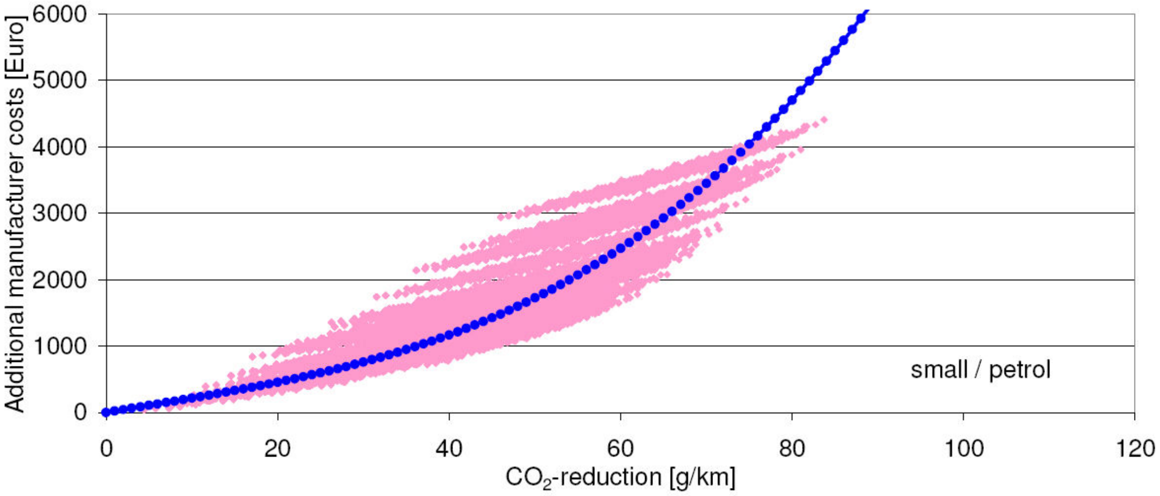


Figure 3.4 Cost curve for small petrol cars (manufacturer costs as a function of reduction of Type Approval CO_2-emission). Starting point for the x-axis is the TA CO_2-emission of the 2002 baseline vehicle: 148.5 g/km.

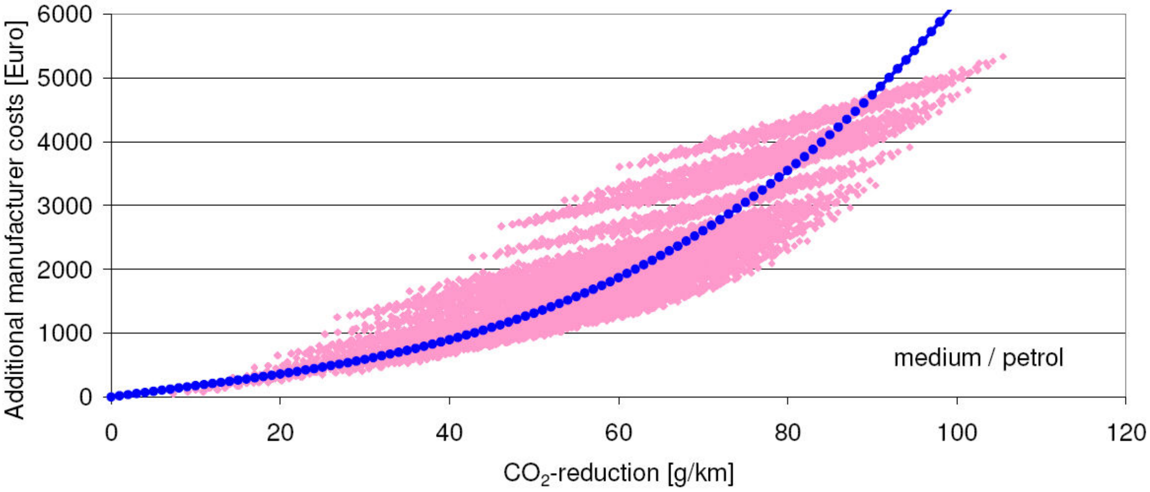


Figure 3.5 Cost curve for medium-size petrol cars (manufacturer costs as a function of reduction of Type Approval CO_2-emission). Starting point for the x-axis is the TA CO_2-emission of the 2002 baseline vehicle: 183.7 g/km.

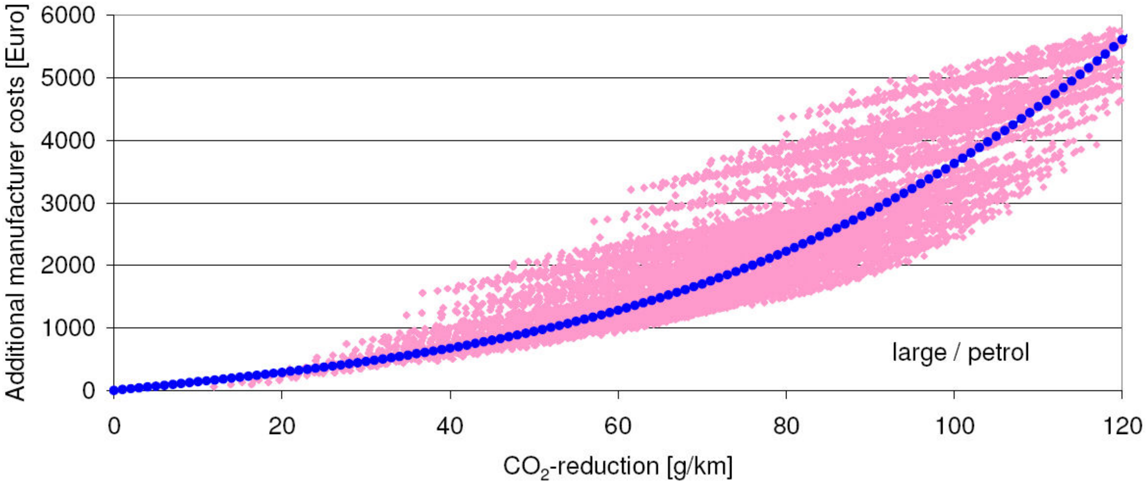


Figure 3.6 Cost curve for large petrol cars (manufacturer costs as a function of reduction of Type Approval CO$_2$-emission). Starting point for the x-axis is the TA CO$_2$-emission of the 2002 baseline vehicle: 237.5 g/km.

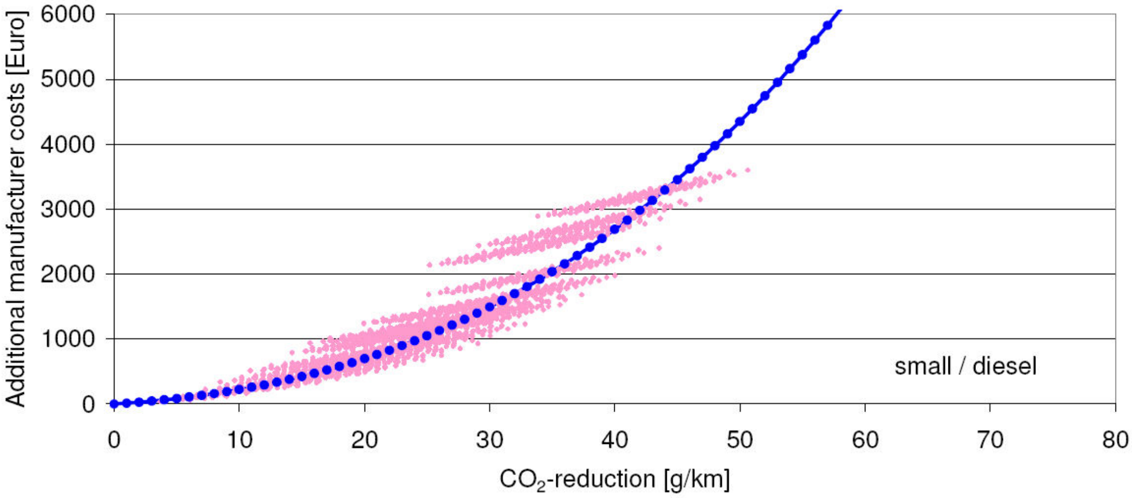


Figure 3.7 Cost curve for small diesel cars (manufacturer costs as a function of reduction of Type Approval CO$_2$-emission). Starting point for the x-axis is the TA CO$_2$-emission of the 2002 baseline vehicle: 123.2 g/km.

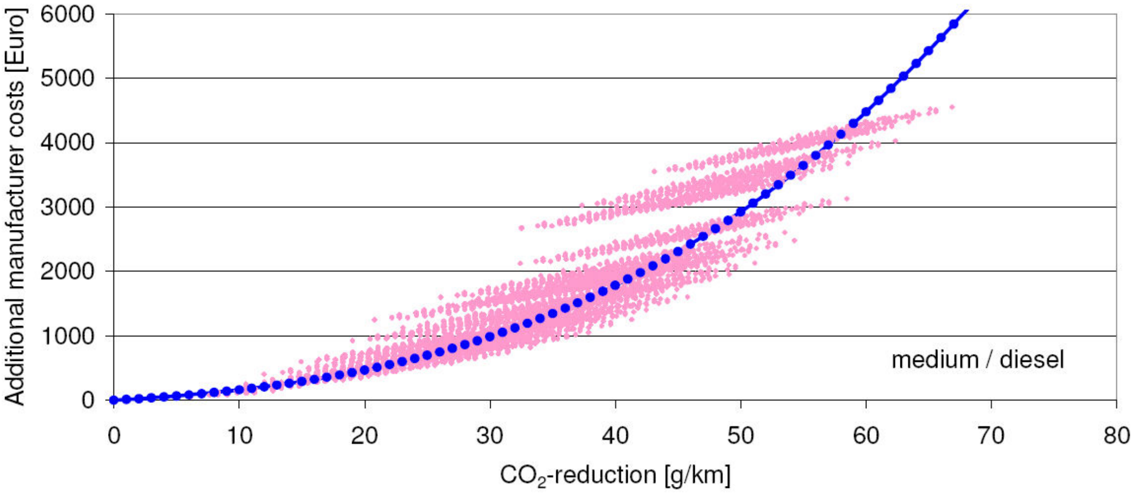


Figure 3.8 Cost curve for medium-sized diesel cars (manufacturer costs as a function of reduction of Type Approval CO_2-emission). Starting point for the x-axis is the TA CO_2-emission of the 2002 baseline vehicle: 152.9 g/km.

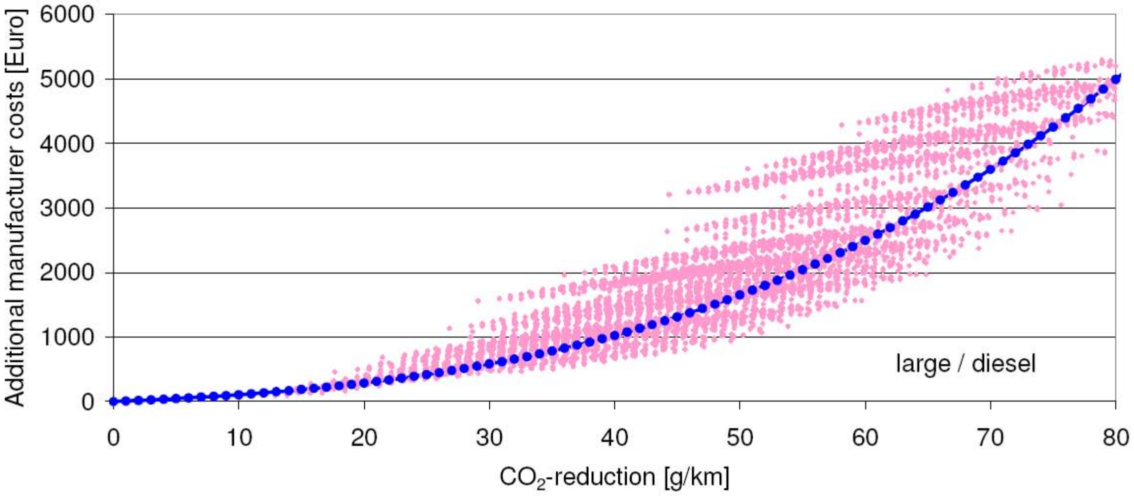


Figure 3.9 Cost curve for large diesel cars (manufacturer costs as a function of reduction of Type Approval CO_2-emission). Starting point for the x-axis is the TA CO_2-emission of the 2002 baseline vehicle: 200.7 g/km.

3.9 Costs for achieving a 2012 target between 140 and 120 g/km

3.9.1 Assumptions on autonomous market developments between 2002 and 2012

The main external inputs to the model are the 2002 sales figures per manufacturer per segment and the 2002 average CO_2-emission figures per manufacturer per segment. Obviously, even without the voluntary agreements for 2008/9 and possible additional measures until 2012 the market is not remaining static. Three main autonomous market developments are accounted for in the model:

Sales volume growth

Similar to the [IEEP 2004] study a constant sales volume growth of 1% per year has been assumed for the period 2002 – 2012. This constant increase is applied equally to all segments and manufacturers

Autonomous weight increase

Based on consultation with ACEA an autonomous weight increase of 1.5% per annum is assumed. This value has been derived from the monitoring of the progress of the voluntary agreement. This autonomous weight increase mainly results from two factors, one being the increased level of safety measures applied to vehicles in response to European vehicle safety legislation. The second cause is the demand trend towards higher standards of luxury and comfort as a result of the increased spending power of European consumers. This trend results in a gradual increase in size and mass of subsequent versions of the same vehicle model and the application of a higher number of comfort enhancing auxiliaries[14].

It should be stressed here that autonomous weight increase, as modelled in the cost assessment tool used for this analysis, is an exogenous variable. It should be considered as the change in vehicle weight that would occur between 2002 and 2012 in the absence of actions by the manufacturers to reduce CO_2-emissions in response to the self-commitment or a future policy beyond 2008/9. Autonomous weight increase leads to additional CO_2-emission, which needs to be compensated by additional efficiency improvement measures if a certain absolute target for 2008/9 or 2012 is to be met. Compared to a situation without autonomous weight increase manufacturers have to realise a higher gross CO_2-reduction compared to the 2002 baseline, which is equivalent to climbing higher up the cost curves as presented in section 3.8.2.

For a medium size petrol vehicle 1.5% p.a. comes down to a weight increase of 113 kg between 2002 and 2008 and 76 kg between 2008 and 2012. This is significantly higher than the 60 resp. 40 kg that was assumed in [IEEP 2004], and will thus also have a significant impact in the costs for reaching the targets in 2008 and 2012, as the additional CO_2-emissions associated with this additional weight increase has to be compensated by additional measures to improve vehicle efficiency.

The weight increase ΔM is translated into a CO_2-emission increase ΔCO_2 for each segment based on the 2002 vehicle mass value M for that segment using the following formula:

$$\Delta CO_2 / CO_2 = 0.65 * \Delta M / M$$

This formula is also different from the one used in [IEEP 2004], and corresponds to a stronger relation between weight increase and additional CO_2-emission. The formula has been derived based on information provided by ACEA and evaluation of available data from measurements, simulations and vehicle statistics and is roughly equivalent with the relation that 100 kg additional weight results in 0.4 l/100km additional fuel consumption for petrol vehicles and 0.3 l/100km for diesel vehicles as used in evaluations by ACEA. An assessment of the various formulas is presented in Annex C. Different alternative formulas can be translated into the above relative formula. The above formula is based on formulas provided by ACEA that are expressed as additional l/100km for a 100kg weight increase. The factor 0.65 corresponds well with the range of ratios found between relative change of energy delivered at the wheels and relative mass change. Assuming that average engine efficiency is

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[14] A sensitivity analysis of the impact of variations in the assumption on autonomous weight increase is given in section 3.11.3.

not strongly affected by weight increase (which is true if the engine is scaled up to maintain vehicle performance) the relative change in fuel consumption should roughly equal the relative change in energy at the wheels.

The ΔCO_2-values calculated with the above formula are added to the 2002 resp. 2008 CO_2-emission values per segment per manufacturer and provide an extra CO_2-reduction target that is to be achieved by the technical measures applied in 2008 resp. 2012.

Petrol-to-diesel shift

Similar to [IEEP 2004] for the period 2002-2008 a petrol-to-diesel shift has been implemented resulting in a 50/50 petrol-diesel share in 2008, while for 2012 a 45/55 petrol-diesel share has been assumed. These shifts have been implemented by shifting different percentages of the 3 petrol segments to the corresponding diesel segments. Obviously a shift is only applied from segments in which manufacturers have finite sales in 2002 and 2008 respectively. It is assumed that the shift is relatively small in the segment of large vehicles and that the shifts in the small and medium size segments are equal. In the segment of large vehicles consumers are less sensitive to fuel costs and this segment contains a lot of (high-powered) sports cars, which are not eligible for conversion to diesel. This results in the following shift percentages:

Table 3.12 Percentage of sales shifted from the petrol to the corresponding diesel segment between 2002 and 2008 and between 2008 and 2012.

		p,S	p,M	p,L
2002-2008	ACEA	16.9%	16.9%	5.0%
	JAMA	16.9%	16.9%	5.0%
	KAMA	16.9%	16.9%	5.0%
	Other	16.9%	16.9%	5.0%
2008-2012	ACEA	10.7%	10.7%	5.0%
	JAMA	10.7%	10.7%	5.0%
	KAMA	10.7%	10.7%	5.0%
	Other	10.7%	10.7%	5.0%

Applying these shift percentages results in the following shares of petrol and diesel vehicles in the different segments:

Table 3.13 Percentage petrol and diesel vehicle in total sales and per segment in 2002, 2008 and 2012.

	petrol	diesel	p,S	p,M	p,L	d,S	d,M	d,L
2002	59.29%	40.71%	78.3%	50.6%	45.6%	21.7%	49.4%	54.4%
2008	49.99%	50.01%	65.0%	42.1%	43.4%	35.0%	57.9%	56.6%
2012	44.99%	55.01%	58.1%	37.6%	41.2%	41.9%	62.4%	58.8%

Calculations with TREMOVE outside this project will assess the impact of the changes in costs as a result of measures applied to reach the 2008/9 and 2012 targets. If these impacts are found to deviate strongly from the above assumptions then new iteration with the cost assessment model could be justified. Within the context of Task A & B it was assumed that an iterative approach with Task A results feeding into TREMOVE and TREMOVE results feeding into Task A would not be necessary at this stage.

Developments in vehicle price

Various sources monitoring the consumer price index suggest that the retail price of new vehicles have not increased or even decreased over time in the last 5 to 10 years, although the features offered by the cars continuously increase. In this study this aspect has not been taken into account. The autonomous development in vehicle price is considered an exogenous effect that does not impact the calculation of costs and effectiveness of CO_2-emission reduction options studied here. This study looks at additional costs that would not be made in the absence of a policy requiring application of CO_2-emission reduction options. Any autonomous trend in the base vehicle price cancels out when the full costs of the baseline vehicle in different years is subtracted from the full costs of vehicles with additional CO_2-reducing technology. Furthermore it is considered dangerous to draw conclusions on developments of vehicle prices over recent years or to extrapolate such trends into the future. Vehicle prices in different countries have developed very differently in recent years in response to EU policy requiring manufacturers to adopt more uniform pricing policies in EU-countries irrespective of the countries' very different tax regimes. Furthermore car prices have been under pressure for some time due to overproduction in Europe and economic recession.

3.9.2 Costs for achieving the 2008 target of 140 g/km

In this project we are assessing the additional costs of CO_2-reduction measures on top of the existing Commission policy aiming at 140 g/km for new vehicles in 2008/9. In the cost assessment model the first step therefore is an assessment of the costs of reaching the 140 g/km target in 2008/9, starting from the 2002 baseline vehicles as specified in section 3.7.1. The TA CO_2-emissions of new passenger cars in 2002 and 2008/9 and the costs per segment for reaching the 2008/9 target of 140 g/km, as estimated by the cost assessment model based on the cost curves described above, are depicted in Table 3.14. The abatement costs of reducing CO_2-emissions from the average 2002 level to 140 g/km in 2008/9 is given in Table 3.15.

Table 3.14 TA CO_2-emissions of new passenger cars in 2002 and 2008/9 and the costs per segment for reaching the 2008/9 target of 140 g/km.

		p,S	p,M	p,L	d,S	d,M	d,L	average
2002 TA CO_2-emission	[g/km]	149	184	238	123	153	201	166
2008/9 TA CO_2-emission	[g/km]	120	148	185	115	141	178	140
additional manuf. costs	[€/veh.]	1029	1152	1573	356	518	773	832
additional retail price (excl. tax)	[€/veh.]	1194	1337	1824	412	601	896	965
additional retail price (incl. tax)	[€/veh.]	1482	1659	2265	512	746	1113	1198

Table 3.15 Abatement costs of reducing CO_2-emissions from the average 2002 level to 140 g/km in 2008/9

2008 target [g/km]	CO_2-abatement costs [€/tonne] at various levels of fuel costs			
	0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
140	72	48	20	-30

3.9.3 Costs for reaching a 2012 target between 140 g/km and 120 g/km

Figure 3.10, Figure 3.11 and Figure 3.12 present the overall results of the assessment of the costs of reaching a 2012 target between 140 g/km and 120 g/km. Results displayed here are valid for the target-measure combinations involving targets specified per manufacturer without trading. The results in Figure 3.10 are averaged for the six target definitions. When trading is allowed somewhat lower overall costs are achieved than the ones presented here, and furthermore all target definitions lead to the same overall average costs. For other target applied per car the average costs are generally higher as can be seen from Table 3.16 to Table 3.25.

The costs per vehicle as displayed in Figure 3.10 are the additional costs of going from a TA value of 140 g/km in 2008 to various reduced targets in 2012. In Figure 3.11 the impact of different target definitions (see section 3.7) is presented for scenarios in which the target is applied to manufacturer without the option of trading. The influence of the target definition on the average costs per vehicle for reaching the target is found to be relatively small. Figure 3.12 presents the CO_2-abatement costs of reaching a 2012 target as a function of the target value and the fuel price.

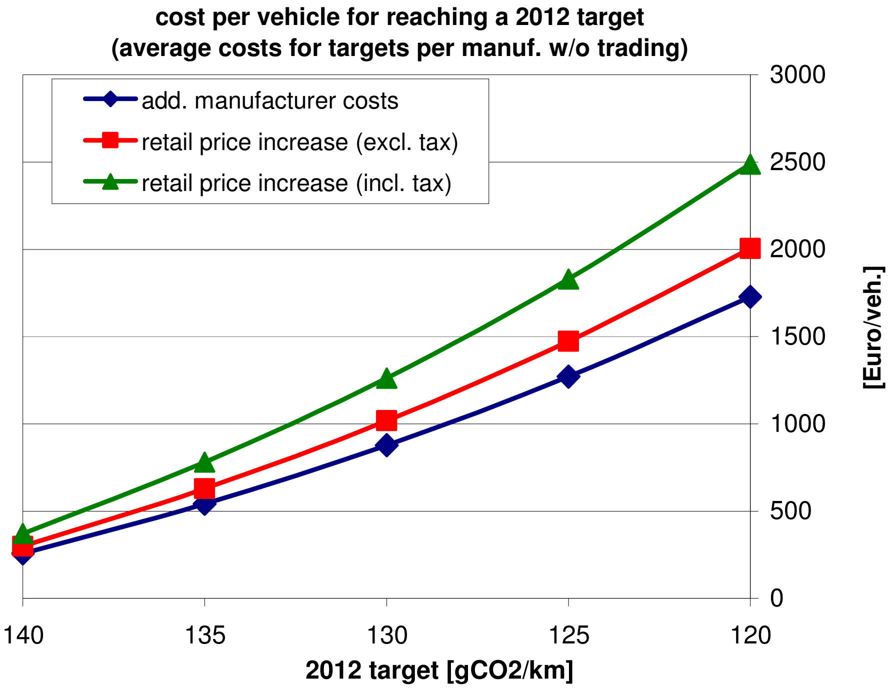

Figure 3.10 Average additional costs per vehicle for reaching various 2012 targets compared to the 2008 situation for targets applied per manufacturer without trading.

In Figure 3.12 the CO_2-abatement costs are calculated with investment costs including dealer cost (= retail price – tax = 1.16 * manufacturer costs = 0.81 * retail price). CO_2-abatement costs are calculated with an interest rate of 4% and assuming an average annual mileage of 16,000 km and an average vehicle lifetime of 13 years. The reference case is an average 2012 vehicle emitting 140 g/km on the TA test (including the additional costs of maintaining 140 g/km by applying CO_2-reducing measures to compensate the effects of autonomous weight increase). Fuel consumption benefits are based on the real-world fuel consumption which is assumed to be 1.195 times the TA value. The CO_2-reduction is also based on the real-world CO_2-emission, calculated from the TA value using a factor of 1.195, and furthermore includes the avoided WTT CO_2-emissions, by multiplying the real-world TTW CO_2-emission with a factor of 1.184. This factor is the average of the WTW/TTW factors for petrol and diesel as derived from [Concawe 2006], weighted with the expected sales distribution of petrol and diesel in 2012 (see Table 3.13). This definition is different from the one used in [IEEP 2004]. Besides the new definition of additional investment costs, real-world driving and WTW-aspects are included to make the CO_2-abatement cost calculation comparable to the assessments for e.g. eco-driving (chapter 9) and biofuels (chapter 7).

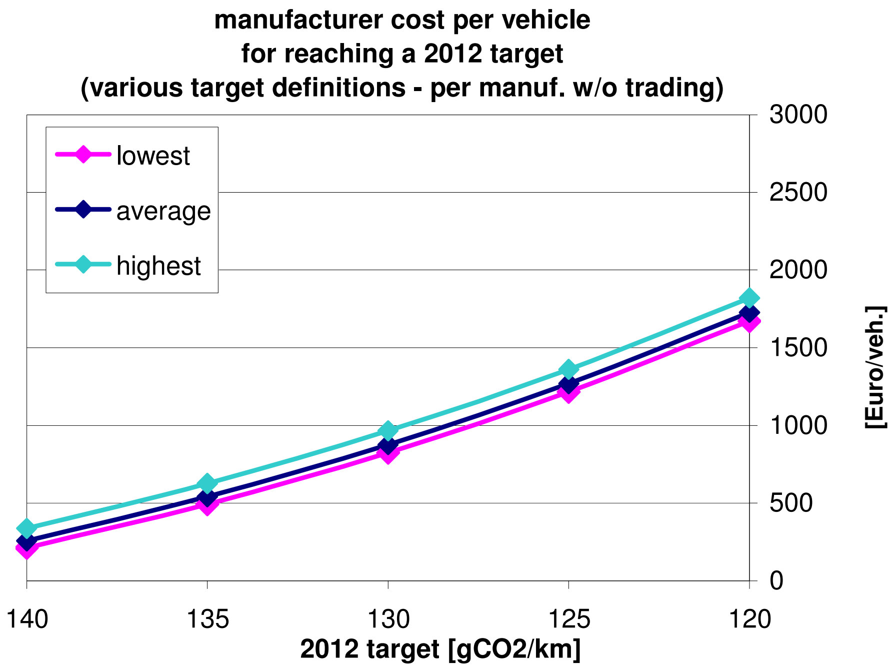

Figure 3.11 Variation of the additional manufacturer costs per vehicle for reaching various 2012 targets compared to the 2008 situation in response to different target definitions applied per manufacturer without trading.

Maintaining 140 g/km involves finite costs as the effects of autonomous weight increase between 2008 and 2012 need to be compensated. In the calculation of CO_2-abatement costs the costs for maintaining 140 g/km, however, need to be subtracted from the cost per vehicle for reaching targets below 140 g/km, as the costs of maintaining 140 g/km are to be attributed to the existing policy of reaching 140 g/km in 2008, instead of to a new policy aiming at a reduced goal in 2012. The CO_2-abatement costs for maintaining 140 g/km can furthermore not be calculated as the net CO_2-reduction is zero.

Detailed results of the manufacturer cost per vehicle in the various segments and the required CO_2-reduction on the TA test are presented in Table 3.16 to Table 3.25 for 2012 targets of 140 g/km, 135 g/km, 130 g/km, 125 g/km and 120 g/km. Data are specified for the different target-measure combinations that were also studied in [IEEP 2004]. Manufacturer costs can be translated into retail price (incl. tax) by multiplication with a factor 1.44. Additional investment costs (retail price excl. tax) is equal to 1.16 times the manufacturer costs.

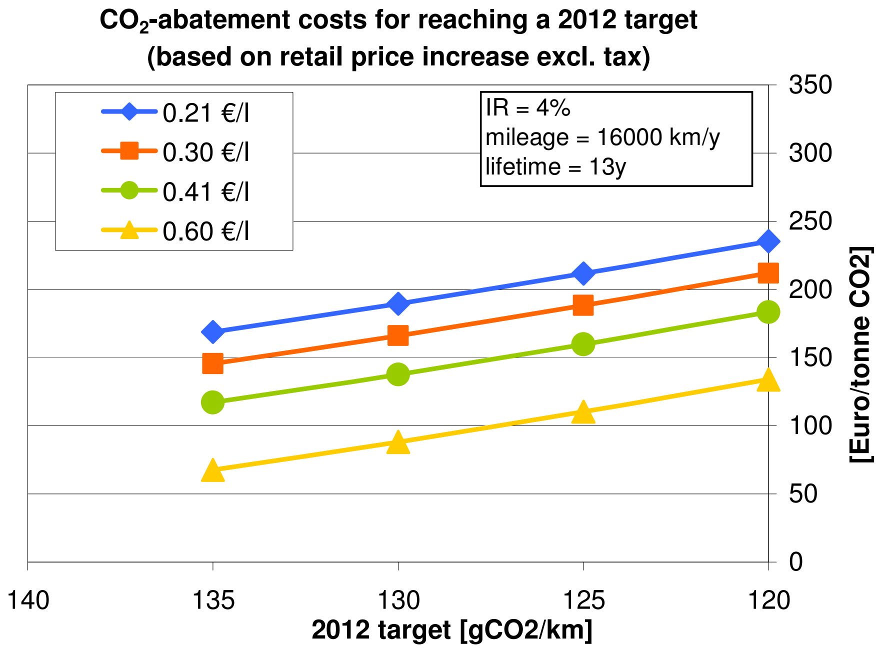

Figure 3.12 CO_2-abatement costs of reaching various 2012 targets, depending on fuel costs. In the CO_2-abatement cost formula investment costs are retail price increases excl. tax. Fuel cost savings are based on real-world fuel consumption and CO_2-emission reduction includes Well-to-Tank GHG emissions.

It is clear from Table 3.16 to Table 3.25 that the distribution of costs per vehicle over the different segments depends heavily on the target-measure combination that is assumed to be implemented for reaching the specified target. The influence on the average costs, however, is limited as already indicated in Figure 3.11.

Figure 3.14 and Figure 3.15 in section 3.11.1 show the gross CO_2-emission reductions (i.e. including the reduction necessary to counteract the effects of autonomous weight increase) that are required on average[15] from petrol and diesel vehicles in the three different segments for reaching the 2008/9 target of 140 g/km and a 2012 target of 120 g/km under various target measure combinations. In the spread for reaching the 2012 target (indicated width of the grey bars) all target measures are included except the measures in which a fixed or a percentage target is applied to each car. These target-measure combinations are unlikely to be implemented and lead to very large required reductions for some segments.

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[15] In the model required CO_2-emission reductions are assessed per manufacturer. Depending on their initial average CO_2-emissions per segment the required reductions per manufacturer may be smaller or larger the average values indicated here.

*Table 3.16 Manufacturer costs per vehicle for maintaining **140 g/km** in 2012*

Manufacturer costs per vehicle [Euro/vehicle]							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
each car - uniform target	-511	772	4294	-386	316	4581	689
each car - % reduction	186	232	291	109	218	292	208
each car - utility based CO2-curve (V^2/3*P^1/3)	944	329	653	378	-91	304	332
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	587	400	1107	105	-32	734	315
each car - utility based CO2-curve (pan area = l*w)	303	460	2614	-128	-82	1686	377
each car - optimised utility based CO2-curve (pan area = l*w)	619	385	2236	52	-162	1161	361
per manufacturer - uniform target	108	456	1550	45	232	765	338
per manufacturer - % reduction	253	266	378	130	163	224	213
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	215	312	610	96	176	319	234
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	191	328	739	83	179	378	243
per manufacturer - utility based CO2-curve (pan area = l*w)	161	358	1021	65	185	491	266
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	179	339	903	73	177	432	254
all cars (trading) - uniform target	-810	655	2583	-1146	266	2234	210
all cars (trading) - % reduction [1]	317	319	467	100	99	159	210
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	786	268	365	306	-181	-4	210
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	1411	117	-504	875	-355	-880	210
all cars (trading) - utility based CO2-curve (pan area = l*w)	253	391	1750	-245	-168	1021	210
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	1935	-26	432	1182	-855	-900	210

[1]) costs per segment based on an division of total deficit costs over the various segments
on the basis of applying a fixed percentage per car to all segments. This, however, does not
yield correct deficits due to disturbances in market shares resulting from the petrol-diesel shift!!

*Table 3.17 TA CO$_2$-emission per vehicle per segment for maintaining **140 g/km** in 2012*

CO2-emission per vehicle [g/km] on TA test							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**avg**
2008 TA value [g/km]	120.4	148.0	184.5	115.3	140.6	177.6	140.1
each car - uniform target	140.0	140.0	140.0	140.0	140.0	140.0	140.0
each car - % reduction	120.6	148.4	185.0	115.5	141.0	178.1	140.1
each car - utility based CO2-curve (V^2/3*P^1/3)	108.8	147.6	183.4	111.6	148.7	183.7	140.0
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	114.2	146.2	175.8	116.5	147.2	176.1	140.0
each car - utility based CO2-curve (pan area = l*w)	119.2	145.1	156.3	122.4	148.5	163.7	140.0
each car - optimised utility based CO2-curve (pan area = l*w)	113.7	146.5	160.6	117.7	150.7	170.0	140.0
per manufacturer - uniform target	124.0	146.6	170.4	117.6	142.3	173.5	140.0
per manufacturer - % reduction	119.3	147.7	183.3	115.1	142.0	179.4	140.0
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	120.4	147.3	180.3	115.9	142.0	178.0	140.0
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	121.0	147.2	178.6	116.2	142.1	177.3	140.0
per manufacturer - utility based CO2-curve (pan area = l*w)	121.8	147.0	175.3	116.7	142.3	175.9	140.0
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	121.3	147.2	176.6	116.5	142.3	176.6	140.0
all cars (trading) - uniform target	119.2	147.7	184.0	115.0	141.9	179.7	140.0
all cars (trading) - % reduction [1]	119.2	147.7	184.0	115.0	141.9	179.7	140.0
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	119.2	147.7	184.0	115.0	141.9	179.7	140.0
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	119.2	147.7	184.0	115.0	141.9	179.7	140.0
all cars (trading) - utility based CO2-curve (pan area = l*w)	119.2	147.7	184.0	115.0	141.9	179.7	140.0
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	119.2	147.7	184.0	115.0	141.9	179.7	140.0

Table 3.18 Manufacturer costs per vehicle for reaching ***135 g/km*** *in 2012*

Manufacturer costs per vehicle [Euro/vehicle]							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
each car - uniform target	-357	1119	4898	-367	635	5408	993
each car - % reduction	411	519	644	338	519	675	491
each car - utility based CO2-curve (V^2/3*P^1/3)	1237	628	1044	655	136	669	613
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	871	703	1507	347	206	1143	598
each car - utility based CO2-curve (pan area = l*w)	542	774	3143	38	148	2257	658
each car - optimised utility based CO2-curve (pan area = l*w)	915	683	2712	286	38	1621	640
per manufacturer - uniform target	412	820	2164	198	451	1128	626
per manufacturer - % reduction	575	614	874	308	381	525	493
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	533	666	1137	267	396	635	517
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	507	682	1273	251	399	698	526
per manufacturer - utility based CO2-curve (pan area = l*w)	472	715	1591	227	403	828	551
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	494	693	1451	238	394	757	536
all cars (trading) - uniform target	-741	1006	3280	-1105	570	2907	490
all cars (trading) - % reduction [1]	563	625	857	282	385	537	490
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	1097	561	727	567	57	330	490
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	1865	375	-341	1266	-158	-747	490
all cars (trading) - utility based CO2-curve (pan area = l*w)	483	702	2321	-67	71	1510	490
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	2480	207	756	1626	-744	-770	490

[1]) costs per segment based on an division of total deficit costs over the various segments on the basis of applying a fixed percentage per car to all segments. This, however, does not yield correct deficits due to disturbances in market shares resulting from the petrol-diesel shift!!

Table 3.19 TA CO_2-emission per vehicle per segment for reaching ***135 g/km*** *in 2012*

CO2-emission per vehicle [g/km] on TA test							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**avg**
2008 TA value [g/km]	120.4	148.0	184.5	115.3	140.6	177.6	140.1
each car - uniform target	135.0	135.0	135.0	135.0	135.0	135.0	135.0
each car - % reduction	116.3	143.1	178.4	111.4	136.0	171.7	135.1
each car - utility based CO2-curve (V^2/3*P^1/3)	104.9	142.3	176.8	107.6	143.4	177.2	135.0
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	109.9	141.1	170.0	112.1	142.0	170.3	135.0
each car - utility based CO2-curve (pan area = l*w)	115.0	140.0	150.7	118.0	143.2	157.9	135.0
each car - optimised utility based CO2-curve (pan area = l*w)	109.2	141.4	155.2	113.1	145.5	164.4	135.0
per manufacturer - uniform target	117.8	140.4	162.2	114.5	138.4	168.4	135.0
per manufacturer - % reduction	113.5	141.5	174.5	111.9	138.1	174.1	135.0
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	114.5	141.1	171.7	112.7	138.1	172.8	135.0
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	115.1	141.0	170.1	113.0	138.2	172.1	135.0
per manufacturer - utility based CO2-curve (pan area = l*w)	115.9	140.9	166.8	113.6	138.4	170.8	135.0
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	115.3	141.0	168.2	113.3	138.4	171.4	135.0
all cars (trading) - uniform target	113.4	141.5	175.1	111.8	138.0	174.4	135.0
all cars (trading) - % reduction [1]	113.4	141.5	175.1	111.8	138.0	174.4	135.0
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	113.4	141.5	175.1	111.8	138.0	174.4	135.0
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	113.4	141.5	175.1	111.8	138.0	174.4	135.0
all cars (trading) - utility based CO2-curve (pan area = l*w)	113.4	141.5	175.1	111.8	138.0	174.4	135.0
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	113.4	141.5	175.1	111.8	138.0	174.4	135.0

Table 3.20 Manufacturer costs per vehicle for reaching ***130 g/km*** *in 2012*

Manufacturer costs per vehicle [Euro/vehicle]							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
each car - uniform target	-180	1515	5547	-310	1026	6320	1350
each car - % reduction	667	852	1047	623	892	1144	830
each car - utility based CO2-curve (V^2/3*P^1/3)	1563	974	1486	988	430	1117	949
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	1195	1050	1949	653	508	1623	935
each car - utility based CO2-curve (pan area = l*w)	812	1136	3720	257	443	2916	995
each car - optimised utility based CO2-curve (pan area = l*w)	1256	1026	3228	587	297	2150	972
per manufacturer - uniform target	763	1244	2869	390	715	1552	965
per manufacturer - % reduction	948	1022	1461	527	645	887	826
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	901	1081	1756	478	661	1013	852
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	875	1097	1895	461	663	1078	861
per manufacturer - utility based CO2-curve (pan area = l*w)	833	1133	2252	429	666	1228	888
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	860	1107	2087	445	657	1142	871
all cars (trading) - uniform target	-651	1404	4036	-1020	943	3675	823
all cars (trading) - % reduction [1]	826	975	1259	534	744	986	823
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	1439	898	1131	882	358	744	823
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	2321	684	-95	1685	112	-493	823
all cars (trading) - utility based CO2-curve (pan area = l*w)	740	1059	2945	160	375	2086	823
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	3055	485	1131	2123	-571	-558	823

[1]) costs per segment based on an division of total deficit costs over the various segments
on the basis of applying a fixed percentage per car to all segments. This, however, does not
yield correct deficits due to disturbances in market shares resulting from the petrol-diesel shift!!

Table 3.21 TA CO_2-emission per vehicle per segment for reaching ***130 g/km*** *in 2012*

CO2-emission per vehicle [g/km] on TA test							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**avg**
2008 TA value [g/km]	120.4	148.0	184.5	115.3	140.6	177.6	140.1
each car - uniform target	130.0	130.0	130.0	130.0	130.0	130.0	130.0
each car - % reduction	112.0	137.8	171.8	107.3	130.9	165.4	130.1
each car - utility based CO2-curve (V^2/3*P^1/3)	101.0	137.0	170.3	103.6	138.1	170.6	130.0
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	105.5	135.9	164.1	107.7	136.9	164.4	130.0
each car - utility based CO2-curve (pan area = l*w)	110.7	134.8	145.1	113.6	137.9	152.0	130.0
each car - optimised utility based CO2-curve (pan area = l*w)	104.7	136.3	149.8	108.5	140.3	158.9	130.0
per manufacturer - uniform target	111.9	134.3	153.9	111.2	134.5	163.2	130.0
per manufacturer - % reduction	107.9	135.3	165.8	108.6	134.1	168.7	130.0
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	108.8	135.0	163.1	109.4	134.1	167.4	130.0
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	109.3	134.9	161.7	109.7	134.2	166.8	130.0
per manufacturer - utility based CO2-curve (pan area = l*w)	110.1	134.7	158.4	110.3	134.4	165.5	130.0
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	109.5	134.9	159.8	110.0	134.4	166.2	130.0
all cars (trading) - uniform target	107.7	135.4	166.3	108.4	134.1	169.2	130.0
all cars (trading) - % reduction [1]	107.7	135.4	166.3	108.4	134.1	169.2	130.0
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	107.7	135.4	166.3	108.4	134.1	169.2	130.0
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	107.7	135.4	166.3	108.4	134.1	169.2	130.0
all cars (trading) - utility based CO2-curve (pan area = l*w)	107.7	135.4	166.3	108.4	134.1	169.2	130.0
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	107.7	135.4	166.3	108.4	134.1	169.2	130.0

*Table 3.22 Manufacturer costs per vehicle for reaching **125 g/km** in 2012*

Manufacturer costs per vehicle [Euro/vehicle]							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
each car - uniform target	25	1962	6243	-205	1498	7321	1765
each car - % reduction	959	1236	1505	967	1345	1707	1231
each car - utility based CO2-curve (V^2/3*P^1/3)	1924	1371	1981	1382	799	1656	1345
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	1563	1448	2433	1030	884	2180	1334
each car - utility based CO2-curve (pan area = l*w)	1118	1549	4348	534	815	3672	1392
each car - optimised utility based CO2-curve (pan area = l*w)	1645	1418	3787	965	624	2751	1365
per manufacturer - uniform target	1169	1736	3674	627	1028	2045	1362
per manufacturer - % reduction	1378	1499	2150	792	958	1318	1217
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	1326	1563	2476	734	976	1460	1246
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	1299	1579	2615	716	978	1526	1255
per manufacturer - utility based CO2-curve (pan area = l*w)	1250	1619	3015	676	979	1696	1282
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	1283	1589	2819	697	969	1595	1264
all cars (trading) - uniform target	-537	1854	4847	-883	1390	4541	1214
all cars (trading) - % reduction [1]	1118	1370	1723	854	1173	1534	1214
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	1813	1285	1581	1256	733	1247	1214
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	2788	1049	226	2143	461	-120	1214
all cars (trading) - utility based CO2-curve (pan area = l*w)	1028	1466	3621	444	752	2755	1214
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	3609	826	1597	2634	-302	-192	1214

[1]) costs per segment based on an division of total deficit costs over the various segments
on the basis of applying a fixed percentage per car to all segments. This, however, does not
yield correct deficits due to disturbances in market shares resulting from the petrol-diesel shift!!

*Table 3.23 TA CO_2-emission per vehicle per segment for reaching **125 g/km** in 2012*

CO2-emission per vehicle [g/km] on TA test							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**avg**
2008 TA value [g/km]	120.4	148.0	184.5	115.3	140.6	177.6	140.1
each car - uniform target	125.0	125.0	125.0	125.0	125.0	125.0	125.0
each car - % reduction	107.8	132.5	165.2	103.2	125.9	159.0	125.1
each car - utility based CO2-curve (V^2/3*P^1/3)	97.2	131.7	163.7	99.7	132.8	164.0	125.0
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	101.0	130.8	158.3	103.2	131.7	158.6	125.0
each car - utility based CO2-curve (pan area = l*w)	106.5	129.6	139.5	109.3	132.6	146.2	125.0
each car - optimised utility based CO2-curve (pan area = l*w)	100.1	131.2	144.5	103.9	135.2	153.4	125.0
per manufacturer - uniform target	106.1	128.3	145.7	107.8	130.5	158.0	125.0
per manufacturer - % reduction	102.3	129.3	157.1	105.2	130.1	163.3	125.0
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	103.3	128.9	154.5	106.0	130.1	162.1	125.0
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	103.6	128.8	153.3	106.3	130.2	161.5	125.0
per manufacturer - utility based CO2-curve (pan area = l*w)	104.4	128.7	150.0	106.9	130.4	160.2	125.0
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	103.9	128.8	151.5	106.5	130.4	160.9	125.0
all cars (trading) - uniform target	102.1	129.3	157.5	105.0	130.1	163.8	125.0
all cars (trading) - % reduction [1]	102.1	129.3	157.5	105.0	130.1	163.8	125.0
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	102.1	129.3	157.5	105.0	130.1	163.8	125.0
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	102.1	129.3	157.5	105.0	130.1	163.8	125.0
all cars (trading) - utility based CO2-curve (pan area = l*w)	102.1	129.3	157.5	105.0	130.1	163.8	125.0
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	102.1	129.3	157.5	105.0	130.1	163.8	125.0

*Table 3.24 Manufacturer costs per vehicle for reaching **120 g/km** in 2012*

Manufacturer costs per vehicle [Euro/vehicle]							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
each car - uniform target	263	2465	6988	-44	2058	8418	2246
each car - % reduction	1288	1676	2022	1377	1886	2375	1700
each car - utility based CO2-curve (V^2/3*P^1/3)	2322	1824	2535	1840	1254	2297	1809
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	1978	1899	2964	1485	1343	2821	1800
each car - utility based CO2-curve (pan area = l*w)	1462	2018	5030	876	1273	4530	1856
each car - optimised utility based CO2-curve (pan area = l*w)	2086	1862	4390	1426	1027	3432	1824
per manufacturer - uniform target	1637	2301	4587	913	1395	2611	1821
per manufacturer - % reduction	1871	2049	2948	1107	1326	1824	1673
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	1815	2120	3307	1041	1345	1982	1704
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	1788	2135	3442	1022	1346	2047	1712
per manufacturer - utility based CO2-curve (pan area = l*w)	1729	2179	3887	973	1346	2238	1741
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	1771	2144	3658	1000	1335	2119	1720
all cars (trading) - uniform target	-392	2359	5710	-684	1921	5511	1669
all cars (trading) - % reduction [1]	1441	1817	2237	1240	1685	2182	1669
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	2221	1726	2079	1694	1190	1848	1669
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	3287	1468	596	2664	892	353	1669
all cars (trading) - utility based CO2-curve (pan area = l*w)	1348	1927	4347	791	1210	3525	1669
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	4196	1221	2114	3207	48	273	1669

[1]) costs per segment based on an division of total deficit costs over the various segments
on the basis of applying a fixed percentage per car to all segments. This, however, does not
yield correct deficits due to disturbances in market shares resulting from the petrol-diesel shift!!

*Table 3.25 TA CO_2-emission per vehicle per segment for reaching **120 g/km** in 2012*

CO2-emission per vehicle [g/km] on TA test							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**avg**
2008 TA value [g/km]	120.4	148.0	184.5	115.3	140.6	177.6	140.1
each car - uniform target	120.0	120.0	120.0	120.0	120.0	120.0	120.0
each car - % reduction	103.5	127.2	158.6	99.1	120.9	152.7	120.2
each car - utility based CO2-curve (V^2/3*P^1/3)	93.3	126.5	157.2	95.7	127.5	157.5	120.0
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	96.6	125.7	152.5	98.7	126.5	152.8	120.0
each car - utility based CO2-curve (pan area = l*w)	102.2	124.4	134.0	104.9	127.3	140.3	120.0
each car - optimised utility based CO2-curve (pan area = l*w)	95.5	126.1	139.2	99.2	130.0	147.9	120.0
per manufacturer - uniform target	100.4	122.3	137.5	104.3	126.4	152.7	120.0
per manufacturer - % reduction	96.9	123.2	148.4	101.7	126.1	157.8	120.0
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	97.7	122.9	145.9	102.5	126.1	156.6	120.0
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	98.1	122.8	144.9	102.7	126.2	156.2	120.0
per manufacturer - utility based CO2-curve (pan area = l*w)	98.8	122.7	141.6	103.4	126.4	154.8	120.0
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	98.3	122.8	143.2	103.0	126.3	155.6	120.0
all cars (trading) - uniform target	96.5	123.2	148.7	101.5	126.2	158.4	120.0
all cars (trading) - % reduction [1]	96.5	123.2	148.7	101.5	126.2	158.4	120.0
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	96.5	123.2	148.7	101.5	126.2	158.4	120.0
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	96.5	123.2	148.7	101.5	126.2	158.4	120.0
all cars (trading) - utility based CO2-curve (pan area = l*w)	96.5	123.2	148.7	101.5	126.2	158.4	120.0
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	96.5	123.2	148.7	101.5	126.2	158.4	120.0

3.10 Total reduction potential

The overall reduction potential in Mtonnes/y for the EU-15 of reducing the average TA CO_2-emissions of passenger cars is assessed using a vehicle stock spreadsheet containing time series of data on the number of vehicles of different years of construction in the fleet, their average CO_2-emission and their average annual mileage. The overall reduction will evolve over time and is calculated for the period 2008 to 2020. The overall reduction achieved by reducing the average TA CO_2-emissions of passenger cars to 120 g/km in 2012 can serve as a benchmark for other (packages of) measures. The general methodology for the “back-of-the-envelope” calculations of overall GHG-emission reductions made in this report is described in section 2.5. Outside the context of this project (Task A) TREMOVE calculations will be used to calculate the overall reduction in more detail, also taking into account impacts of changes in vehicle prices on sales of different vehicle types, modal split and transport volumes.

The annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) resulting from technical measures applied to passenger cars in order to reach 2012 targets of 135, 130, 125 and 120 g/km (sales average based on Type Approval test results) is displayed in Figure 3.13. The overall reduction in 2012 and 2020 for the different 2012 target levels is listed in Table 3.26.

Type Approval values for intermediate years between 2009 and 2012 have been determined by means of linear interpolation. After 2012 the Type Approval CO_2-emission of new vehicles is assumed to remain constant at the 2012 level. Real-world CO_2-emissions in the policy scenarios for the different target values have been determined using scaling factors based on the development of Type Approval values between 2009 and 2012 which are applied to the real-world CO_2-emission factors as included in the TREMOVE baseline data. Calculations of the overall reduction include well-to-tank emissions based on [Concawe 2006].

As can be seen from Figure 3.13 the overall reduction resulting from measures taken between 2008 and 2012 still increase after 2012 as the share of vehicles meeting the 2012 target in the fleet is still increasing after 2012. For the 135 g/km target a decrease is visible after 2015. This is caused by the fact that the TREMOVE baseline includes some autonomous efficiency improvements between 2009 and 2020, while in the policy scenarios emissions of new vehicles are assumed constant after 2012. The motivation for the latter is that technical options that may be used in the autonomous developments assumed in the TREMOVE baseline scenario are used earlier in the policy scenario for reaching the 2012 target.

Table 3.26 Total GHG emission reduction for EU-15 in 2012 and 2020 for different 2012 target levels

	WTW GHG emission reduction [Mtonnes/y]	
	2012	**2020**
135 g/km TA	3.0	5.1
130 g/km TA	6.8	21.4
125 g/km TA	10.6	37.7
120 g/km TA	14.4	54.1

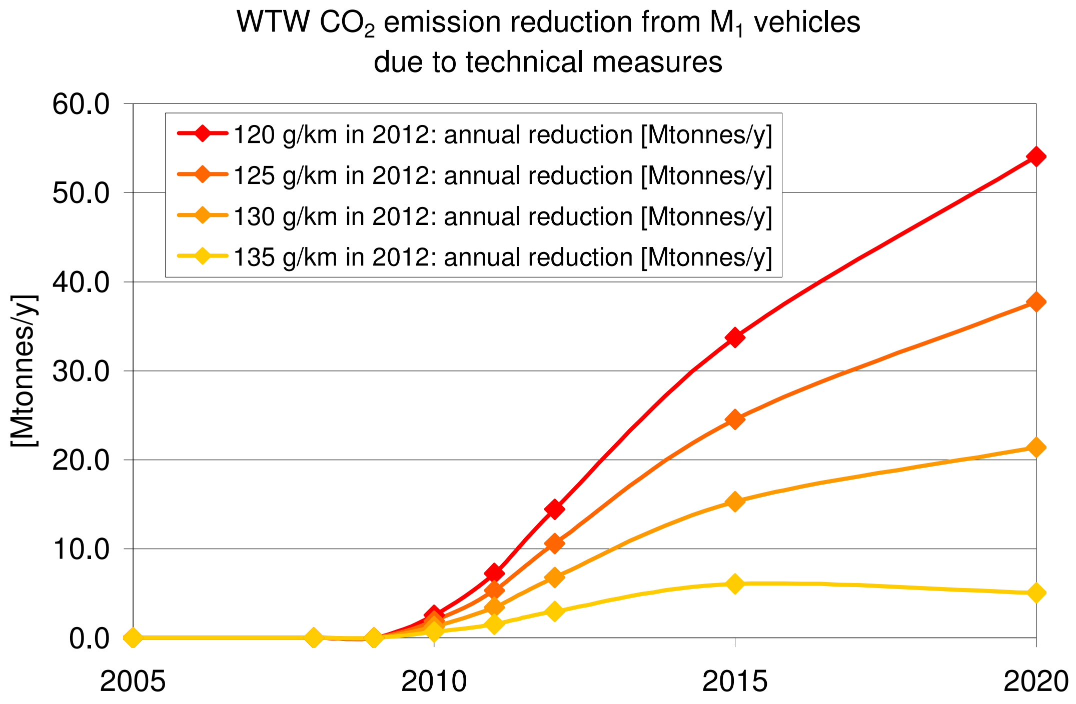

Figure 3.13 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO$_2$-eq. p.a.) for EU-15 resulting from technical measures applied to passenger cars in order to reach a 2012 target between 135 and 120 g/km.

3.11 Discussion of the results

3.11.1 The role of hybrids in reducing CO$_2$-emission from passenger cars

In Figure 3.14 and Figure 3.15 the green dots represent packages of technical options which do not include a mild or full hybrid powertrain, while the pink dots represent packages including a mild or full hybrid powertrain.

Looking at where the grey bars for the 2012 target of 120 g/km cross the blue cost curves as used in the assessment gives an indication of whether or not the application of hybrid technology is necessary for reaching the 2012 target of 120 g/km. In general it can be concluded that, regardless of the type of policy measure that is chosen, reaching a new vehicle sales average TA CO$_2$-emission of 120 g/km requires the introduction of hybrid vehicles in the segments of small, medium ad large petrol cars and of large diesel cars. For small diesel cars the necessity for hybridisation depends on the policy measure, while for medium size diesel cars hybridisation is necessary for none of the policy measures.

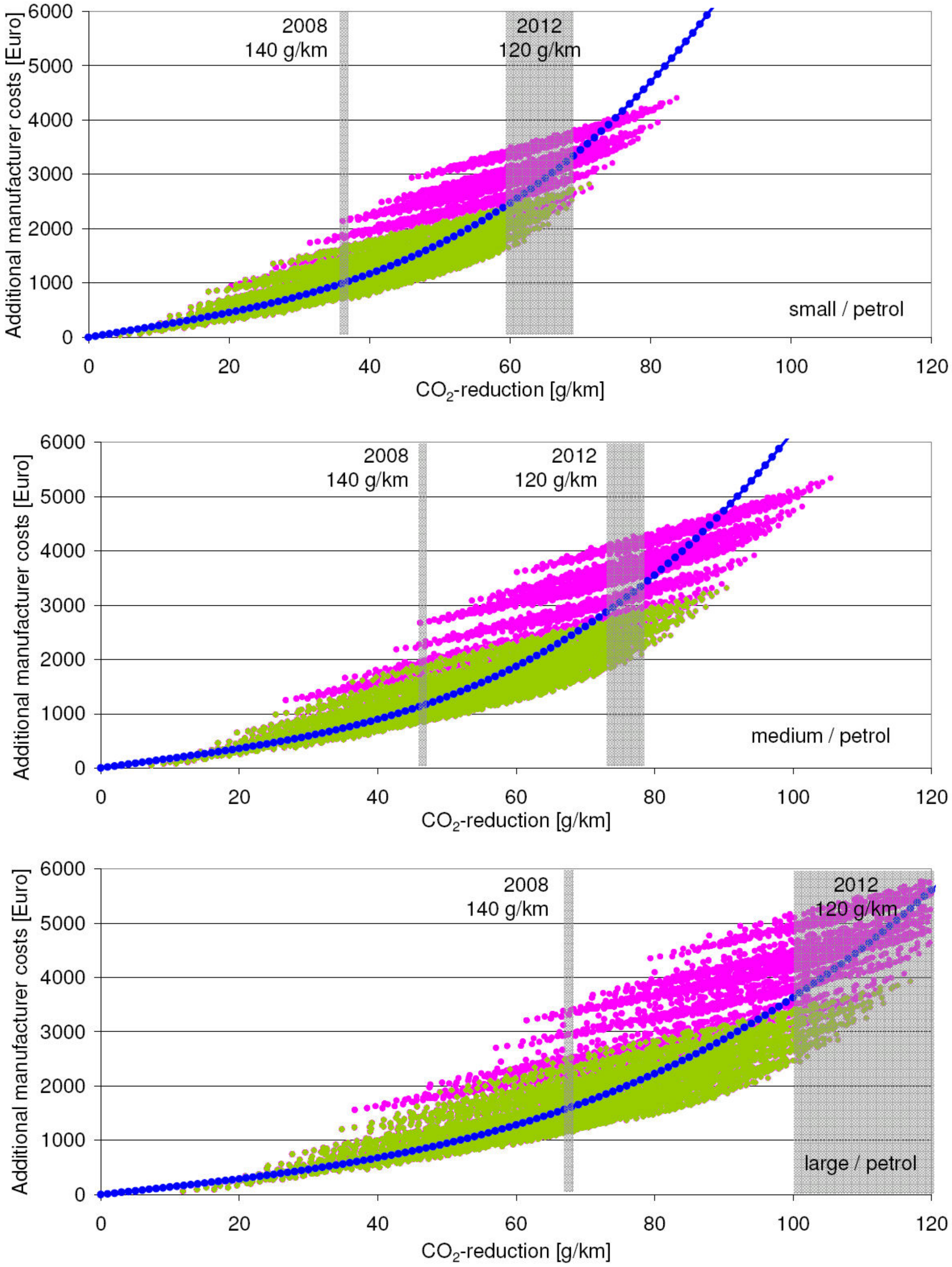

*Figure 3.14 Gross CO$_2$-emission reductions required from **petrol vehicles** for reaching the 2008 target of 140 g/km and the 2012 target of 120 g/km. Green dots represent packages without a mild or full hybrid powertrain, pink dots represent packages including a mild or full hybrid powertrain*

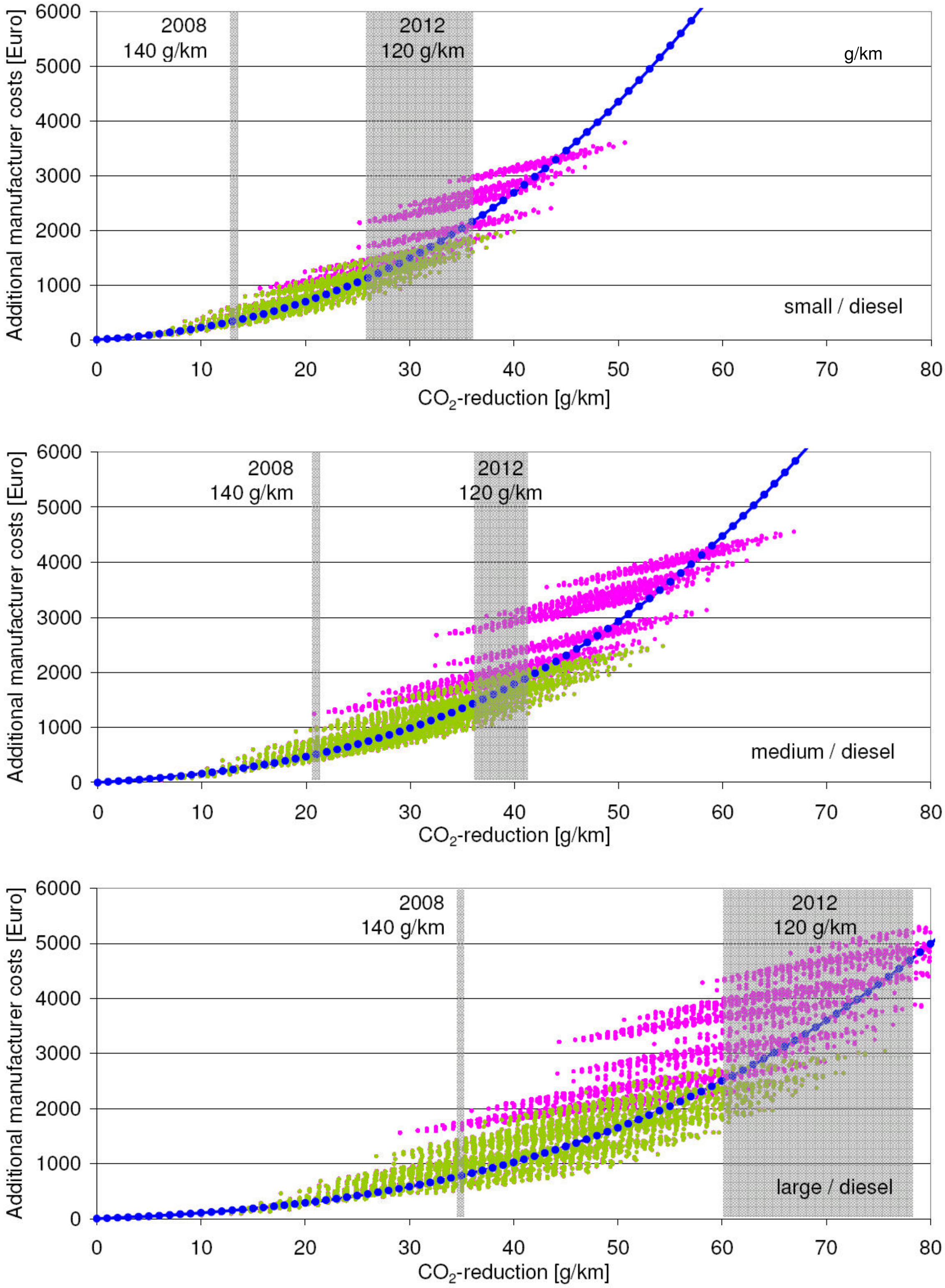

Figure 3.15 Gross CO$_2$-emission reductions required from ***diesel vehicles*** *for reaching the 2008 target of 140 g/km and the 2012 target of 120 g/km. Green dots represent packages without a mild or full hybrid powertrain, pink dots represent packages including a mild or full hybrid powertrain.*

3.11.2 Sensitivity analysis with respect to the definition of cost curves

In section 3.8.1.1 it is explained how cost curves are created based upon the clouds of data points that result from assessing the overall costs and CO_2-reduction of a large number of feasible packages of technical measures. Cost curves are drawn to follow the curvature of the outer envelope of the "cloud" of data points at a certain distance that serves as a "safety margin" to account for the fact that simply combining the CO_2-reduction potential of individual measures using the formula given section 3.8.1.1 in tends to overestimate the overall CO_2-reduction potential of the complete package. For the assessment presented so far the cost curves have been positioned in such a way that roughly 2/3 of the data points is on the left side of the curve and 1/3 on the right side. That this margin is somewhat larger than the one that was used in [IEEP 2004] is one of the factors that contribute to the fact that the costs for reaching the 2008/9 and 2012 targets as estimated in this study are significantly higher than the results from [IEEP 2004]. It therefore makes sense to provide some more quantitative insight in the impact of this change in approach. This analysis also provides more general insight into the sensitivity of the calculated (abatement) costs to variations in the underlying estimates for costs and reduction potentials of CO2-reducing technologies.

First all it should be mentioned that the "safety margin" as used in [IEEP 2004] was drawn in an intuitive way based on expert judgement, without substantial underlying quantitative analysis. This is also the case in this study. The qualitative reasons for using a "safety margin" relative to the lower envelope of the "cloud" are absolutely clear and justified, but quantitative materialisation is still chosen based on expert judgement. In this project a renewed evaluation led to a more conservative judgement. In the high end of the cost curves combinations are included of e.g. a full hybrid powertrain with a DI-petrol engine, engine downsizing and variable valve timing or control. All these options aim to improve part load efficiency or avoid part load operation of the engine. The overall effect of combining these options is easily overestimated in a simplified approach as used in this study.

Quantitative justification for the width of the safety margin can be obtained through detailed computer simulations of the fuel efficiency of vehicles with a number of packages of CO_2-reducing options. Due to budgetary constraints these could not be performed in the context of this project. In the questionnaire and meetings as part of the stakeholder consultation process manufacturers have been requested to submit information on their assessments of overall costs and CO_2-reduction potential of feasible packages but such data have not been provided.

It could also be argued that the overall cost of a package of technological options is not necessarily the sum of the costs of the individual options. In this case the overall cost could be lower then the sum due to synergetic effects in the integration of systems. It should be noted here that most of the options considered are not simple "add-on" options but options that can only be optimally applied if they are integrated in the design of a new engine, powertrain or vehicle platform. The costs of the options have been estimated under the assumption of mass production and should thus be considered to already include possible costs or benefits associated with system integration. If synergetic effects would be underestimated in the cost formula as given in section 3.8.1.1 then correcting for this would result in shifting the cost curves downwards. This would counteract to some extent the required correction for the overestimation of the CO_2-reduction potential.

To assess the influence of the size of the safety margin, as well as of variations of input data in general, on the costs of reaching the 2008/9 target of 140 g/km and the 2012 target of 120 g/km two alternative cost curves for medium size petrol vehicles are drawn in Figure 3.16 and compared to the cost curve as used in the assessment presented so far (labelled "baseline", see Figure 3.5 and Figure 3.14). Seen in the direction of the x-axis (CO_2-reduction) the alternative cost curve labelled "scenario 1" is drawn halfway between the original cost curve and the lower outer envelope of the cloud of data points. In the original assessment the curve was drawn in such a way that 2/3 of the data points are on the left side of the curve and 1/3 on the right side. For the alternative cost curve the distribution is 5/6 – 1/6. With the new cost curve the manufacturer costs for reaching the 140 g/km target are €190 lower than with the original curve, corresponding to a reduction of 17%. The manufacturer costs for reaching the 120 g/km target are €530 lower than with the original curve, also corresponding to a reduction of 17%. The additional costs for reaching the 2012 target of 120 g/km relative to the 2008/9 target of 140 g/km will thus also be 17% lower for scenario 1.

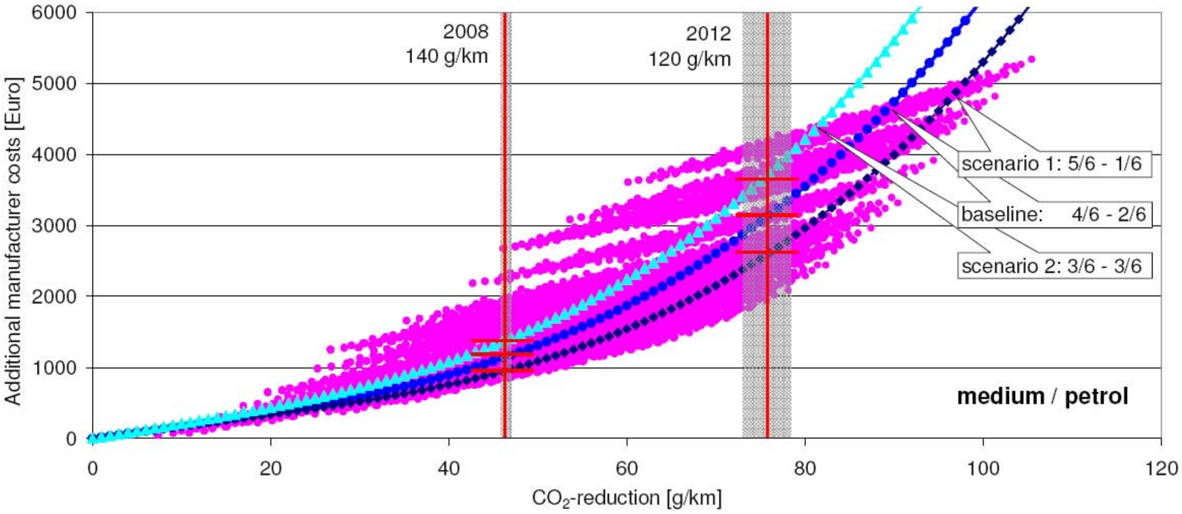

Figure 3.16 Assessment of the impact of a different "safety margin" in drawing the cost curves on the costs of CO_2-reductions required to meet the 2008/9 and 2012 targets.

For symmetry reasons in Figure 3.16 also a second alternative costs curve, labelled "scenario 2", is depicted. This cost curve represents a similar size of variations in assumptions but in the opposite direction compared to "scenario 1", and as such is drawn halfway between the right and left outer envelope of the data cloud (1/2 – 1/2). It should be noted, however, that this level of overestimation of the combined effectiveness of CO_2-reducing measures in scenario 2 can better be seen as a hypothetical example in which a combination of changes in assumptions and changes in input data on costs and CO_2-reduction potential of individual technical measures leads to a costs curve that is above the baseline found in this study. It is clear from Figure 3.16 that for the 1/2 – 1/2 assumption leads to a variation in overall costs for reaching the 140 and 120 g/km targets of the same size (but of opposite sign) as is the case for scenario 1.

Similar alternative cost curves can be drawn for the other 5 segments. As the functional relationship between the original and the alternative cost curve is not a simple scaling factor[16], the distribution over the 6 segments of the CO_2-reductions required to meet the 2008/9 and 2012 targets (the latter for different target / measure combinations) will generally be slightly different when the alternative curves are used, but the overall impact on the average costs of reaching the 2008/9 and 2012 targets will be of the same relative size as the effect indicated for the case of medium size petrol vehicles in Figure 3.16. It can thus be concluded that the impact on estimated additional manufacturer costs or retail price increase of the different choice with regard to the safety margin in drawing the cost curve is of the order of 10 - 20%.

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[16] $a'x^3 + b'x^2 + c'x \neq d \cdot (ax^3 + bx^2 + cx)$

3.11.3 Sensitivity analysis with respect to assumptions on autonomous weight increase

In the last 10-15 years the car fleet has undergone a process of development which included the application of very weight intensive technologies. This, together with a demand trend towards safer, bigger and more comfortable cars has resulted in a continuous trend towards heavier cars. On the basis of these historic trends, as discussed in section 3.9.1, it has been assumed in the cost assessment that the average weight of passenger cars autonomously increases with on average 1.5% p.a. between 2002 and 2012. The 1.5% p.a. value results from studies monitoring the achievements of the car industry in relation to the self-commitments for reaching a sales averaged type approval CO_2-emission of 140 g/km in 2008/9. In the calculations this percentage has been applied uniformly to all vehicle size segments in the model. No shift between classes has been assumed, although it should be acknowledged that part of this new vehicle fleet average value may result from a shift of sales towards larger car segments[17]. If there is an autonomous trend towards larger vehicles to be taken into account, than modelling this as a uniform weight increase applied to all segments is expected to result in slightly different average costs for reaching the 2008/9 and 2012 targets than actually modelling the shift of vehicle sales between segments (as the cost curves for the three segments are not the same), but the effect that additional weight due to market trends requires additional measures ("climbing further up the costs curves") to reach a given 2008/9 or 2012 target is in any case taken into account in first order by assuming a constant weight increase per segment.

The definition of weight increase, as used in this study, includes possible effects of measures to improve safety and reduce exhaust emissions in response to existing European legislation as well as market trends towards bigger, more powerful and more comfortable cars including the increased use of auxiliaries such as power steering, airco, electric windows, DVD-players, etcetera. It does not include technical weight reduction measures taken by the automotive industry (e.g. the use light weight materials for body or other components) to reduce the CO_2-emissions in response to the targets set by the industry's self-commitments. As such the annual weight increase percentage should be interpreted as the autonomous trend that would occur in the absence of the self-commitments.

It may, however, be argued that the historic trend of 1.5% p.a. will not continue at the same level into the future as:

- the most important safety measures have by now been applied[18];
- new exhaust emission regulations will be largely met with system optimisations rather than new, additional systems;
- and new auxiliaries will be largely in the realm of electronic equipment with more limited weight implications than previously added auxiliaries, and which furthermore tend to become lighter over time.

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[17] Please note that the definition of small / medium / large segments used in this study is based on an aggregation of more detailed market segments as distinguished by Polk Marketing Data, which is also used by industry. The segments are not based on cc or weight classes as commonly used in vehicle statistics. In these statistics the autonomous increase of weight and/or cylinder content of given vehicle models is translated into a shift of sales towards higher segments, while in the market segmentation as used by Polk Marketing Data and industry vehicle models generally remain in the same segment while the average characteristics of the segment evolve over time.

[18] Almost all cars coming to the market already receive 4 or 5 stars in the EuroNCAP, proving that they are ahead of current European safety regulations.

Additional vehicle weight results in additional fuel consumption and associated CO_2-emissions which need to be compensated by additional CO_2-reducing measures to meet absolute CO_2-emission targets for 2008/9 and 2012. Assumptions on the level of autonomous weight increase thus influence the costs of reaching these targets. As a sensitivity analysis to explore the effect of the assumption on autonomous weight increase on the costs of reaching the 2008/9 and 2012 targets, additional calculations have been performed for two scenarios, one with a more moderate weight increase and one with a stronger weight increase than assumed in the baseline. These scenarios are detailed in Table 3.27. In both scenarios it is assumed that the historic value is valid until 2004. In scenario **a** it is assumed that this value gradually decreases to 0.5% in 2012 in response to assumed market demands and/or EU policies affecting vehicle weight as discussed above. As an alternative scenario exploring the effect of variations in the other direction also scenario **b** is constructed. In this scenario it is assumed that the annual autonomous weight increase is growing from 1.5% in 2004 to 2.5% in 2012. This scenario could be valid e.g. in a situation where strong economic growth leads to a further increase for larger and especially more luxurious cars with more added accessories. The average annual weight increase values for the 2002 – 2008 and 2009 – 2012 period are used in the model to replace the 1.5% p.a. constant value.

Use of these values, while keeping all other assumptions and data the same, leads to costs for reaching the 2008/9 target as displayed in Table 3.28 (scenario **a** and **b**). The additional manufacturer costs for reaching a 2012 target of 120 g/km based on this scenario are given in Table 3.29 (scenario **a**) and Table 3.30 (scenario **b**). These results should be compared to Table 3.14 resp. Table 3.24 for the baseline calculations based on the 1.5% p.a. value.

Table 3.27 Alternative scenario for autonomous weight increase

	autonomous weight increase [p.a.]*	
year	**scenario a**	**scenario b**
2002	1.50%	1.50%
2003	1.50%	1.50%
2004	1.50%	1.50%
2005	1.38%	1.63%
2006	1.25%	1.75%
2007	1.13%	1.88%
2008	1.00%	2.00%
2009	0.88%	2.13%
2010	0.75%	2.25%
2011	0.63%	2.38%
2012	0.50%	2.50%
average 2002-2008	**1.29%**	**1.71%**
average 2009-2012	**0.69%**	**2.31%**

*) p.a. relative to 2002 weight

Table 3.28 TA CO_2-emissions of new passenger cars in 2002 and 2008/9 and the costs per segment for reaching the 2008/9 target of 140 g/km for the alternative ***scenarios a and b*** *regarding autonomous weight increase.*

scenario a		**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
2002 TA CO_2-emission	[g/km]	149	184	238	123	153	201	166
2008/9 TA CO_2-emission	[g/km]	121	148	185	115	140	177	140
additional manuf. costs	[€/veh.]	962	1083	1475	324	478	718	776
additional retail price (excl. tax)	[€/veh.]	1116	1256	1712	375	554	832	900
additional retail price (incl. tax)	[€/veh.]	1385	1560	2125	466	688	1033	1117

scenario b		**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
2002 TA CO_2-emission	[g/km]	149	184	238	123	153	201	166
2008/9 TA CO_2-emission	[g/km]	120	148	184	116	141	178	140
additional manuf. costs	[€/veh.]	1099	1225	1675	390	561	831	891
additional retail price (excl. tax)	[€/veh.]	1275	1421	1943	452	651	964	1033
additional retail price (incl. tax)	[€/veh.]	1583	1764	2412	561	808	1197	1283

Using the alternative scenario **a** on autonomous weight increase, the costs for reaching the 2008/9 target of 140 g/km are found to be 6.7% lower than for the calculations based on the 1.5% p.a. value. For scenario **b** a cost increase of 7.1% is found. In scenario **a** the additional costs compared to 2008/9 for reaching a 2012 target of 120 g/km are found to be 19% lower than for the calculations based on the 1.5% p.a. baseline value, while in scenario **b** these additional costs are 21% higher. As expected assumptions on autonomous weight increase have a significant, albeit not dominant, effect on the costs of reaching the 2008/9 and 2012 targets. Furthermore it can be concluded that weight reduction through technical means or by limiting the amount of extra weight added to vehicles can be an important means to reduce the CO_2-emissions of passenger cars.

Table 3.29 Manufacturer costs per vehicle for reaching ***120 g/km*** *in 2012 km for the* ***scenario a*** *regarding autonomous weight increase.*

Manufacturer costs per vehicle [Euro/vehicle]							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
each car - uniform target	159	2095	6274	-120	1652	7372	1887
each car - % reduction	1059	1371	1666	1112	1521	1925	1382
each car - utility based CO2-curve (V^2/3*P^1/3)	2028	1517	2166	1507	950	1852	1488
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	1689	1589	2591	1169	1034	2355	1478
each car - utility based CO2-curve (pan area = l*w)	1243	1691	4459	657	967	3842	1531
each car - optimised utility based CO2-curve (pan area = l*w)	1775	1558	3901	1108	766	2911	1504
per manufacturer - uniform target	1331	1907	3903	716	1137	2189	1500
per manufacturer - % reduction	1537	1675	2408	882	1071	1477	1360
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	1488	1740	2734	825	1088	1618	1389
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	1462	1756	2866	807	1090	1680	1397
per manufacturer - utility based CO2-curve (pan area = l*w)	1411	1795	3262	766	1091	1849	1424
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	1446	1764	3065	788	1080	1747	1406
all cars (trading) - uniform target	-402	1991	4987	-741	1538	4696	1356
all cars (trading) - % reduction [1]	1219	1505	1855	958	1341	1766	1356
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	1924	1428	1754	1377	887	1434	1356
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	2917	1187	375	2280	610	43	1356
all cars (trading) - utility based CO2-curve (pan area = l*w)	1147	1607	3773	573	905	2927	1356
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	3736	965	1744	2769	-152	-29	1356

[1]) costs per segment based on an division of total deficit costs over the various segments
on the basis of applying a fixed percentage per car to all segments. This, however, does not
yield correct deficits due to disturbances in market shares resulting from the petrol-diesel shift!!

*Table 3.30 Manufacturer costs per vehicle for reaching **120 g/km** in 2012 km for the **scenario b** regarding autonomous weight increase.*

Manufacturer costs per vehicle [Euro/vehicle]							
target - measure combination	**p,S**	**p,M**	**p,L**	**d,S**	**d,M**	**d,L**	**average**
each car - uniform target	379	2869	7741	53	2514	9543	2642
each car - % reduction	1541	2014	2413	1672	2294	2877	2054
each car - utility based CO2-curve (V^2/3*P^1/3)	2639	2163	2934	2208	1601	2797	2166
each car - optimised utility based CO2-curve (V^2/3*P^1/3)	2294	2238	3362	1843	1695	3335	2158
each car - utility based CO2-curve (pan area = l*w)	1700	2376	5638	1126	1624	5285	2217
each car - optimised utility based CO2-curve (pan area = l*w)	2426	2194	4907	1787	1325	4001	2178
per manufacturer - uniform target	1977	2734	5334	1137	1682	3075	2178
per manufacturer - % reduction	2013	2719	3228	1262	1893	1924	2067
per manufacturer - utility based CO2-curve (V^2/3*P^1/3)	2177	2540	3939	1284	1632	2387	2054
per manufacturer - optim. utility based CO2-curve (V^2/3*P^1/3)	2149	2555	4074	1264	1633	2452	2061
per manufacturer - utility based CO2-curve (pan area = l*w)	2081	2603	4573	1206	1631	2669	2092
per manufacturer - optim. utility based CO2-curve (pan area = l*w)	2130	2563	4308	1240	1619	2530	2070
all cars (trading) - uniform target	-375	2760	6478	-606	2350	6401	2016
all cars (trading) - % reduction [1]	1692	2163	2662	1542	2066	2659	2016
all cars (trading) - utility based CO2-curve (V^2/3*P^1/3)	2538	2055	2429	2046	1536	2316	2016
all cars (trading) - optim. utility based CO2-curve (V^2/3*P^1/3)	3677	1779	846	3082	1218	720	2016
all cars (trading) - utility based CO2-curve (pan area = l*w)	1565	2279	4957	1039	1558	4186	2016
all cars (trading) - optim. utility based CO2-curve (pan area = l*w)	4678	1507	2517	3679	288	632	2016

[1]) costs per segment based on an division of total deficit costs over the various segments on the basis of applying a fixed percentage per car to all segments. This, however, does not yield correct deficits due to disturbances in market shares resulting from the petrol-diesel shift!!

An important reason to use the "historic" 1.5% p.a. value in the main calculations for this report is that it is a proven trend. Deviating from the historic trend requires a motivated prediction of what the trend will be in the future, which is not only difficult but also involves the danger of projecting desired developments. Furthermore developments in vehicle weight are both a cause and an effect of the topic under study. In this respect it should be noted here that technical measures to reduce vehicle weight are part of the list of options that are the basis of the cost curves. If these measures are applied in order to meet 2008/9 or 2012 targets then the net weight of vehicles (autonomous increase minus applied weight reduction) will increase less than the values assumed in the baseline scenario or the alternative scenarios **a** and **b**[19].

Concerning the difficulties to predict the autonomous weight increase trend for the future the following issues should be considered:

- An important aspect influencing the exogenous trend in vehicle weight is economic growth. If the economy grows (net growth of GDP per capita) the spending power of consumers increases, and manufacturers will want to capture a part of that increased spending power by either selling more vehicles, by selling more vehicles in the larger / heavier segments, or by selling more expensive vehicles within each segment. In the latter case the additional costs are justified by applying new technologies to the vehicles which represent added value to the consumer. In general such new technologies add weight to the vehicle although the amount of weight may depend on the type of technology. Not fully capturing the increased spending power of consumers by selling more expensive vehicles within each segment has the risk of leading to increased cars sales, notably in the smaller segments for vehicles used as 2nd and 3rd cars in households, likely resulting on the one hand in an increase in overall road traffic and associated CO_2-emissions and on the other hand in misleading results of monitoring the success of CO_2-reduction policies as a larger share of small vehicle sales reduces the sales-weighted average CO_2-emission value.

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[19] With 1.5% p.a. the total autonomous weight increase for a medium size petrol car is 189 kg between 2002 and 2012. The "strong weight reduction" option results in a weight decrease of 113 kg compared to the baseline vehicle to which it is applied.

- If the increased spending power of consumers as a result of economic growth is not captured within the passenger car market, consumers are likely to spend their money on other products and services that involve energy consumption and CO_2-emissions (e.g. holiday travel by airplane). Assuming some kind of moral change in the consumer's car purchasing behaviour, e.g. as a result of flanking policy measures such as information campaigns or energy-labelling, resulting in a lower autonomous weight increase than the historic trend so far, involves the risk of ignoring the effects of the still existing relation between economic growth and energy consumption;
- As a result of the cost increase due to CO_2-reducing measures manufacturers may decide to postpone the introduction of new features which create added value to the consumer but also add weight. This, however, affects the profitability for manufacturers which is an effect that may be considered in Task B but is beyond the scope of this study. In principle the division of work between Task A (this study) and Task B and the TREMOVE calculations (see Chapter 1) is that Task A takes account of exogenous trends to calculate the first order effects on costs of reaching a 2012 CO_2-reduction target, but that Task B and TREMOVE, as part of the assessment of overall reduction potentials and CO_2-abatement costs, evaluate the (to a large extent second order) impacts of cost / price increases and fuel consumption reductions on consumer choice with regard to vehicle purchasing, modal split and transport volumes and on manufacturers' marketing choices;
- Achieving a lower autonomous weight increase than 1.5% p.a. between now and 2012 is also related to the success of possible flanking policy measures aiming at consumer purchasing behaviour. Given that at present the other two pillars of the EC policy for reducing CO_2-emissions from passenger cars (labelling and tax differentiation) are so far not very effective, it would seem safe to assume some level of continuation of autonomous market trends in baseline projections for 2012.

It can be concluded that the impact of the assumed autonomous development of vehicle weight on the outcome of the calculations is sufficiently large to justify further analysis. However, as prediction of this autonomous trend requires detailed analysis of underlying market developments and economic developments as well as a careful separation of causes and effects in relation to the policy measures under study, such an analysis would need to be carried out with other instruments than those foreseen in the scope of this study. For that reason, and for the reasons mentioned above, an extrapolation of the observed historic trend is used a first approximation for this study.

3.11.4 Effects of variations in cost estimates on the calculation of CO_2-abatement costs

The sensitivity analysis presented in section 3.11.2 shows that variations on the assumptions underlying the construction of cost curves may lead to variations of 10 to 20% in the estimated costs at the vehicle level for reaching 120 g/km in 2012. Similarly the alternative scenarios for the assumption on autonomous weight increase, as discussed in section 3.11.3, lead to a variation of plus or minus 20% in the costs for reaching the 120 g/km target. Combination of these two aspects yields a significant bandwidth for the costs of reducing CO_2-emissions from 140 g/km in 2008/9 to 120 g/km or another target in 2012.

Besides the impact on additional manufacturer costs or additional retail price also the impact of variations on CO_2-abatement is of importance. CO_2-abatement costs in this study are calculated using the formula below, which is discussed in detail in section 2.2:

$$CO_2\text{-abatement costs} = \frac{\text{investment} - \text{NPV (lifetime fuel cost savings)}}{\text{lifetime } CO_2\text{-reduction}}$$

The numerator in the above formula is the difference between two numbers that may be of the same order of magnitude. As a result this formula contains an intrinsic leveraging or amplification for variations in the input variables. If for example the lifetime fuel cost savings equal 60% of the investment costs, then a 10% variation on the investment costs leads to a 25% variation of the calculated CO_2-abatement costs. For specific case of the costs of reaching a 2012 target of 120 g/km this leveraging effect is illustrated in Table 3.31. Based on the vehicle costs and fuel cost savings as assessed for the baseline situation, the absolute and relative effect on CO_2-abatement costs of different (hypothetical) levels of variations on the vehicle investment costs are calculated.

As could be expected, the leveraging effect becomes more prominent at higher oil prices resulting in relatively high fuel costs savings. At 36 €/bbl the leveraging effect leads to relative variations of the abatement costs which are a factor of 1.5 times the relative variations in vehicle investment costs. At 74 €/bbl the leveraging is a factor of 3. For this oil price a +30% variation on the costs leads to abatement costs which are a factor of 2 higher than in the baseline, while a -30% variation in vehicle costs leads to abatement costs which are a factor of 10 lower than the baseline.

Table 3.31 Effects of variations in vehicle cost estimates on the calculation of CO_2-abatement costs.

	vehicle cost variation	**CO_2-abatement costs at different oil price levels [€/tonne]**			
		25 €/bbl	36 €/bbl	50 €/bbl	74 €/bbl
absolute	-30%	108	84	56	7
	-20%	131	108	79	30
	-10%	154	131	102	53
	baseline	177	154	125	76
	10%	201	177	149	99
	20%	224	200	172	122
	30%	247	224	195	146
relative	-30%	-39%	-45%	-55%	-91%
	-20%	-26%	-30%	-37%	-61%
	-10%	-13%	-15%	-18%	-30%
	baseline	0%	0%	0%	0%
	10%	13%	15%	18%	30%
	20%	26%	30%	37%	61%
	30%	39%	45%	55%	91%

These results show that interpretation and comparison of CO_2-abatement costs resulting from calculations as presented in this study should be carried out with great care. This is especially the case for comparison of CO_2-abatement cost data from different sources (concerning the same subject or e.g. in the context of comparing abatement costs between sectors), where underlying assumptions and methodologies are often not compatible or not clearly documented.

The analysis presented in Table 3.31 also leads to the conclusion that the results on vehicle costs and CO_2-abatement costs of this study should preferably not be presented as singular numbers but rather as confidence intervals. Calculating these confidence intervals, however, requires knowledge of the possible variations in input data that may occur. Quantification of these variations for all technologies specified in Table 3.9 and Table 3.10 would require detailed information on the methodologies and associated assumptions and uncertainties underlying the estimates of costs and CO_2-reduction potentials of the individual technologies presented in the various information sources used in this study. Such information, however, is not available and generating this information is considered beyond the scope and budget limitations of this study.

In addition to that also the possible impacts of learning effects, economies of scale and innovation in the timeframe under consideration could be factored in. It is know that ex-ante assessments generally tend to overestimate costs. A recent comparison between ex-ante and ex-post assessments of environmental technologies and policies [IVM 2006] has shown that the difference between estimated costs and the real costs for application of environmental measures may be a high as a factor of 2 to 6. Unfortunately the reasons for this overestimation seem to differ from case to case. In all cases, however, it seems clear that in general not sufficient information is available to adequately assess the possible impacts of innovation, learning effects and economies of scale on the development over time of costs and performance of new technologies.

3.11.5 Comparison with the results of [IEEP 2004]

The results obtained in this study differ significantly from the results obtained in [IEEP 2004]. The assessment in [IEEP 2004] used the same overall methodology and some of the same data sources but arrived at much lower estimates for the costs of reaching the 2008/9 and 2012 target. These differences in results as well as the underlying origins for these differences are briefly discussed here.

In [IEEP 2004] it was estimated that the 2008/9 target could be reached at average additional manufacturer costs of 220 €/vehicle, leading to CO_2-abatement costs compared to 2002 of -41 €/tonne (IR = 5%, fuel price = 0.30 €/l). In this study the average manufacturer costs for reaching 140 g/km in 2008/9 are estimated at 832 €/vehicle, leading to CO_2-abatement costs compared to 2002 of 48 €/tonne (IR = 4%, fuel price = 0.30 €/l).

The additional manufacturer costs for reaching 120 g/km in 2012 were estimated in [IEEP 2004] to vary between 987 and 577 €/vehicle depending on the target-measure combination, leading to CO_2-abatement costs compared to 2008 of 176 to 67 €/tonne (IR = 5%, fuel price = 0.30 €/l). In this study the additional manufacturer costs for reaching 120 g/km in 2012 are found to vary between 2246 and 1669 €/vehicle with associated CO_2-abatement costs compared to 2008 of around 215 €/tonne (IR = 4%, fuel price = 0.30 €/l) for most target-measure combinations. For both studies the higher values relate to the target-measure combination of applying a uniform legislative target to all vehicles, while for most other target-measure combinations the costs are closer to the lowest values as given above.

Expressed in terms of retail price increase or additional investment costs to society (retail price excl. tax) the differences are less pronounced, as [IEEP 2004] used a factor of 2 for translating manufacturer costs into retail price while this study uses a newly derived factor of 1.44.

The most important reasons for the differences between the results of this study and those of [IEEP 2004] are the following:

- The translation from retail price data from literature to manufacturer costs is done with a different factor (1.44 instead of 2.0), leading to higher values for the manufacturer costs as most literature sources only present their results in retail price estimates;
- The cost and CO_2-reduction data for individual options have been newly estimated taking into account new literature data, information from industry and evolved expert judgement;
- The resulting overall cost curves for packages of measures that target engine and powertrain efficiency have been assessed more conservatively (larger "safety margin").
- In the present study a higher autonomous weight increase has been assumed than in the previous study. This study assumes 1.5% p.a., while [IEEP 2004] assumed 60 kg between 2002 and 2008 and 40kg between 2008 and 2012 (which on average amounts around 0.75% p.a. for medium size vehicles). The value in [IEEP 2004] was a "guesstimate" agreed between the consultants and the

Commission Services, while the present value is based on historic data from monitoring of the results of the industry's self commitment;

- The effects of autonomous weight increase have been modelled with a different formula resulting in higher additional CO_2-emissions to be compensated (but also a higher effectiveness per kg of weight reduction as a technical means to reduce CO_2-emissions). The reasons for adopting the new formula are explained in section 3.9.1;
- In [IEEP 2004] CO_2-abatement costs were calculated based on the following assumptions:
    - investment costs = manufacturer costs;
    - fuel cost savings based on the TA fuel consumption;
    - lifetime CO_2-savings based on TA CO_2-emission.

  In the present study investment costs in the formula for assessing CO_2-abatement costs are assumed to equal retail price minus tax, fuel cost savings are calculated on the basis of real-world fuel consumption, while lifetime CO_2-savings are based on real-world TTW CO_2-emission plus the WTT emissions coming from the fuel chain.

3.11.6 Impact of other legislation on CO_2-emissions

3.11.6.1 Emission legislation

During the course of this project the European Commission also decides on the emission levels and date of entry into force of Euro 5 for passenger cars. Euro 5 for passenger is expected to enter into force in 2008. For diesel vehicles the foreseen Euro 5 limits contain a PM-limit that can only be reached by means of the application of a diesel particulate filter (DPF). Due to energy needs for regeneration as well as through increased back pressure DPF systems increase the CO_2-emissions of diesel vehicles by 1.5 to 2%. This effect was not taken into account in the calculations of [IEEP 2004] as by that time discussions on Euro 5 emission levels were not even started. In this study the impact of Euro 5 on CO_2-emissions is taken into account by adding a CO_2-penalty to the 2008 – 2012 baseline diesel vehicles.

When the use of alternative engine technologies for CO_2-reduction in petrol vehicles requires the application of advanced aftertreatment to reach Euro 4 or Euro 5 emission limits this is also taken into account in the construction of cost curves. For packages of technological options containing such engine technology and associated advanced aftertreatment (e.g. NO_x-storage catalyst for lean-burn petrol engines) a CO_2-penalty is added to the overall CO_2-reduction of the package. The costs of the aftertreatment technology are assumed to be fully attributed to the implementation of Euro 4 and 5.

As no information is available yet on the possible level and date of entry into force of Euro 6 for passenger cars, the possible effects of this stage of emission legislation are not taken into account in this study.

3.11.6.2 Other legislation

New vehicle legislation related to safety tends to result in increased weight of vehicles due to the applied technical safety measures. For the coming period especially legislation related to pedestrian safety is expected to have an impact on vehicle weight. This legislation may also affect body design and as such have a negative impact on the air drag resistance of vehicles. The latter effect is ignored in this study. Effects of safety regulations on vehicle weight are included in a generic way in the assumptions on autonomous weight increase, of which the effects are accounted for in the cost assessments for reaching the 2008 and 2012 targets. To this end an annual weight increase is translated into an additional CO_2-emission which has to be compensated by climbing further up the cost curves in order to reach the 2008 140 g/km target or a target between 140 and 120 g/km in 2012. In consultation with the involved automotive industry the value of the autonomous weight increase has been set to 1.5% p.a..

3.11.7 Influence of other greenhouse gases

Besides CO_2, passenger cars also emit other greenhouse gases. Emissions from the airco system are dealt with in Chapter 4. The most notable greenhouse gas components in the exhaust gases of passenger cars are CH_4 and N_2O. Methane has a Global Warming Potential of 23, while nitrous oxide has a GWP of 296. A detailed comparison of the Tank-to-Wheel greenhouse gas emissions of different fuels is presented in Chapter 6.

CH_4 is part of the HC-emissions which are regulated by Type Approval. The analysis in Chapter 6 shows that, expressed in CO_2-equivalents, for petrol and diesel vehicles the methane emissions are below 0.5 gCO_2-eq./km. The contribution of CH_4 to the overall greenhouse gases of passenger cars on petrol and diesel can thus be considered negligible. Also there are no trends that may lead to an increase of these emissions as a result of future emission legislation or as a result of attempts to reduce the fuel consumption of passenger cars.

N_2O is especially produced in the reducing environment that is created in the three-way catalyst of modern petrol vehicles. Concerns over possible increased N_2O-emissions in 2003/4 have triggered a wealth of research into this issue. However, as also discussed in Chapter 6, measurements have shown that the overall emissions of N_2O from three-way catalysts are fairly low. Expressed in CO_2-equivalents the emissions of nitrous oxide from Euro 3 petrol vehicles is assessed to be 0.5 gCO_2-eq./km [TNO 2003a, TNO 2003b]. For Euro 3 diesel vehicles a value of 1.5 gCO_2-eq./km is found. It can thus be concluded that the contribution of exhaust N_2O to the overall GHG emissions of passenger cars is limited and can be considered negligible in the context of this analysis. There do not seem to be any trends that may lead to an increase of these emissions as a result of future emission legislation or as a result of attempts to reduce the fuel consumption of passenger cars.

In the evaluation of the Well-to-Wheel energy chain of alternative fuels such as CNG and biofuels the emission of the greenhouse gases CH_4 and N_2O is an important issue. This is dealt with in Chapters 6 and 7.

3.12 Policy options to promote CO_2-reduction in passenger cars through technical measures

Policy measures promoting CO_2-reduction in passenger cars through technical measures can be aimed at manufacturers and consumers.

Measures aimed at manufacturers include:

- Extension of the voluntary agreement / self commitments beyond 2008/9;
- Setting mandatory CO_2-target implemented through one of the following possible combinations of target definition and measure through which the target is enforced:
  - car-based targets:
    - fixed target per car
    - percentage reduction target per car
    - a utility-based target per car
  - manufacturer-based targets
    - fixed target per manufacturer
    - percentage reduction target per manufacturer
    - a utility-based target per manufacturer
  - manufacturer based targets with allowing trading of CO_2-credits
    - fixed target per manufacturer including the possibility of emission trading
    - percentage reduction target per manufacturer including the possibility of emission trading
    - a utility-based target per manufacturer including the possibility of emission trading

- Including passenger cars in ETS:
    - if trading is done by manufacturers then a monitoring and accounting methodology needs to be developed with default values for annual or lifetime mileage of vehicles must be determined in order to assess total CO_2-emissions.

Car-based targets expressed as a fixed or percentage reduction target are not practical. The first target definition leads to huge costs for large cars and the second is difficult to define as car models come and go. A utility-based target per car, however, could be feasible. Manufacturer-based targets, with or without trading, are feasible. In the present assessment the effect of trading on the overall costs and the division of CO_2-emission reductions over the various segments is found to be limited. In the assessment trading does significantly influence the division of costs over the various segments, but that is mainly due to the fact that the model automatically adds costs or revenue of trading to the size of the CO_2-deficit or surplus in each of the segments. Manufacturers, however, may choose to pass through the costs or benefits of trading in a different way.

For different target-measure combinations the division of CO_2-emission reductions and costs over the individual manufacturers can be very different. This was already analysed in detail in [IEEP 2004]. The main conclusions, that remain valid also for this study, were:

- The combination of a fixed 120g/km target applied to individual cars is very expensive, and simplifications in the model (i.e. not going down to actual vehicle models) suggest that even these calculated costs may be an underestimate, and potentially significantly so. Many vehicle models would be unable to meet the limit value without huge modification, and for others they are simply unrealistically high reductions from some segments of different manufacturers. This option is therefore unattractive;
- Company bubbles reduce costs substantially relative to car-based targets as they always give a degree of flexibility. However, the cost can still vary substantially from manufacturer to manufacturer with some target/instrument combinations;
- Trading schemes generally offer further cost reductions, and are always the cheapest instrument in relation to any one target option. In a fully optimised market, trading should cause convergence of costs for all the target options – although this would never be fully achieved in practice. Distributional effects vary considerably depending on the target instrument chosen, but the spread in costs per car to the manufacturers is always reduced by trading, so this reduces the distributional effects.
- The percentage reduction model offers the cheapest and least disruptive target option, and minimises distributional effects among manufacturers. In this case, the incremental cost benefit of a trading regime over manufacturer bubbles is so low as to render trading unnecessary – and thereby saving on administrative complexity. This solution can however be considered inequitable in that it penalises early movers and rewards laggards. This could be solved to an extent by taking an earlier base year if data were available. This would address the ‘early mover’ issue to a degree, but would not address structural (i.e. not time-dependent) differences in CO_2 efficiency between the different manufacturers. However, there still remains a problem in that the costs under the % reduction increase less in proportion to vehicle size than in some of the other scenarios and would represent a missed opportunity to stimulate a trend away from large vehicles or at least to counteract an autonomous shift towards larger vehicles. Indeed this target seems to promote larger vehicles relative to the other targets. This would mean that an intermediate change in the target would be necessary – i.e. to reduce by more than is currently assumed for the 120g/km average to be met overall;
- A utility-based target appears intuitively the best and fairest option. However, the viability depends on the exact formulation of the utility function. For example with a utility function of $V^{2/3}P^{1/3}$ trading leads to high costs for small vehicles - which could result in similar effects to

those described under the percentage reduction model. On the other hand, pan area, which is intuitively less attractive, when combined with trading, does work. Utility functions optimised to minimise trading volume seem not to be attractive as they result in very high costs for small cars. Utility-based limit functions also offer considerably reduced costs relative to the single target model, while retaining important elements of fairness between manufacturers. The selection of a suitable utility parameter and limit function, however, needs further consideration.

The following measures aimed at consumers can be envisaged:

- Improved labelling of the TA fuel consumption or CO_2-emission of passenger cars;
- Subsidies for fuel efficient passenger cars, preferably in combination with an improved CO_2-labelling scheme;
- Fiscal measures:
    - increasing tax on fuel
    - CO_2-based taxation of passenger cars, preferably in combination with a CO_2-labelling scheme;
- Public procurement of low-CO_2 passenger cars (limited overall impact but measure that may help to create an initial market for new technology).

3.13 Output supplied to TREMOVE and Task B

Output from Task A to TREMOVE is derived from the results as presented above, and is delivered to TML using separate, dedicated spreadsheets. Results include:

- CO_2-emissions of vehicles in the various segments in 2008/9 and the additional investment costs (retail price minus tax) compared to 2002 for reaching 140 g/km;
- CO_2-emissions of vehicles in the various segments in 2012 and the additional investment costs (retail price minus tax) compared to 2008 for reaching target ranging from 140 g/km to 120 g/km for all of the target-measure combinations;
- CO_2-emissions of vehicles in the various segments in intermediate years and the additional investment costs (retail price minus tax) for reaching target ranging from 140 g/km to 120 g/km. These data are derived by interpolation assuming a linear reduction of the new vehicle CO_2-emission over time and a non-linear increase in costs determined on the basis of overall cost curves derived from the assessment of costs for reaching 2012 targets between 140 g/km and 120 g/km;
- The above data on CO_2-emissions and costs expressed in relative terms so that they can be applied to TREMOVE baseline data.

Notes:

- Task A delivers average cost data expressed as retail price minus taxes to TREMOVE. It will be up to TML to translate those to country-specific costs and costs to the consumer by including margins, taxes and fuel costs. Taxes and fuel cost are included in the TREMOVE database, but a hypothesis on margins may be provided by Task B and agreed with TML and Task A.

- In [IEEP 2004] as well as this study various levels of hybridisation are included in the continuous cost curves. In this way hybrid vehicles are treated as an evolution of the conventional vehicle, rather than as a separate category. TREMOVE, however, has a separate category for hybrids. In interaction with TML it has been decided not to model hybrids as a separate category in this study. There are various reasons for this decision:
    - One important issue is that hybrid technology can also be combined with other measures at the vehicle level. Making a distinction between hybrids and other technologies is therefore difficult;
    - Furthermore many types of hybrids can be considered (from engine-assist systems to full hybrids with various levels of pure-electric range) while in TREMOVE only one type can be

modelled per vehicle class. The elegance of the overall cost curve approach as developed in [IEEP 2004] is that various levels of hybridisation and various combinations of hybridisation with other engine and vehicle related technologies are incorporated in the development of one continuous cost curve. Every point on the cost curve can either be seen as a specific technology package or as a market average of a number of packages with varying CO_2-reduction levels and associated costs.

- Costs after 2012 are assumed to remain constant. The costs of additional CO_2-reduction measures necessary to compensate for the effects of autonomous weight increase are assumed to be balanced by cost reductions for the various applied technologies that will occur after 2012 as a function of the increased production volume and learning effects.

3.14 Conclusions

Using the methodology as developed in [IEEP 2004] an assessment has been made of the costs for reaching various possible targets for the sales averaged type approval CO_2-emissions of newly sold vehicles in 2012, reaching from maintaining the 140 g/km level of 2008 to 120 g/km. For this assessment a new review has been made of available data from literature on costs and CO_2-reduction potential of a wide range of technical options that can be applied to passenger cars. Also data have been collected from industry associations by means of a questionnaire and meetings. Based on these data and expert judgement by the consultants a new data set has been drawn up for CO_2-reduction measures to be applied to passenger cars. Based on these data the assessment of costs and CO_2-abatement costs has provided the following results:

- The costs of reaching an average CO_2-emission of new vehicles of 140 g/km in 2008 will involve additional manufacturer costs of €832 per vehicle compared to the 2002 baseline. This translates into an additional retail price of €1200 per vehicle. The CO_2-abatement costs of reaching the 2008/9 target of 140 g/km compared to the 2002 baseline value of 166 g/km are 72 €/tonne at an oil price of 25 €/bbl, 20 €/tonne at an oil price of 50 €/bbl, and even go down to -30 €/tonne at an oil price of 74 €/bbl.

- The overall costs as well as the distribution of CO_2-reductions and costs over the different segments of passenger cars depend strongly on the policy measure that is used to implement the target.

- For most target-measure combinations the manufacturer costs for reaching a 2012 target of 120 g/km are around €1700 per vehicle compared to average costs of the 2008/9 baseline vehicle emitting 140 g/km. This translates into an additional retail price of €2450 per vehicle.

- The results of the new assess costs are significantly higher than the value calculated in [IEEP 2004][20]. The reasons for this significant difference are the following:
    - The translation from retail price data obtained from literature to manufacturer costs has been done with a different factor (1.44 instead of 2.0), resulting in higher input on the manufacturer costs;
    - The effects of autonomous weight increase have been modelled with a different formula resulting in a higher amount of additional CO_2-emissions to be compensated;
    - Cost and CO_2-reduction data for individual options have been newly estimated taking into account new literature data, information from industry and evolved expert judgement;
    - The resulting overall CO_2-reduction of packages of measures that target engine and powertrain efficiency has been assessed more conservatively;

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[20] 600 – 1000 €/vehicle for measures without trading, and 577 €/vehicle for the measures with trading.

  - In the present study investment costs in the formula for assessing CO_2-abatement costs are assumed to equal retail price minus tax, fuel cost savings are calculated on the basis of real-world fuel consumption, while lifetime CO_2-savings are based on real-world TTW CO_2-emission plus the WTT emissions coming from the fuel chain. In [IEEP 2004] investment costs were assumed equal to additional manufacturer costs, while the other variables were estimated on the basis of TA values instead of real-world and WTW values.

Table 3.32 CO_2-abatement costs of reaching various levels of the 2012 target

2012 target [g/km]	CO_2-abatement costs [€/tonne] at various levels of fuel costs			
	0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
135	169	146	117	68
130	190	166	138	88
125	212	188	160	110
120	235	212	183	134

- The abatement costs of reducing CO_2-emissions with technical measures applied to passenger cars depends on the reduction target and the oil price / fuel costs. For an oil price of 25 €/bbl the CO_2-abatement costs range from 166 to 233 €/tonne for 2012 target values between 135 and 120 g/km. For an oil price of 50 €/bbl the CO_2-abatement costs range from 114 to 181 €/tonne for 2012 target values between 135 and 120 g/km. CO_2-abatement costs in this assessment are based on real-world fuel consumption and CO_2-emissions and include the Well-to-Tank greenhouse gas emissions.

- A sensitivity analysis shows that variations on the assumptions underlying the construction of cost curves may lead to variations of 10 to 20% in the estimated costs at the vehicle level for reaching 120 g/km in 2012. Similarly the alternative scenarios for the assumption on autonomous weight increase lead to a variation of plus or minus 20% in the costs for reaching the 120 g/km target. Combination of these two aspects yields a significant bandwidth for the costs of reducing CO_2-emissions from 140 g/km in 2008/9 to 120 g/km or another target in 2012. Due to a leveraging, that is intrinsic to the formula for calculating CO_2-abatement costs, variations on the vehicle costs of this relative order of magnitude lead to even higher variations in the CO_2-abatement costs, especially in the case of high fuel prices. Interpretation and comparison of CO_2-abatement costs resulting from calculations as presented in this study should be carried out with great care. This is especially the case for comparison of CO_2-abatement cost data from different sources (concerning the same subject or in the context of comparing abatement costs between sectors), where underlying assumptions and methodologies are often not compatible or not clearly documented.

- In general it can be concluded that, regardless of the type of policy measure that is chosen, reaching a new vehicle sales average TA CO_2-emission of 120 g/km requires the introduction of hybrid vehicles in the segments of small, medium ad large petrol cars and of large diesel cars. For small diesel cars the necessity for hybridisation depends on the policy measure, while for medium size diesel cars hybridisation is necessary for none of the policy measures.

- If a 2012 target is to be reached through a legislative approach this can be implemented through a large number of combinations of the definition of the target and the measure under which it is applied. Targets can be either uniform, expressed as a percentage reduction compared to a reference situation or can be differentiated according to a parameter that quantifies the utility of the vehicle. Each of these targets can be applied to all cars or to average sales of each manufacturer ("company bubbles"), either without or with the option of emission credit trading among manufacturers.

- The feasibility of different target-measure combinations has not been assessed in detail in this study. Based on results from [IEEP 2004] and from the a brief review of the detailed results for individual manufacturers as provided by the cost assessment model car-based targets expressed as a uniform or percentage reduction target do not seem practical. The first target definition leads to huge costs for large cars and the second is difficult to define as car models come and go. A utility-based target per car, however, could be feasible and could be related to already developed or improved labelling schemes. Manufacturer-based targets without trading seem generally feasible, but the practical feasibility of including trading should be further analysed with respect to e.g. transparency of the market and the costs of setting up and maintaining a trading system in comparison to the benefits of trading for cost optimisation of reaching the 2012 target. In the present assessment the effect of trading on the overall costs and the division of CO_2-emission reductions over the various segments is found to be rather limited. In the assessment trading does significantly influence the division of costs over the various segments, but that is mainly due to the fact that the model automatically adds costs or revenues of trading to the size of the CO_2-deficit or surplus in each of the segments. Manufacturers, however, may choose to pass through the costs or benefits of trading in a different way. A more detailed assessment of the pros and cons of different target-measure combinations will be undertaken by the European Commission at a later stage.
- For different target-measure combinations the division of CO_2-emission reductions and costs over the individual manufacturers can be very different. This was already analysed in detail in [IEEP 2004].
- A first assessment of the overall GHG reduction potential associated with reducing the TA CO_2-emissions of new M_1-vehicles from 140 g/km in 2008/9 to 120 g/km in 2012 shows that for EU-15 a total reduction of 14.4 Mtonne/y would be achieved in 2012 growing to 54 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

3.15 Literature

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4 Review of options for fuel efficient air conditioning systems

4.1 Goal of Task 1.6

The goal of this Task is to review the possible CO_2-benefits and costs of technologies for fuel-efficient mobile air conditioning systems (MACs) and to evaluate options for promoting the application of these systems.

4.2 Approach

- Based on results of existing studies by TNO and others (e.g. work carried out in the context of MVEG) a review is made of:
  - the impact of conventional air conditioning systems on the real-world fuel economy of vehicles in 2012;
  - possible improvements that can be achieved by the use of fuel efficient air conditioning systems (advanced conventional air conditioning systems as well as CO_2-based air conditioning systems) on the real-world fuel economy of vehicles in 2012.

  The information gathered is used to derive correction factors to account for the impacts on real-world CO_2-emissions of passenger cars.
- Collection of data on costs of fuel-efficient air conditioning systems by means of literature and interactions with Tier 1 suppliers.
- Important information sources are:
  - [TNO 2002], [TNO 2005], [EMPA 2005], [NREL 1999], [HBEFA] and data from the ARTEMIS-project and the DACH-NL-S-UK group;
  - MAC Summit 2003 (EU);
  - SAE ARCRP, the SAE Alternate Refrigerant Cooperative Research Program; USA-Core, JAMA and VDA.;
  - ARSS, the Alternative Refrigerant System Symposium (1999, 2000, 2002, 2003);
  - B Cool (EU 6th framework project);
  - VDA Alternative Refrigerant Meetings (2002...2006.);
  - MACS, Mobile Air Conditioning Society.

4.3 Relevant aspects and considerations

- The vehicle's additional energy consumption and CO_2 emissions resulting from the use of mobile air conditioning systems and other auxiliaries is currently not included in the type approval test results. As more and more vehicles are standard equipped with air conditioning systems, their impact on the real-world energy use of road traffic is increasing. This problem has been recognised by the European Commission.
- The impact of air conditioners on real-world CO_2-emissions of vehicles is difficult to assess at the moment as it not only depends on technical data but also on information on how and when these systems are used. This study relates to assumptions and data as used in emission factor modelling. Such information is available in e.g. the ARTEMIS-project and through the participation of TNO in the DACH-NL-S-UK collaboration group of institutes and authorities involved in emission measurement and emission factor modelling.
- On behalf of the European Commission TNO has been and is involved in projects to design measurement procedures to account for the energy use of air conditioning systems and other

auxiliaries [TNO 2002] [TNO 2004]. The procedure developed in [TNO 2004] has turned out to be insufficiently accurate and reproducible for inclusion in the Type Approval test procedures (Directive 80/1268/EEC). As a consequence also the option of an energy labelling of airco systems based on TA data is not feasible.

- The procedure developed in [TNO 2004] can, however, be used in the context of a more general monitoring programme to assess overall progress in improving the energy consumption due to airco use (through efficient airco systems and measures reducing the heat load on the vehicle interior). In order to improve the statistical significance of test results either a single vehicle has to be tested several times to achieve a significant average for that vehicle / airco system or a sufficiently large group of vehicles can be tested to achieve a significant average for that group. To meet the EC's objectives on labelling and ranking [TNO 2004] proposes two alternative approaches:
    - Periodic (for instance: annual) monitoring of the trends in additional CO_2 emissions from air conditioning systems in general. Such a monitoring programme would consist of measuring the additional CO_2 emissions due to airco use on a significant cross section of a typical fleet. Such a programme would give information on average additional CO_2 emissions due to airco use of the fleet and would show the general progress made by the automotive industry in order to improve system efficiency.
    - Periodic (for instance: annual) benchmarking of individual systems or groups of systems, by applying the developed test procedure to a significant amount of typical airco systems. This set up will, in addition to the monitoring, also give information suitable for labelling purposes, if for a certain vehicle the system incorporated can be technically identified.
- As the energy consumption resulting from airco use can, for the time being, not be measured in Type Approval, a different approach has to be developed to monitor the effectiveness of policy measures that can be adopted to promote the application of fuel-efficient air conditioning systems.
- Air conditioner systems using electrically propelled compressor systems, as applied for example in some hybrid electrical vehicle (HEVs) and as required in cars that feature engine-stop functionality, are not evaluated in the context of potential CO_2 effects, although a reduction of CO_2-emissions can be expected. The major benefit in energy terms is that the compressor can be driven independently of engine speed and so it can be adapted better to the actual cooling demand. Even though the generation of the electrical energy is less efficient than energy transfer through a belt drive, the better load adaptation of an electrical drive is expected to result in a better overall efficiency (a generator is generally quoted to have an efficiency of about 60%, a conventional belt drive does more than 95%). The actual reason the electrically propelled compressor system was not taken into account in this assessment is that such systems first require the cars electric power net to be 42V. Given the uncertainty about a 42V power net future in 2012 these systems are thought to have only small potential to penetrate the market. Application of electric air conditioner systems may gain importance together with the introduction of HEVs, the 42V power net and the engine start-stop feature.
- Next to the actual air conditioner system there are additional on-car features and design parameters that may contribute to a decrease of the indirect CO_2 emission. Such features and parameters include; reflective glazing, cabin design, ventilation, directioned cooling, seat ventilation, interior and exterior colour and even the paint itself may contribute to a decreased demand for cool air. The assessment of these matters was beyond the scope of this investigation.

4.4 Impact of current and future mobile air conditioners on fuel consumption and CO_2 emissions

4.4.1 Introduction

The use of a mobile air conditioner brings about additional CO_2 equivalent emissions which are considered to be either *direct* or *indirect*. The direct emissions originate from the leakage of (high GWP) coolant from the system during the airco's lifetime as well as from coolant spillage during regular service and end of life service. The indirect emissions are emitted through the tailpipe of the car and are caused by the additional fuel consumption of the car's engine to operate the air conditioner compressor and the generator for operating the fans of the air conditioner. Additionally, the weight of the system induces an elevated rolling resistance and inertia which both demand more engine power i.e. more fuel and thus increase the tailpipe CO_2 emission.

The EC has proposed several measures to reduce greenhouse gas emissions from passenger cars in the next decade. The EC aims at reducing greenhouse gas emissions from aircos by a ban on the high GWP R134a as a refrigerant for all mobile air conditioner systems as from 2011. As a result of this legislation, the auto industry will be challenged to develop new systems which use low GWP refrigerants as an alternative to R134a. Parallel to these developments, the industry investigates possibilities to improve existing systems, as such legislation is not proposed for other parts of the world and as for the EU still some time has to be bridged before switching to alternatives.

The enlarged EU has the largest car market in the world; it produces about 17 million vehicles per year. Every year it imports vehicles worth €30 billion and exports worth €60 billion. Driven by legislation about 2 million alternative MAC systems will enter the EU market in about seven years time. Each following year some 2 million additional alternative systems will enter the market. After the completion of the phase-out (in about 5 years) the EU will see annually over 15 million new alternative units with an annual sales of €4-5 billion.[21]

Alternative systems are stimulated for their low direct emissions. But what about the indirect emissions? Will future systems be able to meet current standards when it comes down to efficiency? Besides, will they meet the level of performance, safety and customer acceptance of current systems? It is this task's goal to review the possible *indirect* CO_2 effects, costs of technology and other possible demands required for future alternatives to the current R134a systems.

As the introduction of alternative systems in the near future will be the result of legislation that is already being prepared, this task will base estimates for improvements for the indirect emissions on the systems that are expected to enter the market as a result of that legislation. In terms of options for additional measures to reduce the CO_2-emissions from passenger cars this task therefore investigates only the possible *additional* improvements *on top of* the improvements that are *already* the result of the new legislation. But, before this can be achieved one should have a realistic view on the potential of the currently known alternatives to be able to point out the most promising ones, which are to be taken as the reference for the future situation.

4.4.2 The current situation

Presently, most newly sold passenger cars are equipped with R134a systems. They have shown to be safe, they are reliable to an agreeable extent, they perform well when pull down is considered and

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[21] Robert Donkers & Matti Vainio, European Commission, 2004 SAE ARSS

they are not very complicated. This makes these systems commonly accepted and world wide the best sold systems. An R134a system can be regarded as the standard for today's MAC.

Base-line system 2008

A current R134a system generally consists of a compressor, two heat exchangers with fans and a throttling device. The compressor is belt-driven by the vehicle's engine over an electro-mechanical clutch. Two compressor types can be distinguished; a fixed displacement type and a variable displacement type (VDC). The latter improves control of the temperature, has the merit of improved efficiency at part load conditions (by approximately 30%) and improves driveability. Because of these reasons MACs with variable displacement compressors already rapidly enter the European market. The throttling device can be of a simple construction, like an orifice or tube, or can be of a somewhat more sophisticated design, in the form of a variable adjustable restriction valve. The systems can be either manually controlled or automatically controlled. The latter is often called 'climate control' and in such a system the airco is an integral part of the 'heating, ventilation and air conditioning system' (HVAC).

The baseline system in 2008 will be more or less the same as the current system, albeit that by 2008 more systems will have variable displacement compressors and a better system control. The incentive for such a development is, as stated earlier, the fact that VDCs and improved airco control improve the driveability of mainly smaller cars. Besides, such systems adapt better to ambient conditions meaning that comfort can be optimized.

As a result of legislation regarding the leakage rates of R134a systems, which entered into force in 2006, the new systems from then on have lower leakage rates (40g of coolant per year for single evaporators and 50 g coolant per year for dual evaporators). Lower leakage rates may also lead to an overall better efficiency of MACs because filled systems probably work more efficiently. The size of this effect is however not known.

Indirect emissions of the base-line system

The indirect tailpipe emission of CO_2 as a result of the use of MACs was addressed in several studies. Most problematic in such calculations is the estimation of the *use* of MACs. Some studies do not take the use of an air conditioner directly into account, but use a simplified model to determine required air-conditioner power as a function of temperature and use temperature distributions and model power train efficiencies to calculate the average energy required annually (and so for the additional CO_2 emission). NREL applies a 'comfort based model' in which the amount and way of operation of the air conditioner is determined as a function of passenger comfort. This 'comfort' is determined from a more sophisticated model that takes into account heat transfer to the cabin and the amount of heat sensation experienced by the driver and occupants by that heat.

[TNO 2002] investigated the effect of the use of mobile air conditioner in passenger cars and applied different temperature distributions for different regions in Europe. As a result [TNO 2002] presented an additional 0.21 l/100km for North Europe, 0.28 l/100km for central Europe and 0.44 l/100km for Southern Europe. This equals respectively 5, 7 and 11 g/km at shares of petrol and diesel of 0.65 and 0.35 respectively.

'HandBuch Emissions Faktoren' [HBEFA] is the German, Austrian and Swiss emission model. It based it's figures on several studies and one dedicated measurement program [EMPA 2005] The 2004 version of the model uses 4 g/km for diesel to 7 g/km for petrol passenger cars. These figures are typical for the climate as occurs in these countries.

NREL calculated for the ARSS in 2004 a 5000-7000 kg of indirect CO_2 per lifetime of a passenger car in Phoenix U.S.A., which is about 18 to 24 g/km. For Germany they calculated an indirect emission of

1000 kg CO_2 per lifetime. With an annual mileage of 22.000km and a life of 13 years this comes down to 3.5 g/km.

The additional CO_2 emission of the use of a MAC is on average 3.5 to 11 g/km, averaged over the year. Compared to an average CO_2 emission of 186 g/km the effect of MAC use ranges from 2 to 6%, but may even be more for hotter climates in the South of the EU. From the Phoenix figures it is clear that the figures strongly depend on the climate (temperature, humidity and solar radiation).

4.4.3 Future developments and impacts on indirect emissions

4.4.3.1 EU Legislation

The EC has adopted legislation for a ban on R134a as a refrigerant in MACs. This legislation has a direct impact on system choice for the period 2008 to 2012. The prepared legislation consists of a few key elements:

- it accounts for M_1 and N_1 class I vehicles;
- no Type Approval is granted for vehicles with a MAC containing R134a, starting January 1, 2011;
- there is a full ban on R134a systems on sold cars as of 2017 and;
- as of 2011 only refrigerants will be allowed with a GWP lower than 150.

4.4.3.2 Technological developments

Because of the recently adopted EU legislation the industry now faces a challenge to develop new mobile air conditioner systems, using alternative low GWP refrigerants. It is the industry’s goal to develop these systems with a performance and efficiency comparable to the current baseline system using R134a, to be reached with a minimal impact on costs [Auto Motor und Sport 2005]. For the latter, the German auto industry VDA joined forces in a voluntary programme to exchange technological information and to develop *system standards* to decrease costs. Additionally, an SAE platform (SAE Interior Climate Control Standards Committee) established the SAE Alternative Refrigerants Cooperative Research Programme (SAE ARCRP) in 2001 to develop and assess new solutions for MACs.

For the near future the improved R134a may still be an acceptable system, especially if leakage rates are improved. Such a system would have (hermetically) sealed connectors and lines, making these systems more acceptable. Furthermore, such a system would have improved control and improved efficiency. Examples of improvements on the baseline are: externally controlled compressor, low pressure drop suction line, improved evaporator and condenser, improved control of the throttling device, improved sealing of connections and the compressor, strengthened lines and improved servicing.

As a result of the EU-legislation alternative refrigerants for MACs are a requirement for the period starting 2011. The alternatives are:

- systems with hydrocarbons as refrigerant e.g. R290;
- systems with R152a as refrigerant;
- systems with R744 as refrigerant and
- one of these refrigerants in a 'secondary loop system' with a secondary coolant like ethylene glycol + water.

Table 4.1 Overview of refrigerants: their names and environmental characteristics.

Refrigerant	Name	ODP	GWP
CFC-12	Dichlorofluoromethane	1	8500
HFC-134a	1,1,1,2-Tetrafluoroethane	0	1300
HFC-152a	1,1-Difluoroethane	0	120
R290	Propane	0	20
R744	Carbon Dioxide	0	1

ODP: Ozone Depletion Potential
GWP: Global Warming Potential

R744 (CO_2)

The general operating principle of a mobile air conditioner with CO_2 as refrigerant is the same as for a conventional system. The use of CO_2 as refrigerant, however, imposes some additional requirements on the system. First, the CO_2 system runs at a much higher pressure, and as a result the capacity of the compressor can be reduced significantly. A reduced capacity could bring about a small advantage in packaging size for the compressor [Wolf, VDA 2002]. The lines and connectors should be reinforced to resist the high pressures of more than 120 bar. Secondly, the system needs an internal heat exchanger to help bringing the temperature of the refrigerant further down before it enters the expansion valve and the evaporator. As a second functionality a CO_2 system may be used as a heater by reversing the process.

For service and repair additional training of servicing personnel and certification of servicing stations would be required, because of the high pressure of the R744 system. Requirements like these are not part of this investigation because it is this task's goal to investigate only the effects of possible improvements *upon* the already ongoing process of the change to systems using alternative refrigerants.

R152a

R152a has a GWP of 120 which is about 94 percent less than R134a (GWP = 1300). Compared to R134a, it is attractive because of its better thermal efficiency. With improved thermal efficiency, a lower system charge may be used in a direct expansion system to achieve satisfactory cabin cooling. The amount of charge is further reduced if it is used in a secondary loop system. The main drawback of the use of R152a is that it is flammable and forms (thermally decomposes to) highly toxic HF (Hydrogen Fluoride) if exposed to a glowing filament [Mager VDA 2005]. In liquid form, it can be ignited with open flame and therefore may pose some hazard to occupants. If it is used in the cooling circuit in the cabin, a system using sensors and safety releases must be included to guard against unwanted discharge. Currently, the Alternative Refrigerant Committee does not recommended R152a as drop-in replacement for R134a before having evaluated 'issues' related to the heat exchanger.

Secondary loop

At higher concentrations R744 may lead to suffocation and R152a is flammable and may produce highly toxic HF. Hydrocarbons like R290 may even be explosive. As a result, the use of one of these substances as refrigerant could lead to dangerous situations if they would leak into the cabin of the car. Adding a secondary loop would improve safety because the presence of 'dangerous' gases in the cabin would be avoided by using another substance to transport the heat, like ethylene glycol and water, which has none of the dangerous attributes. A secondary loop system will require additional fluid pumps, adding weight and complexity, as well as increasing the electrical load.

In general, before choosing a technological path and developing new systems occupant risks associated with the new refrigerants must be assessed and mitigated to ensure safety and reduce liability. The German OEMs have expressed not to consider flammable refrigerants anymore [Mager VDA 2005].

Weight

Concerning system weight a CO$_2$ system is not expected to bring about a large increase. An estimate based on actual component weight of comparable systems showed an increase of half a kilogram. Information on weight of other systems is scarcely available. For the BCOOL project a weight increase of maximally 1 kg is set as the target for the new CO$_2$ system to be developed. For other systems a weight increase can also be expected because of the required safety measures. A secondary loop and automatic vent systems, for example, probably increase system weight over the weight of the baseline system. This is very likely given the fact that a secondary loop requires an additional pump, an additional heat exchanger, additional plumbing, an additional coolant reservoir and additional coolant. A weight penalty of about 4 kilograms was estimated for a secondary loop system.

4.4.4 Impact and costs

An SAE platform (SAE Interior Climate Control Standards Committee) established the SAE Alternative Refrigerants Cooperative Research Programme SAE ARCRP in 2001 to develop and assess new solutions for MACs. Every year they have a symposium and the members of the Committee (manufacturers, suppliers and Governmental Organisations) present results with respect to the technological development of some alternative systems and their potentials and problems. For the SAE ARSS 2003 the potential of several systems was assessed and held against the baseline R134a system. Besides, costs estimations were made for those systems. The table below summarizes the findings.

Table 4.2 Potential of different alternative MAC systems with respect to direct and indirect emissions and cost estimates. The costs for decreasing indirect emissions are said to include safety aspects and 'direct' and 'indirect' features. The costs to decrease the direct emissions only include costs for improved fittings. The amount of actual investment required per choice still needs to be determined (Source: SAE ARSS 2003).

System choice	**Reduction indirect**	**Costs* [Euro]**	**Reduction direct**	**Costs [Euro]** (improved fittings only)
HFC-134a VDC	Baseline	Baseline	Baseline	Baseline
Improved HFC-134a	25-30%	40	50%	15
HFC-152a	10%	20-25	94%	=Baseline
Improved HFC-152a	25-30%	??	96%	15
Secondary loop	0%	40-60	94+%	=Baseline
R744	20-25%	80-120	100%	40
Improved R744	40%	40-80	100%	??

*Manufacturer costs, including safety, direct and indirect features.

The results of the effort so far still needs to be verified, concluded the Committee in 2003. A test method has to be defined that requires the definition of standards. Independent laboratories should verify the results of the prototype systems.

Additionally, the ARCRP Committee presented the requirements and costs for the service infrastructure.

Table 4.3 Impacts on the Service Infrastructure (Source: SAE ARSS 2003).

System choice	**Time required [yr]**	**Investment / equipment costs**	**Technician Training Certification**	**Testing**
HFC-134a (VDC)	Baseline	Baseline	Baseline	Baseline
Improved HFC-134a	1-3	Minimal cost increase	Training required	Finer leak test may be required
HFC-152a	3-5	More than required for baseline	More extensive	Same as R134a
Secondary loop	3-5	??	Increased diagnostics	Same as R152a
R744	3-5	Less than required for baseline	Increased training requirements	Leak testing, to be investigated

For the indirect emissions the performance of CO_2 systems is still uncertain, because adequate test procedures testing fuel consumption still do not exist. However, tests examining COP and pull down showed promising results and the industry is confident that there still is room for optimisation. This is probably why they presented a reduction potential in the order of 20 to 40%. For current baseline R134a systems such a reduction potential is also believed to be achievable, albeit a little less than for the CO_2 system. Optimised baseline systems, however, do not come with the benefit of the almost zero effect of the direct GHG emissions like CO_2 systems do. Besides, although assumed to be not as much as for CO_2 systems, improvement of the baseline system also requires substantial costs and investments.

In the future, by the time new systems enter the market, establishing trends on indirect emissions could be achieved if testing methods would have been developed that enable monitoring the progress made on MACs. These methods should be based on standardised conditions, discriminating systems under realistic in-vehicle testing conditions. An assessment procedure for effects on fuel consumption is being worked out at the moment under the EU BCOOL project [Malvicino 2005]. The procedure comprises a vehicle-based approach, meaning that the additional fuel consumption is tested on a vehicle with the MAC switched off and on, the latter with the relevant ambient conditions simulated.

4.5 Scenarios for market penetration of various air conditioning systems

The main focus of this study is to review technical options for reducing CO_2-emissions. Possible policy measures to promote or enforce the introduction of viable options will be discussed at a later stage. Nevertheless in this section a baseline scenario and an additional policy scenario are developed to assess the possible impact and CO_2-abatement costs of accelerated introduction of improved and alternative MACs in comparison to a baseline scenario that already contains a substantial amount of existing policy measures that impact the direct and indirect greenhouse gas emissions from passenger cars with MACs in the near future.

Due to lack of quantitative market predictions both scenarios are constructed in an intuitive, semi-quantitative way based on expert judgement of the likely developments in the baseline scenario and a feasible rapid introduction of improved and alternative systems in the additional policy scenario.

In the scenarios described below the following systems are considered:
- R134a with fixed displacement compressor, 40 g/y direct emissions
- R134a with variable displacement compressor, 40 g/y direct emissions

- R134a with variable displacement compressor and improved efficiency, 40 g/y direct emissions
- R744 with variable displacement compressor
- R744 with variable displacement compressor and improved efficiency

4.5.1 Baseline scenario

In the baseline scenario most developments concerning MACs will be the result of the new legislation that that foresees a phase out of R134a (as from 2011 for new types of vehicles and as from 2017 for new vehicles) and lays down measures for the monitoring of the leakage starting around 2007.

Already now, alternatives to the conventional R134a systems are developed and improved. Although the systems have not really shown their competence under real-world and under standardized testing conditions - which should enable a fair comparison with the baseline R134a system - it is generally believed that mainly systems using R744 as refrigerant have a future in MACs.

One supplier believes he can introduce the first CO_2 system already in series production in 2008 for some upper class cars. Another supplier is prepared for series production in 2011, while some manufacturers have a goal to introduce CO_2 systems in upper class cars of their range by 2008 [Auto Motor und Sport 2005]. Furthermore, the ARCRP concluded during an ARSS in 2003 that the timetable for CO_2 systems is 5 years, which from 2003 on means an introduction in 2008. It is therefore very likely that CO_2 systems can enter the EU market from about 2008.

Concerning the R152a systems, these are still considered as an option next to or instead of R744 systems. There a few drawbacks, however. The safety issues of the R152a system and questions regarding accompanying costs have not all been resolved. Furthermore, now that CO_2 is seen as the best candidate, R152a loses even more attention as the industry seeks mainly for one common platform system that replaces R134a. [Mager VDA 2005] concluded upon the assessment of R152a that this refrigerant is not seen as alternative due to its safety risks and limited potential for efficiency improvement and confirmed that German OEMs voted for R744 as the future refrigerant for MACs.

When CO_2 systems will enter the market, the direct emission effect (GHG) will probably decrease substantially as the GWP of CO_2 is only 1, which is very low compared to the currently used refrigerant. Even when considerable leakage rates of CO_2 would be considered the decrease would be substantial. Secondly, a CO_2 system can be used reversibly as a heater which may result into a merit in terms of overall HVAC system compactness and maybe even costs, if the amount of parts formerly required for the heater could be reduced. It is not known, however, whether the efficiency in the heater operating mode improves compared to current heater systems and therefore it cannot be stated whether heater operation of CO_2 systems is beneficial from an energy point of view.

Summarizing, it can be concluded that the introduction of CO_2 systems on newly sold vehicles in the near future starting around 2008 seems feasible at additional manufacturer costs per car in the order of 40 to 80 Euros compared to baseline systems. The introduction of these systems will probably bring about a reduction of direct GHG emissions. Over time these systems will probably also gradually improve in terms of efficiency and as a result eventually bring about reduced indirect CO_2 emissions compared to the baseline system. How much the improvement will be, can not be estimated accurately. The industry, however, quotes improvement rates in the order of 20 to 40%. The reduction rates would be obtainable by a further optimisation of mainly the system control and by improving the efficiency of the heat exchangers.

Definition of the base scenario

The base scenario includes a gradual penetration of the fleet with R744 systems from 2008 onwards, the introduction starting on larger cars, to an almost fully migrated fleet sales by about 2015. Until then, the base-line R134a system will remain in the sales next to the R744 systems. It is assumed that R152a systems will not be applied in vehicles in this scenario.

For the R134a systems a gradual increase of the share of systems with a variable displacement compressor is foreseen until 2011, resulting in a gradual improvement of the average efficiency of vehicles with a MAC based on R134a. After the system is banned for Type Approval in 2011 the sales of R134a systems will decrease rapidly. The increasing use of VDC in R134a systems is already ongoing and is stimulated by 'driveability', and 'comfort' issues. Also for the R744 systems it is assumed that some time after the introduction of first generation systems technical improvements will lead to introduction of a second generation of improved systems. Starting around 2006, systems entering the market will have decreased leakage rates (40g/y) as a result of new legislation, so both the baseline R134a systems and the improved R134a systems with VDC already have decreased leakage rates compared to the systems sold until now.

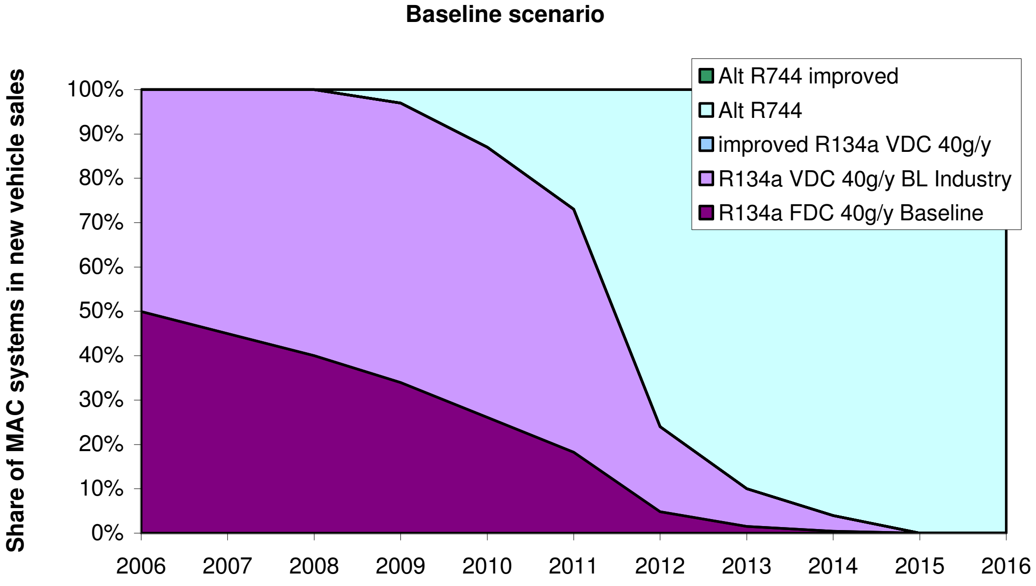

Figure 4.1 Development of the market share of different MAC systems in the baseline scenario.

4.5.2 Scenario with additional policy

This additional policy scenario is based on possible improvements *on top of* the already ongoing process of system optimisation of current baseline systems and the gradual introduction of alternative systems starting in 2008, in the previous paragraph pointed out to be the R744 system. The scenario with complementary measures is based on the assumption that by 2008 a stricter policy would be put into effect that aims at more efficient MACs, i.e. causing a lower indirect CO_2 emission. Because the conventional R134a systems at the moment are already improving in efficiency (on average, by means of applying amongst others VDCs), it is believed that the only attainable substantial improvements can be made by accelerating the introduction of efficient R134a systems.

The R744 systems already under development show good results, but it has still not been demonstrated by a test procedure that discriminates systems under a variety of representative real world conditions that mature systems would bring about a benefit in indirect CO_2 emission, let alone that prematurely introduced types would bring about a benefit if an early introduction of R744 would be enforced. The industry, however, reports good COP values for R744 in combination with a good pull down. On the other hand, for direct emissions an early introduction of R744 will very likely lead to a benefit.

Definition of the additional policy scenario
The additional policy scenario includes the following assumed effects resulting from additional, stricter, policy:

- The total share of R134a systems remains the same as a result of the additional policy, meaning that the share of CO_2 systems entering the market also remains the same. The improvement is from accelerated introduction of enhanced, more efficient, R134a systems, replacing a share of the sales of .baseline R134a systems and the accelerated introduction of improved CO_2 systems.
- Because it is expected that R744 systems can only improve as a result of practical experience with the initially introduced generation of systems, the introduction of improved CO_2 systems is estimated to be starting with a delay and only gradually.

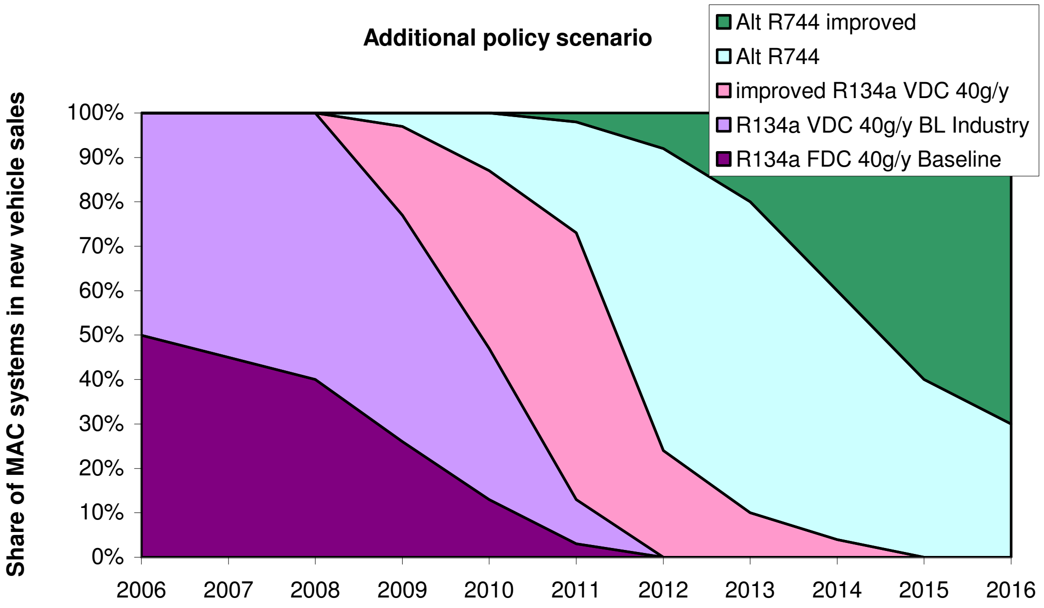

Figure 4.2 Development of the market share of different MAC systems in the additional policy scenario.

4.6 CO_2-reduction and costs of various airco systems

Estimates of the additional manufacturer costs and the direct and indirect greenhouse gas emission of the various MAC systems, based on the various considerations as presented in the previous sections, are depicted in Table 4.4. Direct GHG emissions are based on refrigerant emissions of 40g/y times the GWP of the refrigerant (1300 in the case of HFC 134a) The 40g/y value is derived from various literature sources used in this chapter. For the indirect CO_2 emission a reference value of 6.6 g/km is taken for an average system, today actually representing a mix of 50% VDC (Variable Displacement Compressor) systems and 50% FDC (Fixed Displacement Compressor) systems and a mix of 50% petrol and 50% diesel cars. The VDC systems are estimated being 30% more efficient than FDC systems. The indirect CO_2 emissions of the alternatives are based on the reference value and the reduction rates as presented by the industry, see Table 4.2. The costs are also directly from this information. Where an uncertainty range is given for either costs or reduction potential, the average of this range is used for the calculations. Based on these data the CO_2-abatement costs of the various systems can be calculated and compared to the baseline system (R134a with FDC). This comparison is presented in Alternative systems can also be compared to the average system as sold in 2008 in the baseline scenario (40% R134a with FDC and 60% R134a with VDC). This comparison is given in the right half of Table 4.5.

These data can not be directly used to assess the CO_2-abatement costs of a policy aiming at the increased use of fuel-efficient airco systems. In the baseline scenario already a shift towards more efficient systems is taking place. The CO_2-abatement costs of the increased use of efficient systems will therefore be higher than the CO_2-abatement costs for individual systems compared to the baseline system. The results for the CO_2-abatement costs of the additional policy scenario are presented in Table 4.6.

Table 4.4 Reduction rates (TTW), additional manufacturer costs, indirect TTW CO_2 emissions and direct refrigerant emissions of various MAC systems as used in the baseline and additional policy scenario. Note that the average additional CO_2 emission due to use of an airco is derived from a mix of VDC and FDC systems and that a shift takes place from FDC to VDC systems over time. Also note that the industry uses VDC systems for the baseline whereas the calculations presented here use FDC systems for the baseline.

	add. manuf. costs	relative efficiency	indirect TTW CO_2-emission [g/km]						
	[€]	[%]	2006	2007	2008	2009	2010	2011	2012
R134a FDC 40g/y baseline	0	100%	7.76	7.76	7.76	7.76	7.76	7.76	7.76
R134a VDC 40g/y (= BL industry)	35	70%	5.44	5.44	5.44	5.44	5.44	5.44	5.44
average R134a system			6.60	6.48	6.37	6.25	6.13	6.02	5.90
improved R134a VDC 40g/y	75	53%	4.08	4.08	4.08	4.08	4.08	4.08	4.08
Alt R744	135	56%			4.35	4.35	4.35	4.35	4.35
Alt R744 improved	195	42%			3.26	3.26	3.26	3.26	3.26

	add. manuf. costs	relative efficiency	indirect TTW CO_2-emission [kg/y]							direct refrigerant emission
	[€]	[%]	2006	2007	2008	2009	2010	2011	2012	[kg CO_2-eq./y]
R134a FDC 40g/y baseline	0	100%	124	124	124	124	124	124	124	52
R134a VDC 40g/y (= BL industry)	35	70%	87	87	87	87	87	87	87	52
average R134a system			106	104	102	100	98	96	94	52
improved R134a VDC 40g/y	75	53%	65	65	65	65	65	65	65	52
Alt R744	135	56%			70	70	70	70	70	0
Alt R744 improved	195	42%			52	52	52	52	52	0

*) annual mileage = 16000 km

Table 4.5 CO_2-abatement costs of various MAC systems compared to the baseline R134a system with fixed displacement compressor and 40 g/y direct refrigerant emissions and compared to the average system as sold in 2008 in the baseline scenario (mix of R134a FDC and VDC systems).

	fuel price in [€/l]				fuel price in [€/l]			
	0.21	0.30	0.41	0.60	0.21	0.30	0.41	0.60
	abatement costs compared to R134a FDC baseline 40g/y				abatement costs compared to average system for 2008 in baseline scenario			
	[€/tonne]	[€/tonne]	[€/tonne]	[€/tonne]	[€/tonne]	[€/tonne]	[€/tonne]	[€/tonne]
R134a FDC 40g/y baseline	---	---	---	---	---	---	---	---
R134a VDC 40g/y (=BL industry)	16	-7	-36	-86	16	-7	-36	-86
improved R134a VDC 40g/y	41	18	-11	-61	56	33	4	-45
Alt R744	73	60	44	17	90	80	67	46
Alt R744 improved	93	78	60	30	111	99	83	57

annual mileage = 16000 km
vehicle lifetime = 13 y
IR = 4%

Table 4.6 CO_2-abatement costs of the additional policy scenario compared to the baseline scenario for the various years between 2008 and 2012 and for different fuel costs.

oil price [€/bbl]	fuel cost [€/l]	abatement costs [€/tonne] compared to baseline scenario				
		2008	**2009**	**2010**	**2011**	**2012**
25.0	0.21	--	56	60	66	90
36.3	0.30	--	33	36	42	66
50.0	0.41	--	4	7	14	37
73.8	0.60	--	-45	-42	-36	-12

In the baseline and the policy scenario the introduction curve of CO_2-based R744 systems is the same. The only difference between the scenarios is the introduction of improved HF 134a and R744 systems. The estimate for the cost differential between the FDC HF 134a system, the VDC HF 134a system and the basic R744 system therefore do not influence the assessment of abatement costs based on the comparison the two scenarios.

TREMOVE appears to account for airco use with a value of the additional fuel consumption (separate factors for petrol, diesel and CNG) that is constant over time. However, in our view the baseline should already include an autonomous development of the additional fuel consumption related to airco use, specifically as a result of the increased share of airco systems with VDC in the new vehicle sales. Table 4.7 presents the relative change in additional fuel consumption of the policy scenario compared to the baseline as well as the associated additional (manufacturer) costs per vehicle.

Table 4.7 Average additional fuel consumption and additional costs in policy scenario compared to baseline.

	scenario	**2008**	**2009**	**2010**	**2011**	**2012**	
avg. add. fuel consumption	baseline	0.256	0.249	0.237	0.224	0.190	[l/100km]
relative change compared to 2008	baseline	100%	97%	93%	87%	74%	
avg. add. fuel consumption	policy	0.256	0.231	0.203	0.176	0.169	[l/100km]
relative change compared to 2008	policy	100%	90%	79%	69%	66%	
relative change compared to baseline	policy	0%	-7%	-14%	-21%	-11%	
avg. add. manuf. costs comp. to baseline	policy	0	11	21	31	16	[€/veh.]
avg. add. retail price excl. tax comp. to baseline	policy	0	13	24	35	19	[€/veh.]
avg. add. retail price incl. tax comp. to baseline	policy	0	16	30	44	23	[€/veh.]

4.7 Overall reduction potential

The calculation of the overall reduction potential for fuel-efficient airco systems in EU-15 is based on the baseline and policy scenario as described above. For each year of construction between 2008 and 2020 the average difference in indirect CO_2-emissions (in g/km) is calculated between vehicles equipped with the (mix of) systems as described in the policy scenario and vehicles equipped with the (mix of) systems according to the baseline scenario. In this calculation account is taken of the fact that different indirect emission factors for airco use apply to the different regions in EU-15 according to the methodology as described in [TNO 2002]. This difference in emission factors reflects the difference in airco use (time that the airco is used and the required cooling power) in relation to the differences in climatic conditions. For northern European countries (DK, FI, IE, UK, SE) the airco factor is 0.74 times the airco factor for the central European countries (AT, BE, DE, FR, LU, NL), while the factor for the southern countries (ES, GR, IT, PT) is 1.58 times that of the central European countries.

Combining the results of this for a given year with:

- the number of vehicles per year of construction and the annual mileage of these vehicles according to the fleet spreadsheet derived from TREMOVE 2.42 baseline data as described in section 2.5;
- the shares of air conditioning systems in newly sold vehicles per year of constriction[22],

yields the overall GHG-emission reduction per annum in the given year. The results are multiplied with the average WTW/TTW correction factor (see section 2.4) then yield the overall Well-to-Wheel GHG emission reduction. Results are displayed in Figure 4.3.

The baseline and policy scenarios have been defined such that the transition from R134a to R774 is the same in both scenarios. As a result the possible difference in direct (refrigerant) GHG-emissions for the two types of systems does not impact the annual GHG-emission reduction, even though the model has been designed to take these effects into account.

The annual WTW GHG-emission reduction in 2012 amounts 1.0 Mtonnes/y, increasing to 2.7 Mtonnes/y in 2020. The value increases between 2008 and 2020 for three reasons (see also Figure 4.2):

- the share of so-called improved systems in newly sold vehicles still increases until about 2020;
- the share of efficient airco systems in the fleet still increases;
- the share of airco systems in the fleet still increases from 85% in 2008 to 95% in 2020.

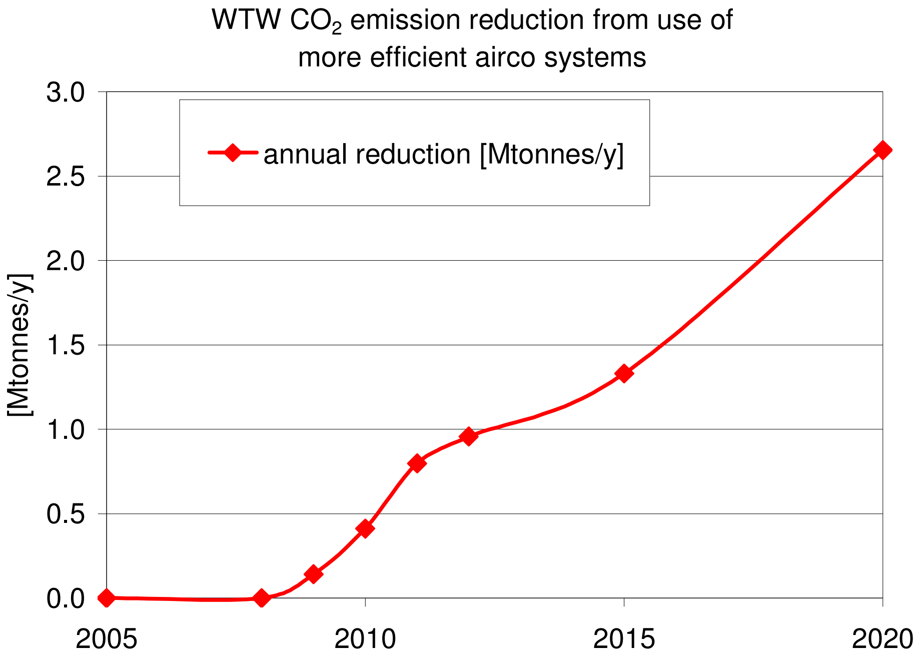

Figure 4.3 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) for EU-15 resulting from more efficient mobile air conditioner systems applied to passenger cars.

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[22] Also TREMOVE data received from TML.

4.8 Policy options to promote the use of energy-efficient airco systems

For the moment there are no means for including the indirect fuel consumption of MACs in the type approval test. In [TNO 2004] a simplified test procedure has been developed to this end, but this procedure was found to yield insufficiently reproducible and accurate results. More accurate ad-hoc test procedures do exist which are applied in vehicle development and testing with regard to airco performance and interior comfort, but these require very expensive test facilities (with full climate control and solar radiation simulation) and elaborate tests that are beyond the scope of the European type approval test. The procedure developed in [TNO 2004] could be used to monitor overall progress in the average indirect CO_2-emissions of MACs when applied in a monitoring programme to a number of vehicles that is large enough to yield statistically significant average results.

The impossibility to include MACs in the TA test procedure for the moment excludes legislative measures aimed at promoting airco efficiency. The existing procedure can be used as a monitoring tool accompanying a voluntary agreement with the automotive industry on improving airco efficiency.

The advantage of a policy coupled to a vehicle-based TA test is that also the effects of other vehicle technologies that affect the indirect CO_2-emissions of MACs can be monitored an taken into account. The indirect CO_2-emissions of MACs can also be reduced by reducing the cooling load of the vehicle, e.g. by using reflective glazing, directional cooling or optimised recirculation. Trends with respect to application of e.g. solar roofs and parking ventilation will tend to increase the indirect CO_2-emissions of MACs.

If the focus is placed solely on the energy efficiency of the airco system, then also a component based policy could be envisaged. This would require a component-based test procedure to measure and monitor the energy efficiency of airco systems. The results of such a test could e.g. be used in an air-conditioning labelling system, possibly accompanied by financial or other stimulating policies offering advantages differentiated according to the score of systems in the labelling scheme. The feasibility of such an approach would need to be further explored.

4.9 Output supplied to TREMOVE and Task B

The output supplied to TREMOVE is based on the results as described in the previous sections. Tables in the agreed format are included in Annex E. Results are expressed in additional fuel consumption factors due to the use of MACs and are differentiated to three regions of Europe with different average temperatures and related airco use, according to the methodology as worked out in [TNO 2002].

4.10 Conclusions

- The EC has proposed several measures to reduce greenhouse gas emissions from passenger cars in the next decade. The EC aims at reducing greenhouse gas emissions from aircos by a ban on the high GWP R134a as a refrigerant for all mobile air conditioner systems as from 2011. As a result of this legislation, the auto industry is challenged to develop new systems which use low GWP refrigerants as an alternative to R134a. Parallel to these developments, the industry investigates possibilities to improve existing systems, as such legislation is not proposed for other parts of the world and as for the EU still some time has to be bridged before switching to alternatives. It is expected that CO2-based systems (R744) will be the dominant alternative and that in response to existing policy these systems will gradually enter the market after 2008, reaching near 100% of new sales by 2014 or 2015.
- Both the existing R134a systems and the future R744 systems have room for improvement with respect to energy efficiency and the resulting indirect CO_2-emissions associated with use of these

aircos. In response to a possible EU policy promoting energy efficiency of MACs it is expected that improved systems will come to the market which have significantly lower energy consumption. The additional manufacturer costs for improved systems are estimated at €40 for R134a systems and €60 for R744 systems. Besides that further improvement of the average efficiency of R134a systems is expected to be achieved by an increased share of systems variable displacement compressors.

- CO_2-abatement costs of a policy promoting the introduction of more efficient MACs is assessed by estimating the total annual indirect CO_2-emissions, investment and fuel costs for a baseline scenario (describing the response to existing policy) and a constructed policy scenario sketching a possible response to a not yet defined EU policy aimed at the efficiency of MACs.
- At low oil prices (25 to 35 €/bbl) the abatement costs for reducing CO_2-emissions by means of energy efficient MACs varies between 40 and 90 €/tonne. At 50 €/bbl the CO_2-abatement costs vary between 15 and 40 €/tonne, becoming even negative for an oil price of 74 €/bbl. Compared to other technical options fuel efficient MACs therefore are a relatively cost-effective measure to reduce CO_2-emissions from passenger cars.
- For the moment there are no means for including the indirect fuel consumption of MACs in the type approval test. In [TNO 2004] a simplified test procedure has been developed to this end, but this procedure was found not to yield sufficiently reproducible and accurate results. More accurate ad-hoc test procedures exist which are applied in vehicle development and testing with regard to airco performance and interior comfort, but these require very expensive test facilities and elaborate tests that are beyond the scope of the European type approval test. The procedure developed in [TNO 2004] could be used to monitor overall progress in the average indirect CO_2-emissions of MACs when applied in a monitoring programme to a number of vehicles that is large enough to yield statistically significant average results.
- The impossibility to include MACs in the TA test procedure for the moment seems to exclude legislative measures aimed at promoting airco efficiency. The existing procedure can be used as a monitoring tool accompanying a voluntary agreement with the automotive industry on airco efficiency.
- A first assessment of the overall reduction potential associated with promotion of the use of fuel-efficient air conditioner systems shows that for EU-15 a total GHG reduction of 1.0 Mtonne/y could be achieved in 2012 growing to 2.7 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

4.11 Literature

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5 Options for reducing vehicle and engine resistance factors

5.1 Goal of Task 1.7

The goal of this Task is to provide a more detailed review of the options available to reduce vehicle and engine resistance factors in addition to the less detailed assessment made in Task 1.1. More specifically this Task is focused on tyre rolling resistance, engine friction and lubrication and their contribution to the overall vehicle fuel consumption. An assessment will be made of the CO_2 reduction potential and costs associated with the implementation to new and existing vehicles of:

- low rolling resistance tyres;
- low friction lubricants;
- tyre pressure monitoring systems.

Policy options will be reviewed for promoting the first equipment of cars with these technologies by means of a bonus or tax incentive, as well as options to make first equipment of cars with these technologies mandatory.

Based on the fact that rolling resistance and engine resistance factors are both created by the same physical phenomenon, friction, they were grouped together for the purposes of this project under the same title and in the same task. However the research conducted showed that despite this basic similarity, the way they affect vehicle fuel consumption and how their effect should be quantified and analyzed is different. Therefore for practical reasons from now on this Task will be divided into 2 sections with regard to the analysis and the effect of each factor in vehicle fuel consumption and CO_2 emissions. The first section deals with tyre rolling resistance and relevant technology and the second with engine friction and low viscosity lubricants.

5.2 Approach

Based on existing literature, possibly accompanied by some dedicated computer simulations, estimates will be made of the impacts of the use of low friction tyres, tyre pressure monitoring systems, and lubricants on the fuel economy of a vehicle. A differentiation of the estimated potential may be necessary for different EU countries depending on different climatic conditions. Additional detail regarding the fuel reduction potential and the cost of these options will be obtained through a market overview and discussions with experts. For all three options separately cost and CO_2-reduction data (with respect to Type Approval and real-world emissions) will be generated as input for the development of scenarios and assessments to be carried out with TREMOVE and in Task B.

Important information sources are:

- Scientific reports of studies conducted on behalf of the European Commission or by other independent researchers;
- Review of possible existing data from other research programs;
- Review of relevant products/techniques currently available in the market;
- A questionnaire aimed at vehicle manufacturers (ACEA), tyre manufacturers (BLIC[23]) and lubricant producers (ATIEL);
- Interviews with consultation of industry experts;
- Important data regarding low rolling resistance tyres and tyre pressure monitoring systems were retrieved from the IEA 2005 workshop on Low Rolling Resistance Tyres (see Annex G).

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[23] Currently named European Tyre and Rubber Manufacturers' Association (ETRMA): http://www.etrma.org

5.3 Review of options to reduce vehicle rolling resistance

5.3.1 Rolling Resistance general

At the following paragraphs the effect of rolling resistance on CO_2 emissions will be examined. As it will be presented, rolling resistance is playing an important role in the energy balance of the vehicle and has significant contribution in fuel consumption. Rolling resistance is determined mainly by the tyres of the vehicle. Therefore the most important technology to reduce vehicle rolling resistance that will be studied here is low rolling resistance tyres (LRRT).

Although Low Rolling Resistance Tyres exist for several years now, there is neither an official definition of Rolling Resistance Tyres nor a standard to define when a Tyre can be characterised as such

The second key factor that helps to reduce vehicle rolling resistance losses is proper tyre maintenance and more specifically tyre pressure. The most important technology currently available in this field is tyre pressure monitoring systems (TPMS). Tyre pressure monitoring systems monitor tyre pressure and indicate to the driver when a tyre needs inflation. As will be explained TPMS can have important benefits in CO_2 savings and therefore they are also studied in the following paragraphs together with LRRT.

5.3.1.1 Tyre and Rolling Resistance

The result of the act of rolling friction on a vehicle is rolling resistance. Rolling friction is the force that occurs when an object (e.g. a wheel or tyre) rolls. It is caused mainly by the deformation of the wheel or tyre or the deformation of the ground and thus it depends very much on the material of the wheel or tyre and the type of the ground. For example, rubber will give a higher rolling friction than steel and sand will give much higher rolling friction than concrete. In the case of rubber vehicle tyres, rubber acts as a visco-elastic material that deforms and returns to its original shape periodically. The term 'hysteresis loss' is often used in literature to describe the energy lost as heat during the repeated deformation of a tyre [NRDC 2004]. As it will be mentioned onwards several other characteristics of the tyre affect rolling resistance. For better understanding and in order to have a clearer view of the tyre and its individual parts that will be discussed in the following analysis Figure 5.1 is introduced.

Rolling resistance together with aerodynamic drag are the most important resistances that a vehicle has to overcome while moving. The main difference between rolling resistance and all other vehicle resistances is that rolling resistance is always present and appears from the moment vehicle wheels begin to turn. Another key characteristic of rolling resistance is that in low speeds is the most significant resistance acting on the vehicle –aerodynamic drag usually surpasses rolling resistance at speeds over 70km/h. It is therefore clear that rolling resistance is the most important resistance factor that affects fuel consumption under **urban** and **rural** driving conditions (average speed close to those of NEDC and its sub-cycles).

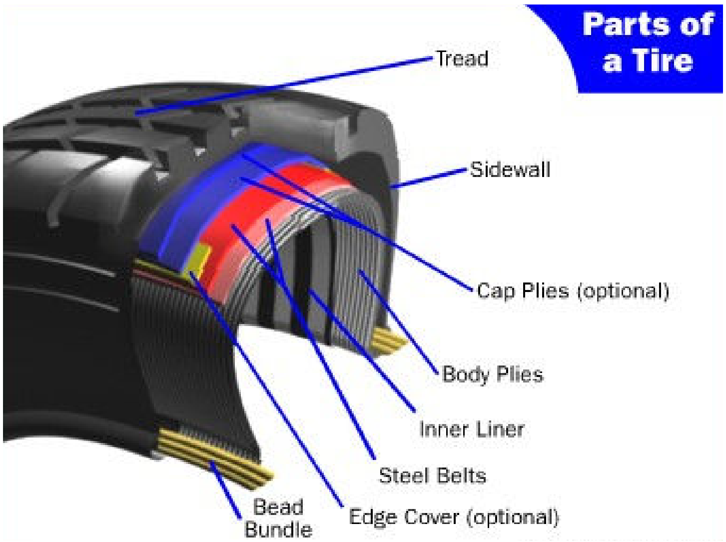

Figure 5.1 Most important parts of a tyre (retrieved from www.howstuffworks.com)

The mechanism that generates rolling resistance is rather complex as several different factors are involved that affect both the tyre and ground. A detailed analysis of these factors is not within the scope of this study. A brief presentation however of their main aspects is interesting and can help the following analysis. At this point the reader should keep in mind that tyres are the 'means' that carry all necessary energy needed to make a vehicle move. This energy flow is behind almost all problems related to rolling resistance because it causes the heating and the deformation of the tyre eventually leading to tyre material fatigue and efficiency deterioration. Amongst the factors that affect the magnitude of the rolling resistance generated by the tyre, are the following:

- Temperature, it affects significantly rolling resistance since its rise is causing a continuous reduction of the rolling resistance value until the tyre reaches nominal operating temperature
- Material and Design, with different types of rubber presenting different 'hysteresis' and thus different grip and rolling resistance characteristics and with radial or smooth tread tyres presenting less friction in lower speeds
- Dimensions, rolling friction is proportional to the contact area (usually no larger than an 'A4' paper sheet) of the tyres - so a thinner tyre will exhibit less friction (but also fewer grips) than a wider one. Additionally tyres present aerodynamic resistances, thus a larger tyre will increase resistances in higher speeds.
- Tyre pressure, partially inflated tyres tend to suffer higher rolling resistance as will be presented onwards and also have reduced lifespan.
- Tyre slip, results in higher rolling resistances and frictional scuffing.

5.3.1.2 Measuring Rolling Resistance

Rolling resistance of a tyre can be measured either in a special test facility or through road tests. In the first case the tyre-road interaction is simulated by rotating drums. The rolling resistance is calculated through the measurement of the slow down time of each tyre. There is also a possibility to use a flat band in order to conduct the measurement. In this case the calculation is based on the measurement of the reaction force. For on road measurements a conventional or a specialised car can be used for measuring the moment/power of the vehicle and through it calculate the rolling resistance. Another on road method requires the use of a trailer. In this case the differentiation of the towing force is measured and through it the rolling resistance of the trailer tyres is calculated.

An ISO standard currently exists for measuring rolling resistance, the "ISO 18164:2000 Truck, Bus. Passenger-Car and Motorcycle Tyres – Methods of Measuring Rolling Resistance". This standard doesn't sufficiently or does not at all describe key factors of the measurement such as: measuring principle, air turbulence, drum diameter, quality of the surface, warming up or rolling time before test, velocity etc [Glaeser 2005]. Currently various institutes and tyre manufacturers throughout Europe are conducting research on developing an adequate methodology for rolling resistance measurement.

5.3.1.3 Tyre pressure effect – TPMS systems

As mentioned in the previous paragraph tyre pressure is maybe the most important factor affecting rolling resistance of a tyre in use. Maintaining proper tyre inflation is essential for both fuel efficiency and better tyre performance. Deflated tyres can cause up to 4% increase in fuel consumption while reducing tyre lifespan by 45% [Hakanen and Jukka]. According to Pirelli (www.pirelli.com) under normal driving conditions the tyres lose 1-2 psi of pressure per month while the tyre pressure should - in some cases- be higher than the standard values, in order to compensate for heavier vehicle conditions. Additionally a tyre may lose up to half its air and not seem to be under-inflated. It should be reminded that insufficient pressure is the main cause of tyre damage and the air-tightness of a tubeless tyre or of the inner tube is not completely guaranteed if a valve cap with seal is not used. Finally deflated tyres are an important factor causing road accidents resulting in numerous fatalities and injuries throughout Europe.

Despite the fact that tyre pressure is important for the operation of the vehicle car owners are not careful with the condition of their tyres. A research conducted by TNO for the Dutch Ministry of Environment showed that 50% of all cars are driven on under-inflated tyres [IEA 2005]. In the US it is estimated that under-inflation causes an increase in the average rolling resistance of about 8% [NRDC 2004]. According to data provided by Michelin the tyres in service are on average 0.2 to 0.4 bar deflated, a fact that corresponds to an increase in fuel consumption of 1 to 2.5% [Penant 2005]. Another important characteristic of additional rolling resistance caused by tyre deflation is that it is a totally 'real-world phenomenon that does not affect at all type approval tests. Therefore it must be accounted amongst the factors that differentiate real world energy performance of a vehicle from type approval and thus it is difficult to control through legislative measures.

In order to address the issue of under inflated tyres several manufacturers –mainly in the US- adopt the solution of Tyre Pressure monitoring Systems (TPMS). TPMS are systems that monitor tyre pressure and warn the driver in case a tyre has to be inflated. In certain cases TPMS also warn for tyre failures for safety reasons. Two different TPMS types are distinguished, indirect TPMS and direct TPMS. The indirect TPMS uses the ABS wheel speed sensor combined with data from ESP to measure the speed of the wheel. Pressure drops are detected by the increase in the ABS wheel speed that is caused by the reduction of the rolling wheel diameter. Direct TPMS have calibrated internal sensors that measure actual tyre pressure and transmit data to receivers. In [NTHSA 2005] a third category of TPMS is mentioned the hybrid TPMS systems which consist of an indirect TPMS for vehicles equipped with an ABS and two direct pressure sensors and a radio frequency receiver. According to the same source no manufacturer had plans to use such a system.

According to tyre manufacturers, technically there is no necessary connection between tyres and TPMS. However, TPMS fitment helps maintain the rolling resistance value of the tyre at its original levels and supports their effect on fuel saving. TPMS is generally necessary for run flat tyre solutions, which may or may not be, low rolling resistance solutions amongst run flat tyres class [BLIC 2005].

5.3.1.4 Rolling resistance impact on CO_2 – NEDC and real world

Being one of the two major vehicle resistances, rolling resistance has a direct impact on the vehicle CO_2 emissions and fuel consumption. Assuming the simple tyre friction model presented in the previous paragraph and a typical vehicle mass of 1360kg and a rolling resistance coefficient f_r of

0.011, the value of the force the vehicle has to overcome equals 146N. At an average constant speed of 50km/h this force would require approximately 2kW of engine power which results in 4kWh energy demand for a 100km distance. Considering 30% optimal engine efficiency the aforementioned energy demand is translated in about 1.46 litres of gasoline i.e. 1.46lt/100 or 34.4 gCO_2/km. This number of course represents just indicative ideal situation as in real life other factors such as the velocity-time profile, lower powertrain efficiency, road surface, tyre pressure variation and the weather will increase these numbers. A complete calculation of the rolling resistance resulted fuel consumption would require detailed knowledge of all these factors.

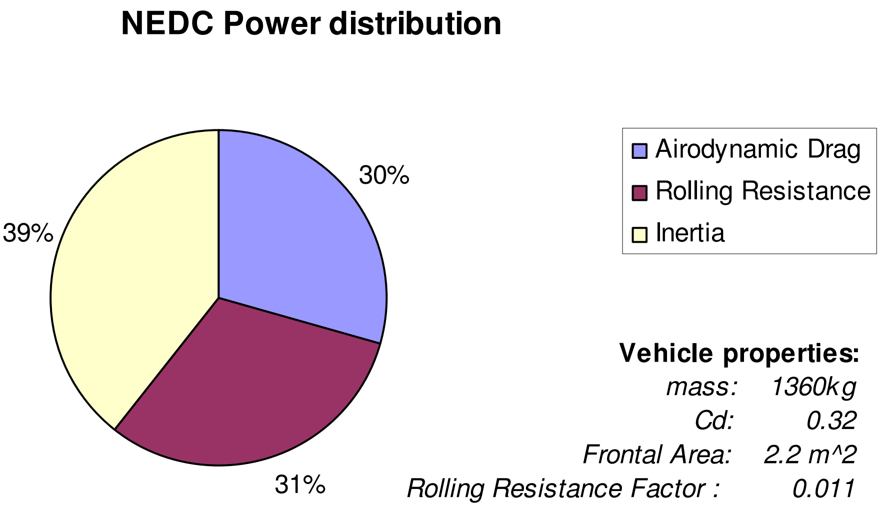

Figure 5.2 Distribution of power demand to overcome external resistances over NEDC

For the case of the legislated driving cycle however it is easy to estimate the exact ratio of energy that is consumed to overcome rolling resistances. This is because legislated driving cycles have a specified velocity-time profile and predefined driving conditions including fixed tyre pressure value, ambient temperature and rolling resistance model. It is therefore possible to estimate the distribution of energy demand for an average vehicle over NEDC as presented in Figure 5.2. The numbers are also similar for the case of the Composite Driving Cycle used for the Federal Test Procedure in the United States (rolling resistance 30.5%, air drag 29.5% and inertia 40%) [Duleep 2005].

It is evident from the above that tyre rolling resistance has a direct impact on the vehicle fuel consumption and CO_2. Apart from these direct effects it should be reminded that tyres also add mass (approximately 30kg for 4 typical tyres plus spare tyre weight), rotating inertia and aerodynamic drag (20-25% of the total drag) to the vehicle [Duleep 2005]. Therefore any actions aiming towards the reduction of the fuel consumption through the use of low rolling resistance tyres should not ignore these tyre characteristics that indirectly affect the energy performance of the vehicle.

5.3.1.5 Present status of application

Tyres with low rolling resistance appeared in the market several years ago. Today many tyre manufacturers provide amongst their products tyre models that are considered as low rolling resistant or more energy efficient. According to the manufacturers these models that are currently in the market **can be used by any regular vehicle**, do not lack any of the characteristics or the performance of regular tyres and do not need any special attention. Meanwhile regular tyres improve as well. According to a MIT research [MIT 2000] today's automobile tyres have 30% lower rolling resistance compared to those in the 1980's, 25% increase in lifetime, 15% reduction in noise, 7% improvement in wet road braking and the same cost. It is evident that tyre technology is developing dynamically and further enhancements are expected.

Detailed data regarding the number of vehicles currently using low rolling resistance tyres were not available and the present level of introduction of LRRT in the European market is unknown. According to tyre manufacturers [ETRMA 2006] the share of LRRT in the fleet by 2008 is estimated at 50% and will grow until 2020 depending on the policy instruments to be applied. According to ETRMA, formerly known as BLIC, the majority of vehicle manufacturers are specifying rolling resistance values in their tyre performance specification list, considering carefully the trade off with the total range of tyre performances and with no compromise on safety performances [BLIC 2005]. Some informal conversations made with tyre experts showed that there are completely different views about the near future of energy efficient tyres within tyre manufacturers. It was made clear, though, that certain tyre manufacturers have given special attention to the development and marketing of low rolling resistance tyres and conduct important research towards improving the energy efficiency of their products. In the bottom-line, as the response to the questionnaire has shown, the market will be a decisive factor for the future development or not of low rolling resistance tyres.

TPMS systems also appeared several years ago but until recently they were applied only in small numbers. Recent efforts initiated in the US to reduce tread wear and improve tyre performance, have increased the interest for such systems. It is expected that from 1/9/2007 even small volume manufacturers will have to fit TPMS in order to meet the TREAD act[24] requirements [Stock 2005]. According to NHTSA there are two compliance options for TPMS. The first compliance option, a vehicle's TPMS must warn the driver when the pressure in any single tire or in each tyre in any combination of tyres, up to a total of four tyres, has fallen to 25 percent or more below the vehicle manufacturer's recommended cold inflation pressure for the tires, or a minimum level of pressure specified in the standard, whichever pressure is higher. Under the second compliance option, a vehicle's TPMS must warn the driver when the pressure in any single tyre has fallen to 30 percent or more below the vehicle manufacturer's recommended cold inflation pressure for the tyres, or a minimum level of pressure specified in the standard, whichever pressure is higher. Tyre industry is strongly opposed to NHTSA's safety regulation which in effect allows the motoring public to drive on severely underinflated tyres [NHTSA 2001].

The situation in Europe is different as no legislation exists and thus TPMS systems are fitted either in expensive vehicles as standard equipment or as a cost option for cheaper cars.

5.3.1.6 Theoretical potential for CO_2 reduction through the use of low rolling resistance tyres and TPMS

Tyres

As presented in the previous section of the text, rolling resistance accounts for a large part of the vehicle energy consumption and therefore for CO_2 emissions as well. The use of tyres with low rolling resistance can improve the energy performance of the vehicle and CO_2 emissions. The improvement depends on many different factors such as the tyre and the vehicle, but also the weather conditions, the use of the vehicle, the quality of the street and maintenance. It becomes therefore clear that it is difficult to standardise a measurement procedure in order to come up with a single relation that will link rolling resistance reduction and fuel savings. Instead it would be more accurate to speak

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[24] This Act may be cited as the ''Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act''.The TREAD Act was passed in the fall of 2000 following the Ford/Firestone crisis. US Congress wanted to make tires safer for the motoring public. The TREAD Act has nine components that affect the tire industry.

about a range of CO_2 emissions reduction through the use of low rolling resistance tyres. Generally, this range stands between 1% and 5% reduction. The tyre industry places the CO_2 emission reduction, achievable through the use of low rolling resistance tyres, within the range 3 to 4%, regardless of the engine type (Petrol or Diesel) and engine displacement.

It is important to remember that rolling resistances depend on two characteristics. The rolling resistance factor of the tyre and the vehicle mass. This study only examines the benefits of low rolling resistance tyres and therefore the benefits of reduced vehicle mass in rolling resistances are not taken into account. From now on when referring to CO_2 reductions and costs, the numbers will correspond to the effects caused by changes in rolling resistance coefficient and not the mass of the vehicle.

A short review of relevant literature has revealed the range of the CO_2 reduction potential of energy efficient tyres but also some other interesting issues as well. Table 5.1 summarises the reduction potential retrieved from various bibliographic sources. The first remark that can be made on these data is that there is an evident inconsistency on what is considered low friction tyre. This was expected due to the lack of specific definition of low rolling resistance tyres (LLRT). Two major approaches are distinguished; reduction potential expressed with regard to a certain rolling resistance decrease (usually 10%) or expressed in relation to the generalised idea of a low rolling resistance tyre. It is estimated that the second equals approximately a 20% reduction of the resistance factor. Additionally, a clear difference is observed between older estimates [IEA 1993] and newer ones. This difference reveals the aforementioned technological improvements that were achieved during the last decade. Finally it must be commented that there is no referenced methodology on which these estimates were based. Due to the lack of a predefined protocol, most of them are based either on measurements that were conducted under different conditions or on calculations that adopted different assumptions. Therefore the presented numbers cannot be directly compared. Finally in few cases such as [DLR 2004], the authors state that no important benefit can occur from low LRRT application in the reported fuel consumption and that manufacturers must focus on reducing the rolling resistance through the reduction of the overall vehicle weight.

It is estimated that the use of low rolling resistance tyres decreases type approval measurement fuel consumption by approximately 2% whereas under real world driving conditions this reduction is higher, estimated at approximately 3%. In the review of available data also input from ACEA and BLIC/ETRMA have been taken into account.

Table 5.1 Review of the CO_2 reduction potential through the use of energy efficient tyres

Source:	LAT	IEEP 2004	CARB 2004a	NRDC 2004		Penant 2005	IEA 1993	
Rolling Resistance Factor Decrease	10%	LLRT	10%	20%	LLRT	LLRT	10%	10%
CO2 emissions benefit	1.7%	2%	2%	3-4%	2-6%	3-4%	1.0%	0.5-1%
Notes	Real World estimates			Based on Measurements	Best Case		IEA estimates	Manufacturers estimates

TPMS

In addition to the application of low rolling resistance tyres, tyre pressure monitoring systems should be investigated as well. As mentioned previously deflated tyres present higher rolling resistances and increase vehicle fuel consumption. Coast down measurements conducted by LAT (see Annex F) in the framework of this programme showed that a 0.5 bar reduction of the tyre pressure from the nominal value (20% deflation) resulted in a 10% increase of the tyre friction factor. Qualitative model runs indicate that such an increase results in a 2.5% increase of the fuel consumption over NEDC.

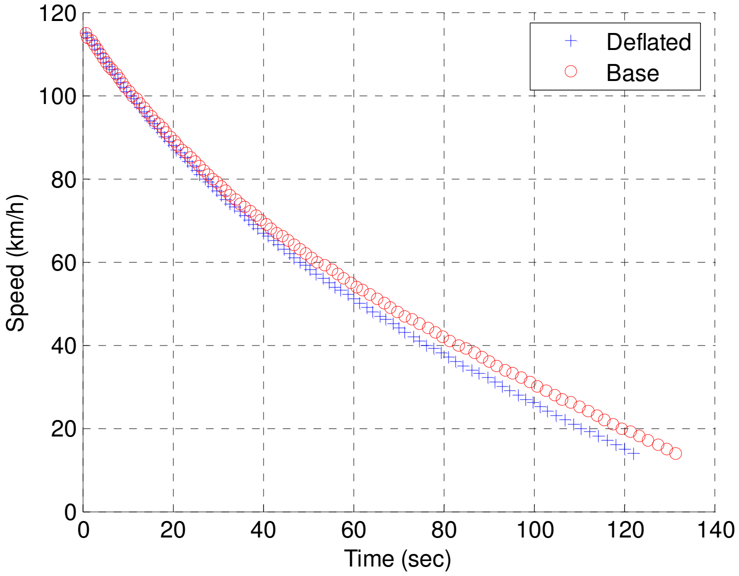

Figure 5.3 Coast down measurements conducted by LAT on test vehicle with different tyre pressures

These numbers that were measured are generally in line with those mentioned in relevant literature [IEA 2005; Hakanen and Jukka] where a 0.4 bar pressure decrease is linked to a 2% increase in fuel consumption and a 30% reduction of the tyre lifespan. A short review of the TPMS potential is presented in Table 5.2.

Table 5.2 TPMS CO$_2$ potential benefit

Source	LAT	Stock 2005	Hakanen and Jukka
TPMS CO2 Benefit Estimates (assuming an avoided 0.5bar deflation)	2.5%	3%	3%

As mentioned in the tyre manufacturers' response to our questionnaire, TPMS are not prerequisite when using low rolling resistance tyres. A characteristic, however, of the measures or the systems that promote proper tyre inflation is that are totally complementary to the low rolling resistance technology. Considering that the majority of the vehicles run constantly on under inflated tyres (70% of all tyres are under inflated on average by 15% [Stock 2005]), it is concluded that a TPMS system is necessary in order to achieve the maximum benefit from any tyre type. A combination of both technologies –TPMS with low rolling resistance tyres- is estimated to improve fuel efficiency in real driving conditions by 4-6%.

- **TPMS do not affect at all type approval measured fuel consumption and CO$_2$ emissions.**

5.3.1.7 CO_2 saving at the vehicle level

It is difficult to come up with an accurate quantification of the CO_2 savings from low rolling resistance tyres and TPMS at vehicle level as no measurement protocols and specifications are currently available. As a result, no consistent data regarding savings per km or per unit of fuel were found in literature. Nevertheless assuming the type approval test as a reference test and average CO_2 emissions over NEDC of 161gCO_2/km (2003 average emissions according to ACEA) then the benefit of low rolling resistance tyre use in the type approval test is estimated to be between 3-6gCO_2/km.

5.3.1.8 Potential scale of application

The tyre market consists of two distinguishable parts, the OEM tyre market and the replacement tyre market. Once a vehicle is sold it is not subjected to the standards that manufacturers must meet in order to be inline with the current emission standard or the requirements of the fuel reduction commitments. The original tyres of the vehicle are replaced approximately 3 years after the sale and the consumer is free to purchase any tyre model available in the market that he finds appropriate. It is estimated that OE tyres represent about 20% of the tyres in use. It becomes clear that a potential large scale application of low rolling resistance tyres by vehicle manufacturers will only ensure fuel consumption improvements over a short period of the vehicle life. Generally, it is agreed that European drivers tend to be loyal to the OE tyre brand but not necessary to the OE tyre model as well so the officially reported energy performance of a vehicle cannot be assured.

On the other hand the fact that tyres are replaced several times during the vehicle lifetime provides the possibility of spreading energy efficient tyre technology throughout the fleet through targeted measures. This fact increases the potential scale of application of low rolling resistance tyres and can be proved to be a very effective measure for quickly reducing transport generated CO_2 emissions. The possibility of adopting measures that will provide incentives to European drivers for purchasing low rolling resistance tyres should be considered by European Commission.

The potential scale of application of TPMS is not as broad as that of energy efficient tyres. Theoretically these systems can be mounted in most existing vehicles but their market is currently developing and some TPMS manufacturers (e.g. Schrader Electronics) are only selling in OE level. Additionally contrary to their low OEM cost TPMS are estimated to be significantly more expensive when retrofitted. In such a case the driver not only burdens the cost of the system but also the labouring for its implementation and additional equipment that might be necessary, factors that can raise the expenses of such systems by an order of magnitude. Therefore the implementation of such systems is expected to remain to the OEMs.

5.3.1.9 Assessment of the potential for EU-25

Due to the complexity of the problem it is difficult to make a detailed assessment of the potential for EU-25. The tyre market and everyday use vary between countries. Indicatively according to Michelin, regulating the maximum allowed rolling resistance of a tyre at OE level, can lead to annual reductions of 3Mt CO_2 / year in the EU. Additionally, the introduction of accurate TPMS on all new vehicles from 2008 can lead to an annual reduction of 3.5-6.5 Mt CO_2 in EU by 2020 [Penant 2005].

5.3.2 Assessment of efficiency

5.3.2.1 Review of available information on costs

Tyres

Contrary to the great amount of information that was found regarding the effect and the potential of LRRT application, few details were retrieved concerning the costs. This is probably due to the fact that tyres are produced by a totally different industry than cars and constitute an autonomous market.

Therefore up to now vehicle analysts did not emphasise much on the issue of tyres. The information presented in Table 5.3 is based on available public literature, but the full analysis is mainly but not exclusively based on the answers tyre manufacturers gave to our questionnaire [BLIC 2005] [ETRMA 2006]. Tyre manufacturers comment that new materials gave great advantages during the last ten years in wet grip and rolling resistance and new approaches are on the way. However, these new materials are more expensive to produce and the processes are not industrialized in short time. LRRTs are also more expensive to design because the balance of all other performances is needed, with no compromise on safety.

Table 5.3 Literature data on costs of low rolling resistance tyres

Source:	IEA 2005	CARB 2004
Price range	50€	17-75€ avg. 46€
Unit	Set of Tyres	Set of Tyres
Remarks	Retail Vehicle Price Increase	Retail Price Estimates

The values supplied by BLIC/ERTMA are largely in line with the data of [IEA 2005] and [CARB 2004], but provide additional detail. It appears that a fair estimation of the incremental cost of low rolling resistance tyres in the vehicle retail price would be about 50€. For the needs of this study a 42€ manufacturer cost increase per tyre set was adopted (60€ retail price increase per tyre set).

TPMS

For the case of TPMS information regarding the costs that is presented was derived mainly from 2 sources, one TPMS manufacturer [Stock 2005] and the NHTSA final ruling on TPMS, as no information was found in other literature sources. This information is summarised in Table 5.4.

Table 5.4 Summary of TPMS costs

TPMS Costs				**Source**
Indirect Systems			Direct	
With 4 channel ABS	Without 4 channel ABS	Without ABS		
7€	7-90€	7-90€	28 €	Stock 2005
10€	21€	100-200€	50-60€	NHTSA 2001

The prices presented above refer to the TPMS cost per vehicle. The specifications of the systems corresponding to these prices are those set within the TREAD act. In short words for a vehicle that is using a direct system (with sensors in each tyre sending a signal to the dashboard) the TPMS does not have to trigger until the tire is 25 percent below the recommended cold psi. An indirect TPMS (that runs off the anti-lock braking system) does not have to trigger until the tyre is 30 percent below the recommended cold psi for that tire. These specifications, introduced for the US market are considered outdated as they allow significant tyre deflation before warning the driver, deflation which limits the fuel economy, shortens the lifespan of the tyre and decreases safety. If TPMS are to be introduced in the European market stricter specifications should be adopted in order to maximise their effect in all aspects mentioned above. A 15-20% deflation should be the maximum limit at which these systems should warn the driver.

As observed in Table 5.4 there are great differences in costs between different TPMS technologies. According to the sources the application of each one of these systems is defined by the vehicle design and manufacturer and not by the requirements of the US legislation. Nonetheless the lower cost systems are sold in greater numbers and it is estimated that these price values will drop even more mainly due to the increased demand in US market.

For indirect systems cost estimation can be made considering the fact that the majority of vehicles are presently sold with 4 channel ABS. Assuming 70% of the vehicles sold (67% in the US according to NHTSA 2001) are equipped with 4 channel ABS and that the vehicles without ABS represent approximately 10% of new registrations, the non 4 channel ABS category (3 channel ABS) represents 20% of the sales. Based on the prices presented above, a fair average cost estimation for near future is 32€/system (70% x 10€ + 20% x 50€ +10% x 150€ = 32€). For this calculation the higher prices from the above mentioned sources were adopted and in case of price ranges the average of the highest price range was used. Assuming a 25% increase in order to make these systems more accurate and reliable so that they will comply with stricter specifications, their price will balance at about 40€.

For direct systems on the other hand things are clearer as they are not depending on other vehicle accessories. In this case the 50-60€ price range presented in NHTSA 2001 (includes sensors, wires, displays etc.) is considered close to the European situation. Hence a fair value for direct systems with relatively stricter specifications is estimated at 65€. Since these systems are more accurate and reliable it is expected that the optimal solution will be to promote their application instead of indirect TPMS. The customer cost is expected to be negative as these systems are cheap, last for the vehicle lifetime and can reduce fuel consumption by 2.5% and increase the tyre lifetime. Assuming real world fuel consumption of 6 l/100km, gasoline, for a lifetime mileage of 200,000 km, TPMS application can save 300 l of fuel.

5.3.3 Overview of impacts and trade offs

5.3.3.1 Environment impact

The application of low rolling resistance tyres is not expected to have any negative environmental impacts. LRRT present similar manufacturing and disposal characteristics as regular tyres and therefore no additional environmental implications are expected by their introduction. At vehicle level, vehicle exhaust pollutant emissions are not affected from the use of LRRT. A small reduction in the engine load can be expected through their application, but this can cause no side-effect in the exhaust emissions.

TPMS are not expected to have any negative impacts on environment and do not affect vehicle pollutant emissions.

5.3.3.2 Economic and social impacts

On economic and social level the application of LRRT and TPMS are expected to have important benefits. The benefits are not limited to the environmental friendlier, more sustainable character of these technologies. These systems increase fuel savings and thus reduce the increasing demand in fuel and help towards achieving security of supply at societal level. At customer level the fuel savings that the combined use of these two systems provide can compensate for their initial purchasing costs and offer relief from future increases in the fuel prices.

In addition TPMS are beneficial for the tyre lifespan which has positive impacts both on customers from replacement tyre savings as well as to society which reduces the amount of waste rubber that needs to be treated.

Finally it must be stressed out that above all TPMS have an **important positive effect on vehicle safety**. Their compulsory introduction in the US market was based mainly on the advantages TPMS present in safety issues.

5.3.3.3 Trade-offs

There are at least 10 different tyre characteristics that affect the tyre performance and at which tyre manufacturers aim when introducing new tyre technology. The most important amongst them are tread wear, wet traction, rolling resistance and noise. In the response to our questionnaire tyre industry states that OEMs define tyre specifications the tyre suppliers must comply with. These specifications include rolling resistance as well as many more performances, such as noise, comfort, wet grip, road handling, price et., and it is the decision of the different vehicle manufacturers how to set the priorities. Tyre industry is also bound by contract not to reveal details about OE tyre sales. From the above it concluded that OE low rolling resistance tyres comply with the vehicle manufacturer criteria and so no significant trade-off in their other characteristics should be expected. In Figure 5.4 a comparison between 3 different tyre types is made considering all important tyre characteristics. The trade-offs observed are characterised as minor.

At this point it should be noted that due to lack of information in the market, consumers are not aware about the LRRT characteristics. Therefore there are various misbelieves such as that LRRT lack in safety or have lower lifespan. It is due to this problem that tyre industry suggests not to use the term 'low friction' when referring to low rolling resistance tyres, although it's technically correct, as it may lead to misunderstandings regarding a tyre's traction. According to the manufacturers the first priority when introducing new tyre technologies is that any advance is not occurring on the expense of passenger safety [BLIC 2005]. Experts claim that tyres that perform well in wet braking can also be of low rolling resistance. Additionally, tyres of good wear performance can be also of low rolling resistance [Aimon 2005] [Friedrich]. According to the manufacturers the LRRT models that are currently in the market do not lack any of the characteristics or the performance of regular tyres, do not need any special attention and have the same weight as standard tyres [BLIC 2005] [ETRMA 2006]. It is therefore concluded that there are no trade-offs between low rolling resistance and other important tyre characteristics.

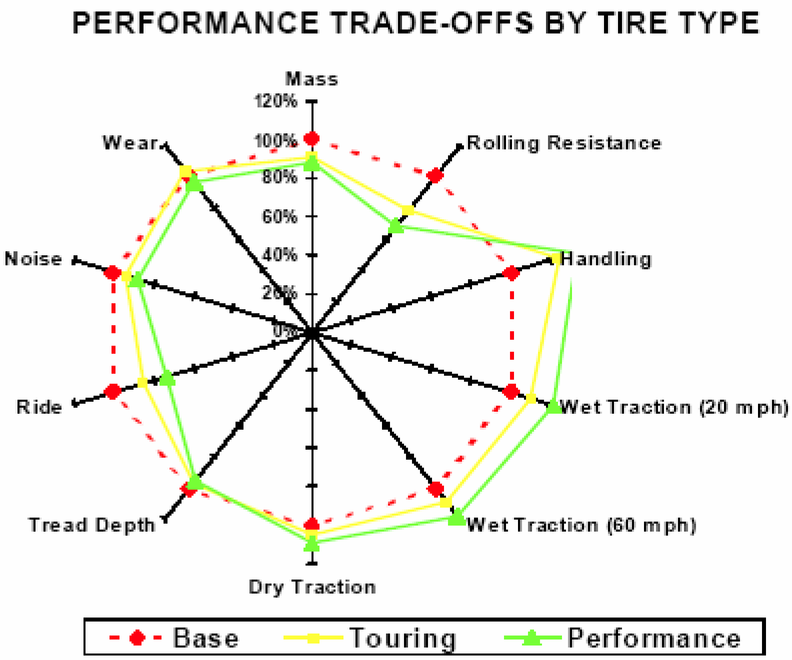

Figure 5.4 Key tyre characteristics and their variations between different tyre types [Duleep 2005]

5.3.4 Policy measures suitable for implementation of LRRT and TPMS

5.3.4.1 Basis of implementation

This review of the current status in low rolling resistant tyre and TPMS markets revealed some basic issues that need to be addressed before proceeding on to any kind of policy measures regarding these technologies. The first and most important issue is that of the definition and the standardisation of TPMS and LRRT. As mentioned before, currently there is no legislative definition of low rolling resistance as well as no official standard regarding a tyre's maximum rolling resistance. A first step in this direction would be to set a maximum value of a tyre's allowed rolling resistance. This is a measure that will stimulate the effort of all manufacturers to provide more energy efficient tyres and will heat up research on tyre efficiency. Moreover a mandatory maximum rolling resistance standard can provide the necessary reference for a definition of low rolling resistance as a percentage of the legislated maximum value (i.e. the maximum limit of the resistance value of a LRRT must be at least 20-30% lower than maximum legislated resistance value). Similar work should be done in the case of TPMS were there is no minimum standardised performance. A minimum performance standard for TPMS could be for example a driver warn of an under inflated tyre or tyres if the pressure remains below a certain level (e.g. 80% of nominal) for some minutes. Through such standardisations the TPMS will be able to provide their maximum potential.

In addition to the actions mentioned above there should be a clarification of the measurement procedures that will be used for measuring tyre rolling resistance. Currently, several methods of measuring rolling resistance exist and are necessary to meet different needs, such as for predicting actual on-road performance and as inputs to complex simulations. However, a single test method for compliance would be attractive to manufacturers, regulatory agencies, and consumers.

5.3.4.2 Policy instruments

Both tyres and TPMS are produced by industries independent from the car manufacturers. Therefore a set of measures for promoting these systems can be adopted by European Union without intervening with the existing policies and agreements signed with the automakers. In fact, as presented in the text the margin of CO$_2$ benefit from LRRT from car manufacturers hardly exceeds 2% and for TPMS is zero (NEDC basis). What needs to be assured is that current gaps in legislation won't allow car manufacturers to present emissions reductions that are not real. For instance, for the purpose of the fuel consumption test, it is possible that since not all model variants are tested, the manufacturer will choose to test the model with the most favourable tyres for fuel consumption. As a consequence the manufacturers may equip type approval variants with low rolling resistance tyres in order to benefit from them and then use standard tyres with other variants or models that reach the market. Measuring experience at LAT reveals that a significant percentage of vehicle models are type approved using a relatively low rolling resistance factor (about 0.009) compared to the 0.011 - 0.012 estimated average rolling resistance factor. It is difficult to avoid such phenomena as under the existing legislative framework, where not all model variants are tested, it is possible that the manufacturer will choose to test the model with the most favourable tyres for fuel consumption. Furthermore it is useless to expect that under these conditions the manufacturers will accept to shoulder the additional cost of replacing all OE tyres with low rolling resistance tyres and provide TPMS as standard equipment when it offers them no economic or marketing advantage.

The main policy instruments that can be adopted in due time for increasing the market share of LRRT and promote the application of TPMS are summarised below.

- Labelling. The first measure to be taken for supporting the introduction of fuel efficient tyres in the market, mentioned almost in all relevant literature, is tyre labelling. Tyre labelling will ensure that the customer has access to information regarding the product's energy performance. Such labelling efforts were applied in other products such as refrigerators or washing machines and have successfully supported the market introduction of product models that were less cheap but more energy efficient. Some of the EU countries are already working on LRRT labelling (application of the Nordic Swan for low rolling resistance and noise). Tyre labelling can be incorporated to the existing product labelling programme in European Union. Tyre industry is in favour of the creation of a "tyre RR evaluation system" defined and made available to the consumer on the internet and at tyre points of sale [ETRMA 2006]

- Purchase incentive programme. An important and very effective measure to reduce the vehicle rolling resistance of the whole fleet and not only of new vehicles should target replacement tyres as they represent the majority of the tyres. As presented in the text above with current oil and LRRT prices the cost for the driver to purchase LRRT is close to zero and in certain cases negative. Through the adoption of a purchase incentive program a faster introduction of LRRT to can be accelerated as the drivers are going to have a motive for moving towards this solution. The cost for the state in this case is expected to be fairly low and will be compensated by the advantages of CO_2 emissions reduction.
- Legislation update – manufacturer incentives. As presented currently the legislated measurement methodology for type approval allows the use of LRRT only for the test regardless of the final setup of the vehicle sold and cannot simulate at all the effect of TPMS. As a result, there is no pressure on the tyre industry to promote the wider application of such solutions. Furthermore due to the existing situation these technologies and their effect should not be accounted in the CO_2 reduction commitments without first amending the existing legislation for type approval, in order to avoid important double-counting. However amending the legislation in order to put pressure on the car industry might prove a time consuming and ineffective approach. Providing incentives to the manufacturers that aim at the promotion of these technologies might result in a quicker and broader application in the target period 2008-2012.
- Dealer - Driver education. Educating drivers as well as car and tyre retailers is another important measure. Most consumers are not aware of the benefits TPMS and LRRT have. The majority of the tyres are purchased by drivers from retailers that are not connected with the original manufacturers of the vehicle. Only few drivers are informed about the tyre characteristics and how much they can be benefit from an efficient, properly inflated and maintained tyre. On the other hand retailers should be educated and be informed on the recent developments on tyre technology in order to help consumers make their choice based on real facts and not market rumours. Media outlets and publications can substantially support these measures.
- Tyre performance testing. The introduction of tyre performance tests that will include not only rolling resistance but other characteristics as well can provide a baseline for comparison and guidance for consumers. Such testing schemes have already been initiated in the US. These tests can be performed by independent organisations to a representative number of tyre models that will reflect the current tyre market situation.
- TPMS performance standard. The adoption of a performance standard for TPMS is essential in order to advance to the wider application of such systems and to support any relevant legislative measure.
- Creation of a database with tyre efficiency data. Up to now the information available to consumers regarding the energy efficiency of tyres as well as their other attributes is only provided by manufacturers. Each tyre manufacturer decides which characteristics of his product will emphasise and which will omit. Therefore tyre manufacturers present tyre data that are not always comparable and even comprehensible by the average public. The creation of a database that will be available to the public, similar to those that already exist for vehicles (VCA, KBA etc.) in several European countries, will provide a very useful tool for

encouraging public debate and analysis on tyre efficiency. Such databases will support not only customer choices but also various academic and private research activities.

The authors believe that apart from measures that are directly connected with the type approval procedure and the official test protocol (possible changes in the coast down curve calculation or rolling resistance table values, obligation to use set of tyres with the same rolling resistance in all vehicles covered by the type approval) no other policy that is to be implemented regarding rolling resistances should be incorporated in the car manufacturers commitments to reduce average CO_2 emissions.

5.3.4.3 Calculation of CO_2-abatement costs

For the purposes of this study and the needs of future scenario calculations it is necessary to calculate realistic values of CO_2-abatement costs for the near future. Based on qualified assumptions regarding the reduction potential and the costs of LRRT and TPMS and the data presented in the text above, 4 different cases were examined (same for LRRT and TPMS) with respect to different oil prices (0.21, 0.30, 0.41 and 0.60 €/l of fuel) and annual fuel costs.

For LRRT an average 3% improvement in fuel consumption was considered at a manufacturer cost increase of 42€ (60€ retail price increase) whereas for TPMS an average 2.5% fuel economy was considered at a manufacturer incremental cost of 50€. These prices were multiplied by a factor of 1.16 in order to account for investment costs.

Note that at this point the potential gain from retrofit systems is not considered in this analysis as the main goal is to obtain a picture of the cost and the implementation strategy in order to achieve the 120gCO_2/km target for newly registered vehicles.

Another issue that should be mentioned is that of the use of LRRT by the manufacturers for type approval. Manufacturers are allowed to use different tyres in the type approval test than those sold with the vehicle. This may cause a double counting of the LRRT effect which already affects the reported emissions. Nevertheless this situation cannot be modelled and thus for this analysis it is assumed that the OE tyres are the same with those used for type approval, and that the measures to be taken will deal with this inconsistency of the legislation.

Table 5.5 CO_2-abatement cost estimation for low rolling resistance tyres

Case	Base case	Case 1	Case2	Case 3	Case 4	
Additional manufacturer costs	0	42	42	42	42	€/vehicle
investment costs[25]	0	49	49	49	49	€/vehicle
CO_2-reduction	0.0%	3.0%	3.0%	3.0%	3.0%	
NEDC CO_2-emission	140	136	136	136	136	g/km
RW CO_2-emission	167	162	162	162	162	gCO_2/km
WTW CO_2-emission	198	192	192	192	192	gCO_2/km
Base fuel consumption	0.067	0.065	0.065	0.065	0.065	l/km
Yearly mileage	16000	16000	16000	16000	16000	Km
Yearly CO_2 emission TTW	2.68	2.60	2.60	2.60	2.60	tonne
Yearly CO_2 emission WTW	3.17	3.07	3.07	3.07	3.07	tonne

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[25] Retail price minus taxes

Yearly CO_2 savings WTW	0.00	0.09	0.09	0.09	0.09	tonne
Fuel price	0.21/0.3/ 0.4/0.6	0.21	0.30	0.40	0.60	€/l
Yearly fuel costs	226/323/ 431/646	219	313	418	626	€
Yearly fuel cost savings		7	10	13	19	€
Vehicle lifetime	2.5	2.5	2.5	2.5	2.5	Years
Interest rate	4.0%	4.0%	4.0%	4.0%	4.0%	
NPV of add. fuel costs	0.00	-16	-23	-31	-45	€
CO_2 abatement costs		139	109	73	15	€/tonne

As presented in Table 5.5 the CO_2-abatement costs for LRRT are 139€/tonne CO_2 for a 0.21 €/l fuel price and approximately 15€/tonne for a 0.61€/l fuel price for a 2.5 years tyre lifetime (40,000km). The fact that tyres are replaced several times throughout the vehicle lifetime makes it difficult to define who and how shoulders the additional costs of low rolling resistance technology. It can be expected that the initial costs will be covered by vehicle manufacturers because through the use of low rolling resistance tyres the vehicle energy performance is improved and the vehicle gains competitive advantage. Furthermore the use of low rolling resistance tyres can help tyre manufacturers approach their commitment for reducing CO_2 emissions to 140gCO_2/km in 2008. A 3% improvement in fuel consumption that can be achieved through the use of LRRT corresponds to more than one year's reduction efforts based on the commitment monitoring results published by ACEA and EC. Such an approach obviously does not take into consideration the fact that several car manufacturers might already use LRRT for type approval tests. In addition the option of sharing the cost between tyre industry and car industry can be examined. However the fact that there are no legislated measures regarding tyre energy performance (e.g. maximum rolling resistance coefficient value) relieves the pressures from tyre industry to work towards improved tyres quickly and thus makes such a compromise difficult. Nevertheless, tyre industry clearly states its intentions to promote energy efficient tyres and claims that is in favour of all possible improvements to make road transportation more sustainable and favourable to the environment, taking into account the three pillars of sustainable development (environment, social-safety and economic impact).

On the other hand, replacement tyres represent approximately the 4/5 of the tyre market. Vehicle manufacturers play no role in this market apart from the influence OE tyres might have on the future tyre choices of the driver. Therefore the incremental cost of advanced tyres will burden drivers or retailers. The cost estimates of around 50€ per set by various sources are considered as a modest estimation and were made probably before the recent rise in oil prices. A more optimistic approach might also lead to negative cost meaning that a driver may also have a small profit from the fuel savings by using LRRTs. The European Commission should examine in more detail the issue of replacement tyre market and the adoption of incentives for LRRTs purchasing. Otherwise there is a risk of widening the gap between real world (actual emissions) and the reported type approval CO_2 emissions.

For the TPMS solutions facts are quite different. Presently these systems are mostly fitted at OE level and their price is much lower than that of LRRT while their benefit lasts for lifetime and is strengthened by the reduction of tyre wear and safety improvements. It is estimated that CO_2-abatement costs of TPMS are negative in for all scenarios except the 0.21€/l one. The gains of TPMS application are not reflected in the type approval test which means that vehicle manufacturers are not benefited for introducing them. Therefore the relatively low costs of TPMS should burden the vehicle buyer while a possible state support through fiscal or other incentives can help the faster application of these technologies.

Table 5.6 CO_2-abatement cost estimation for TPMS

Case	Base Case	Case 1	Case2	Case 3	Case 4	
Additional manufacturer costs	0	50	50	50	50	€/vehicle
investment costs[26]	0	58	58	58	58	€/vehicle
CO_2-reduction	0.0%	2.5%	2.5%	2.5%	2.5%	
NEDC CO_2-emission	140	136	136	136	136	g/km
RW CO_2-emission	167	162	162	162	162	gCO_2/km
WTW CO_2-emission	198	192	192	192	192	gCO_2/km
Base fuel consumption	0.067	0.065	0.065	0.065	0.065	l/km
Yearly mileage	16000	16000	16000	16000	16000	Km
Yearly CO_2 emission TTW	2.68	2.60	2.60	2.60	2.60	tonne
Yearly CO_2 emission WTW	3.17	3.07	3.07	3.07	3.07	tonne
Yearly CO_2 savings WTW	0.00	0.09	0.09	0.09	0.09	tonne
Fuel price	0.21/0.3/ 0.4/0.6	0.21	0.30	0.40	0.60	€/l
Yearly fuel costs	226/323/ 431/646	220	315	420	630	€
Yearly fuel cost savings	646	6	8	11	16	€
Vehicle lifetime		12	12	12	12	Years
Interest rate	12	4.0%	4.0%	4.0%	4.0%	
NPV of add. fuel costs	4.0%	-53	-77	-106	-152	€
CO_2-abatement costs	0.00	5	-20	-50	-98	€/tonne

The above assessment for TPMS assumes that the user of the vehicle appropriately responds to the signals provided by the TPMS. This may certainly be expected when the TPMS is bought as an accessory, but as soon as TPMS becomes a standard auxiliary it seems likely that not all users will inflate their tyres when the TPMS reports underpressure. This poses a problem in terms of monitorability for policies aiming to promote the application of TPMS.

5.4 Review of options to reduce engine resistance factors

5.4.1 Engine friction and lubricants general

In the following paragraphs the effect of engine friction on CO_2 emissions will be studied. As it will be presented, friction in engine parts accounts for an important share of the engine resistances and causes additional fuel consumption. The resistances that appear due to engine friction are determined mainly by the engine design and the lubricant used. In order to improve fuel efficiency, car manufacturers have redesigned certain engine components and use more sophisticated materials. In addition, oil industry in collaboration with engine manufacturers has produced lubricants that reduce engine friction. Use of these oils instead of conventional ones, is assumed to decrease fuel consumption by reducing the friction in the engine. Therefore the most competent technology for reducing engine friction, apart from engine redesign, that will be studied here is low viscosity lubricants (LVL).

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[26] Retail price minus taxes.

5.4.1.1 Engine Friction

Friction appears in all moving parts of the vehicle where there is contact between different surfaces. Inside an internal combustion engine work is dissipated in overcoming the friction due to relative motion of adjacent components within the engine, or to drive the engine accessories such as pumps, fans, generators etc. The first is called rubbing friction work and the second accessory work [Heywood 1988]. For simplicity purposes these two different kinds of energy losses usually are measured as one and referred to as friction losses. This study focuses only at the effect of rubbing friction work and how it can be reduced in order to improve fuel consumption.

Two characteristic conditions of friction can be identified during engine operation, boundary friction and hydrodynamic or viscous friction. The boundary friction between two surfaces in relative motion is determined by surface properties as well as by lubricant properties. Important surface properties are roughness, plasticity, shearing strength and thermal conductivity whereas the lubricant properties are mainly chemical ones which govern the ability of lubricant molecules to attach on surfaces. Hydrodynamic friction occurs when the shape and relative motion of the surfaces form a liquid film in which the pressure is adequate to keep surfaces separated. Hydrodynamic friction is not affected by the surface properties but only from the lubricant's viscosity as resistances to motion occur only from the shear forces in the liquid film and not from the interaction of the surfaces. [Heywood 1998]. Both types of friction appear inside the engine in different parts or under different conditions. There are also cases where a mixed state of friction appears.

A common model used for expressing total rubbing friction work W_f inside the engine takes into account two factors: an engine speed dependent factor C_h which represents the effect of hydrodynamic friction and a constant factor C_b which expresses the effects of boundary friction. These factors are defined by the properties of the surface and the lubricant as mentioned in the previous paragraph.

$$W_f = C_h \text{ x } N + C_b$$

N : Engine speed (RPM)
C_h : Hydrodynamic friction factor
C_b : Boundary friction factor

It becomes clear from the above that friction losses are directly proportional to the engine speed. This is important as it reveals that a first approach towards lowering friction losses and thus saving fuel is driving at the least possible engine RPM or else quickly change to higher gear. Measurements conducted in the past by LAT confirm this linear relationship as presented in Figure 5.5. The values of Figure 5.5 are derived from measurements on a 67kW, 1.9 TDi Diesel engine, a quite typical representative of its class. It is observed that at higher engine speeds friction losses can exceed 15% of the engine's rated power.

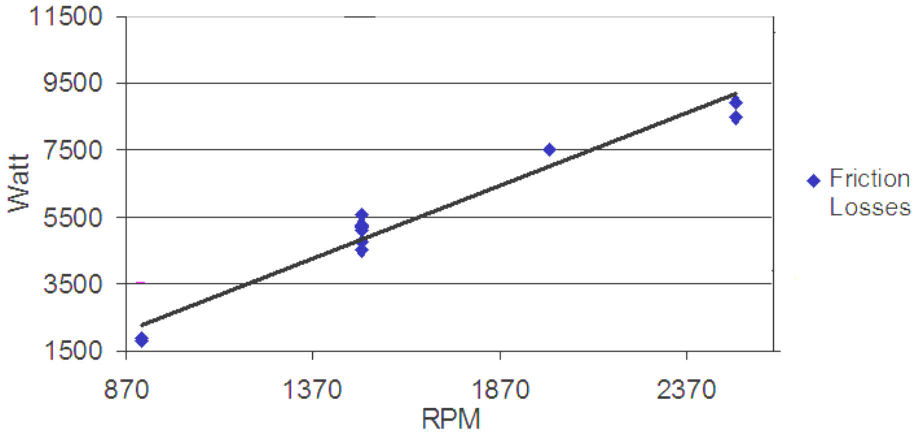

Figure 5.5 LAT measurements on engine friction losses

Another engine characteristic that affects engine friction losses is cylinder geometry. Generally it can be said that engine losses are reversely proportional to the cylinder diameter. As a result between two engines with the same output characteristics and capacity, the one that has fewer cylinders is expected to present less friction losses.

5.4.1.2 Engine Lubricants

Lubricants reduce friction and wear of critical vehicle systems such as the engine, transmission and drive train. Without lubricants, the moving parts inside these systems would grind together causing heat, stress and wear. Engine oils serve several functions, including reducing friction, cooling the engine, limiting wear on the moving parts of the engine, and protecting against corrosion. Amongst these functions it is primarily their effect on friction that impacts on fuel economy. Engine oils reduce friction in two ways. The first is by affecting the aforementioned hydrodynamic friction value which is reduced as oil separates opposing metal surfaces to prevent contact (*hydrodynamic lubrication*). Additionally lubricant properties and friction-modifying additives act on metal surfaces for reducing friction forces where and when metal-to-metal contact exists (*boundary lubrication*).

Oil viscosity is the most important factor influencing friction. Conventional mineral oil lubricants may have too high viscosity to effectively slip between and lubricate the moving parts of various vehicle systems, particularly in newer truck components that are designed with close tolerances and tight fits [IEA 2005]. Additionally, high viscous conventional oils can make it harder for pumps, gears and shafts to move. These effects create energy losses and friction losses, and waste fuel.

There are various specifications for lubricants introduced by different organisations, the most common of which are the ACEA test procedure, the API (American Petroleum Institute) classification, SAE viscosity grades and other specifications introduced by individual manufacturers. Amongst the approval criteria of these tests are wear protection properties, combustion residue, engine type, sulphate-ash content and others. With regard to their viscosity, engine oils are categorized based on the SAE viscosity grades. Two series are employed for the designation of the oil viscosity such as 5W-30 or 10W-30. In the case of 5W-30 as an example, 5W refers to fluidity when cold (W = winter grade). The lower the number, the more fluid the oil at low temperatures, making cold starts easier. The 30 refers to fluidity when hot. The higher the number, the more viscous the oil at high temperatures and the better it protects when hot. A second method of classifying oils is mineral versus synthetic. In literature [IEA 2005] it is mentioned that lubricant manufacturer claim that synthetic oils offer more durability, but no specific claims are made about fuel economy. Hence, synthetic and mineral oil of the same grade may not have significantly different effects on fuel economy, but the oil drain interval may be different.

5.4.1.3 Fuel efficient lubricants

In order to qualify a lubricant as a “fuel economy” oil, both the American Petroleum Institute (API) and ACEA have developed engine tests that measure the fuel consumption of candidate oils relative to reference oils, and the Effective Fuel Economy Increase (EFEI) of the candidate oils has to be better than that of the reference oil by some pre-defined limit in order to claim the oil is fuel efficient [Taylor and Coy]. In Europe, a fuel economy test has been developed using a Mercedes Benz M111 2.0 litre engine. The minimum improvement required when measured in the MIII European fuel economy test engine in order to qualify a low friction, low viscosity, and low HTHS (high temperature high shear) viscosity engine lubricant is 2.5%. Such measurements are made against a conventional lubricant that has not been formulated with friction modifier to reduce frictional losses , is of higher viscosity grading and with a higher HTHS viscosity [ATIEL 2006]. Generally in Europe, the emphasis in lubricant development has been given on durability and not efficiency, since very high speed driving occurs in certain European countries.

5.4.1.4 Impact of engine lubricants on CO_2 emissions – NEDC and real world

As explained the viscosity and up to some point the additives of a lubricant affect engine friction and the losses caused by it. Lowering the viscosity of the lubricant may reduce friction losses and improve a vehicle's energy performance. This effect will appear both in test cycles and real world driving as it is directly linked to the engine operation. Nevertheless, as mentioned above, a lubricant differentiates its properties under different operating conditions. As a result a lubricant may present better friction reduction properties under different temperatures. A rule of thumb in this case is that the lower temperature gets, the thicker lubricants become and higher friction losses appear. So the reduction potential of advanced lubricants increases. However, NEDC is conducted under standard temperature of 20EC which does not examine the lubricant's performance in lower ambient temperatures which are quite common throughout the year in Europe. Furthermore, the speed profile of test cycles results in a very mild engine operation profile that does not allow high engine speeds. Low engine speeds correspond to reduced engine friction and losses. In real driving conditions, the style of each driver can cause significant divergences in engine friction losses compared to those of the type approval test and in this way decrease or most probably increase the vehicle fuel consumption. Friction reductions that are achieved through better design of the engine are expected to have a uniform effect on the test cycle and real world driving.

5.4.1.5 Present status of application

In its 2005 report on car fuel efficiency, IEA gives a short description of the evolutions in engine lubricant market during the past 20 years [IEA 2005]. In recent years, the viscosity of engine oils has fallen significantly. In the 1970s and 1980s the most commonly used grades were SAE 10W-40 and 15W-40. These oils were gradually replaced by SAE 10W-30 and 5W-30 in light-duty engines during the 1980s. Today, the most commonly used factory fill oil in car and light-duty truck engines in all OECD countries is 5W-30, although some fraction of consumers continues to use 10W-30 or 10W-40 oil when the oil is changed. More recently, 5W-20 and 0W-20 oils have appeared in the market. 5W-20 oils are now used in many popular cars such as most model year 2000+ Honda cars and most Ford 2001+ vehicles as factory fill oil, while 0W-20 currently is used only in the new Honda Insight hybrid vehicle. Several major auto-manufacturers concede that, 5W-20 oil should be adequate for most modern (post-1995) cars and light trucks, but most manufacturers do not recommend it officially. However, manufacturers specifically cautioned against the use of 5W-20 oils in some high performance vehicles, vehicles subjected to heavy loads or trailer towing, and in very hot ambient conditions.

5.4.2 Assessment of effectiveness for CO$_2$ emission reduction

5.4.2.1 Theoretical potential for CO$_2$ reduction through improved engine friction

As presented in Figure 5.6, engine friction accounts for a large part of the vehicle energy consumption and therefore for CO$_2$ emissions. More sophisticated engine design, mass reduction, adoption of new materials and the use of lubricants with low viscosity can improve the energy performance of the vehicle and CO$_2$ emissions. The improvement is determined by many factors such as engine design, ambient conditions and the lubricant properties. Because of these reasons it is difficult to define a single relation that will link engine design and LVL properties to fuel savings. Instead it would be more accurate to speak about a range of CO$_2$ emissions reduction through the use of LVL and engine optimisation. Generally, this range stands between 1% and 4%. It is expected that these percentages are not significantly affected by engine type (Petrol or Diesel) and size.

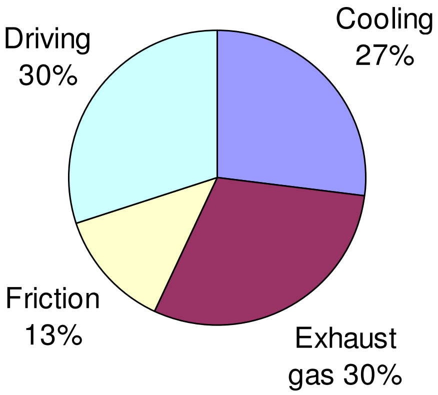

Figure 5.6 Energy distribution during engine operation (Fuel energy = 100%)

A short review of relevant literature has revealed a range of CO$_2$ reduction potentials for improved engine friction and LVL. Table 5.7 summarises the reduction potential retrieved from various bibliographic sources. The first remark that can be made on these data is that in some sources there is no distinction between the effect of LVL and a general reduction of friction that can be achieved through engine redesign and advanced materials. For the following analysis and the scenarios that will be assessed here only the effect of LVL will be considered in order to avoid possible double-counting of the engine improvement effect. Secondly, a clear difference is observed between older estimates [IEA 1993] and [NRC 1992] and newer ones. This difference reveals the aforementioned improvements in lubricant technology that were achieved during the last decade. Finally it must be commented that there is no single referenced methodology on which these estimates were based.

It is estimated that the engine design improvements have the same impact on both test cycles and real world driving, which can lead to approximately 2% reductions in fuel consumption. The LVL effect on the NEDC is estimated at 1.5% percentage, which is expected to increase in real world driving conditions reaching a value of approximately 2.5%. In this assessment also input data provided by ACEA and ATIEL have been taken into account.

Table 5.7 Review of lower engine friction CO_2 reduction potential

Source:	IEA 2005	ECOS 2005	CURTOIS LOPES	US EPA	IEA 1993	IEA 1993	NRC 1992	NRC 1992
CO_2 emissions benefit	1-3.5%	2-4%	~3%	0.5-3%	0.5-1.4%	0.5%	2%	0.5%
Technology Considered	Lubricant	Lubricant	Lubricant	Lubricant	Engine Friction	Lubricant	Engine Friction	Lubricant

5.4.2.2 CO_2 saving at the vehicle level

Based on the data presented in Table 5.7 and input data provided by ACEA and ATIEL the lubricant friction reduction effect on fuel consumption and CO_2 emissions is estimated to be approximately 2.5%. If we assume the type approval test as reference then a first quantification of the CO_2 reductions at the vehicle level can be made. Based on the average CO_2 emissions value of 161 gCO_2/km reported in the 2003 ACEA commitment monitoring report, the benefit of reducing engine friction resistances over the type approval test is estimated to be around 4 gCO_2/km.

5.4.2.3 Potential scale of application

Similarly to tyres, the majority of lubricant market concerns replacement lubricants and not the ones provided by the vehicle manufacturer. In other words the lubricant market is up to a point independent from the car industry. However, contrary to the tyre case, the issue of the manufacturer recommended oil is important because the car warranty only holds as long as the recommended maintenance procedures are followed, and this includes using the recommended oil. This bond between lubricant and engine manufacturer is noted in ATIEL's response to the questionnaire: **"The type of engine lubricant is usually defined by the vehicle manufacturer since they are usually the engine manufacturer"**. Under these conditions drivers tend to use the original oil until the warranty is over. Manufacturers are not explicit in disallowing the use of other oil grades, but are also not explicit about the issue of warranty continuation Lack of hard data on aftermarket oil purchase by consumers makes it difficult to estimate the benefits of mandatory use of 5W-20 oil where required. Although it is likely that 5W-20 oil is used during oil change for a significant fraction of cars where it is the factory fill oil, sales of 5W-30 oil and 10W-30 (even 10W-40) oil is still quite large, according to industry sources. However, oil changes may be preformed in a variety of locations and affecting oil choice may not be easy [IEA 2005].

The vehicle lubricant is replaced on average every 10,000 kilometres. **The consumer is free to purchase any lubricant available in the market that fulfils the engine requirements specified**. It becomes clear that a potential large scale application of LVL by vehicle manufacturers will only ensure fuel consumption improvements over a short period of the vehicle life (up to one and a half year from the purchasing date). As a result, a rapid introduction of more energy efficient lubricants is possible in short time, not only in newly registered vehicles but in older ones as well. However as stated previously European drivers tend to be loyal to the OE lubricant and are highly influenced by the warranty and manufacturer recommendations. Therefore, in order to support the widespread of such solutions it is necessary to adopt measures that will ensure the validity of the engine warrantee and inform the customers about their benefits. The possibility of adopting measures that will provide incentives to European drivers for purchasing LVL should be seriously considered by European Union.

5.4.3 Assessment of efficiency

5.4.3.1 *Review of available information on costs*

Few data are available in the reviewed literature regarding the cost of low engine friction technologies. Therefore the assessment presented here regarding costs is strongly based on ACEA's response to our questionnaire [ACEA 2005] and estimations that were conducted by LAT based on lubricant prices from retailer internet sites (see Table 5.8). Data provided by ACEA refer generally to engine friction reduction manufacturers' costs –including LVL application as well. The lubricant industry provided no data regarding costs [ATIEL 2006].

Table 5.8 Additional costs of reduced friction technologies

Source:	LAT Estimates
Price Range	25-50%
Unit	Consumer Incremental Cost
Technology Considered	Lubricant

Based on LAT estimations an average 50% incremental cost for 1 litre of lubricant translates in approximately 5€. Depending on the vehicle engine size this can result from 15 to 25€ extra costs for a complete engine oil replacement. Nevertheless considering a modest real world efficiency improvement of 2.5% over 15000km at 6l/100km fuel consumption, the fuel savings are calculated at 22.5lt of fuel, which can almost zero the additional expenses.

5.4.4 Overview of impacts and trade offs

5.4.4.1 *Environment impact*

The application of technologies to reduce engine friction is not expected to have any negative environmental impacts. At vehicle level, synthetic oils are in some cases reported to present lower emissions compared to mineral ones [ECOS 2005]. Nevertheless, with new emission standards limiting the permissible emissions to very low levels, no significant effect on the vehicle exhaust emissions is expected from the use of low viscosity lubricants provided that the engine is designed to operate with oils of such specifications. A small reduction in the engine load can be expected through their application, but this can cause no side-effect in the exhaust emissions.

5.4.4.2 *Economic and social impacts*

On economic and social level the application of low engine friction technologies is expected to have benefits. The benefits are not limited to the environmental friendlier, more sustainable character of these technologies. These systems increase fuel savings and thus reduce the increasing demand in fuel and help towards achieving security of supply at societal level. At customer level the fuel savings that the use of LVL provide can compensate for their initial purchasing costs and offer relief from future increases in the fuel prices.

5.4.4.3 *Trade-offs*

Lubricant oils that are supplied by oil manufacturers are inline with the standards regarding their lubricating ability and other important properties –oxidative and thermal stability, low temperature performance. Therefore, provided that the oil used and the vehicle engine is inline with regard to their operating standards, no significant trade-offs should be expected. In addition some manufacturers claim that certain LVL tend to present enhanced properties, such as oxidative stability, compared to the regular mineral lubricants [ECOS 2005].

5.4.5 Policy measures suitable for implementation of engine friction reduction technologies

5.4.5.1 Policy instruments

Lubricants are produced by the oil industry in close cooperation with engine manufacturers. As a result lubricant market is theoretically independent from car industry but strongly influenced by it. This is an important characteristic that should be taken under consideration before any effort or measure to support these technologies is decided. Any policy aiming at the reduction of engine friction should focus both on the engine design and production process and the lubricant aftermarket as well.

The main policy instruments that can be adopted in due time for increasing the market share of LVL are similar to those proposed for energy efficient tyres and are summarised below:

- Warranty limitations. The first and most important issue for any policy is to ensure that the drivers will be able to use any lubricant corresponding to the engine specifications without risking the validity of the engine warranty.
- Purchase incentive programme. An important and very effective measure to reduce the engine friction of the whole fleet and not only of new vehicles should target replacement lubricants. As presented, with current lubricant and fuel prices the net cost for purchasing LVL is close to zero. Through the adoption of a purchase incentive program a faster introduction of LVL will be achieved as the drivers are going to have a stronger motive for moving towards this solution. The cost for the state in this case is expected to be fairly low and will be compensated by the advantages of CO_2 emissions reduction.
- Creation of a database with engine and lubricant data. Such a database will help drivers decide which lubricant available is the most efficient for their vehicle. Such a measure can be combined with a wider effort to inform drivers about what is the best solution according to their individual needs. For example most drivers are unaware about other factors that should be considered when purchasing a lubricant such as climate and vehicle use.
- Labelling programme. Combined with a broader customer support scheme (database etc), labelling could be applied for LVL in order to support the market of more efficient lubricants.

In parallel to the actions described here measures that will stimulate a further development in engine and lubricant technology are of significant importance.

5.4.5.2 Calculation of CO_2-abatement costs

A thorough approach towards setting targets for engine friction reduction and LVL introduction would require much more information and collaboration with industry. However for the purposes of this study and the needs of future scenario calculations it is necessary to calculate realistic values of CO_2-abatement costs for the near future. Based on qualified assumptions regarding the reduction potential and the costs of LVL and the data presented in the text above, 4 different cases were examined with respect to different oil prices (0.21, 0.3, 0.4 and 0.6 €/l of fuel) and annual fuel costs.

For LVL an average 2.5% improvement in fuel consumption was considered at a retail price increase of 25€. This retail price was divided by a factor of approximately 1.45 (set at 17€) in order to account for manufacturer costs.

Note that at this point the potential gain from replacements lubricants is not considered in this analysis as the main goal is to obtain a picture of the cost and the implementation strategy in order to achieve the 120gCO_2/km target for newly registered vehicles. The effect of engine redesign is not taken under consideration as it is assumed that it will be accounted together with all engine related improvements and technologies in Task 1.1. A possible incorporation of the engine redesign at this point bares the risk of double counting its effect.

Table 5.9 Summary of the scenarios developed for LVL

Case	Base Case	Case 1	Case2	Case 3	Case 4	
Additional manufacturer costs	0	17	17	17	17	€/vehicle
investment costs[27]	0	20	20	20	20	€/vehicle
CO_2-reduction	0.0%	2.5%	2.5%	2.5%	2.5%	
NEDC CO_2-emission	140	136	136	136	136	g/km
RW CO_2-emission	167	162	162	162	162	gCO2/km
WTW CO_2-emission	198	192	192	192	192	gCO2/km
Base fuel consumption	0.067	0.065	0.065	0.065	0.065	l/km
Yearly mileage	16000	16000	16000	16000	16000	Km
Yearly CO_2 emission TTW	2.68	2.60	2.60	2.60	2.60	tonne
Yearly CO_2 emission WTW	3.17	3.07	3.07	3.07	3.07	tonne
Yearly CO_2 savings WTW	0.00	0.09	0.09	0.09	0.09	tonne
Fuel price	0.21/0.3/ 0.4/0.6	0.21	0.30	0.40	0.60	€/l
Yearly fuel costs	226/323/ 431/646	220	315	420	630	€
Yearly fuel cost savings	646	6	8	11	16	€
Vehicle lifetime		1	1	1	1	Years
Interest rate	1	4.0%	4.0%	4.0%	4.0%	
NPV of add. fuel costs	4.0%	-5	-8	-11	-16	€
CO_2-abatement costs	0.00	181	150	113	53	€/tonne

Based on the aforementioned assumptions a CO_2-abatement cost value of 181€/tonne CO_2 reduced occurs in the case of the low oil price scenario and a 53€/tonne CO_2 in the high oil price scenario. An important fact that affects lubricant prices is that lubricants last fewer years than the total vehicle mileage, and thus the incremental cost is added after each oil replacement. The reader should keep in mind that contrary to engine redesign, the expenses of LVL application will be covered mainly by the drivers and therefore it is expected that various incentives will be given in order to promote their use. The important issue is that the use of these lubricants won't result in additional costs caused by warranty cancellations due to manufacturers' policy. On the contrary, the car industry is expected to promote the use of such lubricants, at least in newly registered vehicles, as their application can contribute a valuable 1.5-2% (which is the NEDC fuel consumption test potential of LVL) CO_2 reduction in their current effort to achieve the 140g/km CO_2 emissions limit.

5.5 Output to be supplied to TREMOVE and Task B

Based on the analysis presented above the data presented in the following table can be used for the purposes of Task B and TREMOVE runs.

The reduction potential, lifetime data and the retail price increase supplied are the same as those used in the calculations of the CO_2-abatement costs in the previous paragraphs. It is expected that the price increase to be used by TREMOVE is the de-taxed retail price increase presented above. In addition it is important to note that maintenance costs represent the price of the replacement equipment divided

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[27] Retail price minus taxes.

by its lifespan for the case of LRRT and LVL. As a result the additional cost of the original equipment should not be accounted for or in case it is taken into consideration for the years original equipment is used no maintenance costs should be introduced. Finally it is important to remember that **the benefits and prices of these technologies are independent of the engine type and size.**

Table 5.10 Data to be used by TREMOVE and Task B

	Unit	LRRT	TPMS	LVL
Expected FC Reduction	%	3.0%	2.5%	2.5%
Component Lifetime	Years	2.5	as for vehicle (12)	1.0
	km	40000	as for vehicle (200000)	16000
Retail Price Increase	€	60	72	25
R.P. Increase - Taxes	€	50	61	21
Maintenance Costs	€	20	-	21

Based on the information and the experience gained from this study three scenarios that simulate the introduction of each technology in the fleet were developed as guideline for the scenario runs to be conducted by TREMOVE and Task B.

For each technology 3 cases were studied:

- Base Case: Business as usual scenario, no measures taken technologies increase their share in the fleet at an annual rate of 1.75% reaching a 75% share for LRRT and a 25% share for TPMS and LVL by 2020
- 1st Scenario: Compulsory introduction of the energy efficient technology by 2010 through legislative measures
- 2nd Scenario: A 2020 - 99% (2015 for LRRT) market share scenario without compulsory provisions based only on purchase incentives and similar marketing solutions

The 2008 fleet share was estimated at 50% for the LRRT based on the value assumed by tyre manufacturers [ETRMA 2006] and at 5% for the other 2 technologies.

For the base case scenario no measures are considered. However fuel efficient technologies increase their share in the fleet due to other factors such as fuel price increase, consumer awareness and manufacturer promotion by a share of 25% (1.75% annually) within the 2008 -2020 period.

For the first scenario it is assumed that vehicles preserve their original equipment throughout life. As a result the increase of the market share is accounted solely to the new registrations that incorporate the technology. Assuming an average vehicle lifetime of 12 years the annual increase of the technology market share after measures are set into force is approximately 8% per year. Years 2008-2010 are considered as preparatory years thus smaller increases in the market share were considered.

For the second scenario it is assumed that measures target not only original but also replacement equipment. As a result the equipment aftermarket that represents the majority of the sales defines the share of the technology within the fleet. Consequently an introduction period is experienced throughout the first years (2008-2010 for LRRT and 2008-2012 for TPMS and LVL) which are followed by a development period (2010-2013 for LRRT and 2013-2017 for LVL and TPMS) and a maturity period. A similar approach regarding the American tyre market was found in literature [NRDC 2004].

The percentage of the vehicles in the fleet (EU25) incorporating a fuel efficient technology is presented in the following table for each case studied.

Table 5.11 Projected LRRT shares in the fleet

Year	Fleet Percentage		
	Base Case	1st Scenario	2nd Scenario
2008	50%	50%	50%
2009	52%	52%	51%
2010	54%	56%	54%
2011	55%	62%	58%
2012	57%	70%	66%
2013	59%	78%	78%
2014	61%	86%	92%
2015	62%	94%	98%
2016	64%	99%	100%
2017	66%	100%	100%
2018	68%	100%	100%
2019	69%	100%	100%
2020	71%	100%	100%

These scenarios should be seen as suggestions or guidelines for the work done in Task B. It is believed that the 2nd scenario might prove more effective because it involves the whole fleet and not only new registrations, as in the case of the 1st scenario.

For TPMS no retrofitting is expected to occur for the reasons presented in the study. Therefore only the base case and the first scenario are realistic and presented here.

Table 5.12 Projected TPMS share in the fleet

Year	Fleet Percentage	
	Base Case	1st Scenario
2008	5%	5%
2009	6%	6%
2010	8%	10%
2011	9%	16%
2012	11%	24%
2013	13%	32%
2014	15%	40%
2015	16%	48%
2016	18%	56%
2017	20%	64%
2018	22%	72%
2019	23%	80%
2020	25%	88%

For the case of LVL it should be mentioned that the 2nd scenario may prove more effective with the same market shares being achieved much quicker. This can happen because lubricants are replaced on annual basis. Nevertheless lubricants are strongly connected to the engine type and manufacturers' specifications and therefore it is expected that their introduction in the market will be highly influenced by engine manufacturers and developments in engine technology.

Table 5.13 Projected LVL share in the fleet

Year	Fleet Percentage		
	Base Case	1st Scenario	2nd Scenario
2008	5%	5%	5%
2009	6%	6%	6%
2010	8%	10%	7%
2011	9%	16%	8%
2012	11%	24%	12%
2013	13%	32%	23%
2014	15%	40%	40%
2015	16%	48%	61%
2016	18%	56%	79%
2017	20%	64%	90%
2018	22%	72%	96%
2019	23%	80%	98%
2020	25%	88%	99%

5.6 Total reduction potential

As the options described in this section are retrofit options which impact vehicles of all ages (except new vehicles) in the fleet it is not necessary to use the fleet spreadsheet as described in section 2.5 for assessing the total reduction potential of eco-driving. Instead, calculations are based on the fleet averaged CO_2-emission values from the TREMOVE 2.42 baseline. Policies to promote the application of low rolling resistance tyres, tyre pressure monitoring systems and low viscosity lubricants are assumed to be implemented from 2008 onwards. In section 5.5 scenarios are constructed for the use of LRRT, TMPS and LVL in the baseline situation and in situations in which the use of these options is promoted. In those cases where two scenarios are defined in section 9.5, results are presented here only for the scenario 1 which deals with compulsory introduction of the retrofit options by 2010.

Combining the share of the fleet that uses a specific option with the reduction percentages for that option as presented in Table 5.5, Table 5.6 and Table 5.9 gives the average CO_2-emission reduction percentage achieved at fleet level. The overall Well-to-Wheel GHG reduction is calculated by multiplying the average real-world CO_2-emission factors (in g/km) from the TREMOVE 2.42 baseline with the annual mileage, the total number of vehicles in the fleet, the average CO_2-emission reduction percentage and the average WTW/TTW correction factor (see section 2.4). Similar estimates have also been made for the situation in which LRRT, TMPS and LVL are applied to the fleet that results under scenarios from chapter 3 in which a 2012 target between 135 and 120 g/km is reached for the sales average TA CO_2-emissions of new passenger cars. Results based on the TREMOVE 2.42 baseline are presented in Table 5.14 and Figure 5.7.

As LRRT are already expected to be applied to a significant extent in the baseline scenario the impact of promoting the use of LRRT levels off after 2015. For TPMS and LVL the impact still increases after 2015 but is assumed to level off after 2020. The overall reduction estimates for the situation in which LRRT, TMPS and LVL are applied to the fleet that results under a scenario from chapter 3 in which a 2012 target between 135 and 120 g/km is reached for the sales average TA CO_2-emissions of new passenger cars differ less than 10% from the results based on the TREMOVE baseline.

Table 5.14 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) for EU-15 resulting from promoting the use of low rolling resistance tyres, tyre pressure monitoring systems and low viscosity lubricants as retrofit options for existing passenger cars.

	WTW GHG emission reduction [Mtonnes/y]	
	2012	2020
LRRT	2.4	5.3
TPMS	2.0	9.6
LVL	2.0	9.6

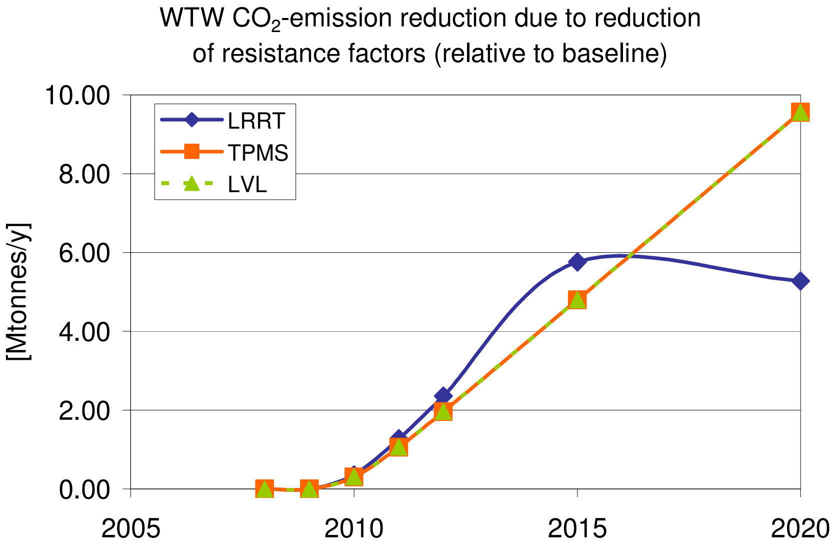

Figure 5.7 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) for EU-15 resulting from promoting the use of low rolling resistance tyres and low viscosity lubricants as retrofit options for existing passenger cars and tyre pressure monitoring systems on new vehicles.

5.7 Conclusions

- Low rolling resistance tyres and tyre pressure monitoring systems showed an important CO_2 reduction potential which was approximated at 3% and 2.5% respectively.
- The CO_2-abatement costs of low rolling resistance tyres remain high compared to other solutions and were estimated to be 140 €/tonne CO_2 reduced for low oil prices and 15 €/tonne for high oil prices in the case of LRRT. For TPMS CO_2-abatement costs were found negative in most cases.
- Important issues that are presented regarding these technologies are the absence of the necessary standardisation and legislative framework that will support their introduction in the market and possible inconsistencies in relation to the vehicle type approval test. As for the last the potential of these technologies has either zero impact on the vehicle type approval test (TPMS) or can be incorporated without necessarily reaching the market (LRRT).
- Low viscosity lubricants present similar characteristics with LRRT and TPMS. Their CO_2 reduction potential was found at 2.5% and their CO_2-abatement costs were estimated at approximately 180 €/tonne for low oil prices and 50 €/tonne for higher oil prices. Certain problems were revealed in the case of LVL regarding standardisation and vehicle warrantee issues when applying LVL.

- Various measures are proposed for supporting and accelerating the introduction of the aforementioned technologies in the market. Amongst them are the application of labelling schemes, creation of consumer support tools such as product databases, adoption of relevant standards for each technology and purchase incentive programs. All of these should be combined with a necessary update of the relevant legislative framework.
- The assessment for TPMS assumes that the user of the vehicle appropriately responds to the signals provided by the TPMS. This may certainly be expected when the TPMS is bought as an accessory, but as soon as TPMS becomes a standard auxiliary it seems likely that not all users will inflate their tyres when the TPMS reports underpressure. This poses a problem in terms of monitorability for policies aiming to promote the application of TPMS.
- Assuming a constructed scenario quantifying the effectiveness of policy measures promoting the application of low rolling resistance tyres, the total reduction potential associated with the increased use of low rolling resistance tyres is estimated for EU-15 at 2.4 Mtonne/y in 2012 growing to 5.3 Mtonne/y in 2020. Similarly for tyre pressure monitoring systems the overall potential is estimated at 2.0 resp. 9.6 Mtonne/y for 2012 and 202. The application of low-viscosity lubricants is estimated to result in an overall GHG reduction at EU-15 level of 2.0 Mtonne/y in 2012 increasing to 9.6 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

5.8 Literature

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6 Application of natural gas

6.1 Goal of Task 1.2

The goal of this activity is to assess the technical feasibility, CO_2 reduction potential and costs of passenger cars running on CNG as a measure to reduce the average CO_2-emissions of passenger cars.

Motivation for excluding LPG from the analysis

The original title of Task 1.2 was "Review of options for application of alternative fuels based on fossil primary energy". This would include CNG and LPG. In contrast to the specifications included in the tender, however, it was decided by the European Commission services that an assessment for LPG would not be carried out. An important reason for this decision is that the CARS21 group has decided not to consider LPG as a mainstream option because of its relatively less interesting CO_2-performance in comparison with other alternative fuels/biofuels.

LPG is a well-established niche fuel in some European countries. It can be argued, however, that the potential for a significant increase of the use of LPG as produced in Europe is limited. LPG is a by-product of refineries and of natural gas production. Besides its limited use as a niche transport fuel, all other LPG produced in Europe is used as a feedstock for the chemical industry.

Initially another motivation for excluding LPG from the analysis was that WTW-data on the LPG energy chain were not available at a European level. In the update of the Concawe/Eucar/JRC-study [Concawe 2006], however, an assessment of LPG was included.

LPG provides a TTW CO_2-reduction of 9 – 12% compared to petrol vehicles, due to the higher H/C-ratio [TNO 2003][Concawe 2006]. The [Concawe 2006] report only considers the use of LPG that is imported from the Middle-East (transport distance 5500 nautical miles per ship), in line with the statement above that European LPG is essentially not available for transport applications. For this energy chain [Concawe 2006] estimates that LPG has WTW GHG-emissions that are about 15% lower than for comparable petrol vehicles in 2010. With this value the WTW GHG-emissions of LPG are in between those of CNG and conventional diesel. Increased use of LPG may thus have a limited but nevertheless significant effect on CO_2-emissions from the European transport sector but, at least in this scenario, increases Europe's dependence on energy from the Middle-East.

6.2 Approach

Work under this Task has consisted of the following activities:

- Determination of additional costs to the manufacturer and retail price increase to the consumer for OEM-vehicles and retrofit installations using CNG (quantified separately for small, medium and large vehicles) based on available literature data and information from manufacturers;
- Determination of fuel costs, including the costs of distribution, based on existing literature;
- Determination of CO_2 emission figures at the vehicle level, based and existing literature;
- Establishing factors for translating CO_2 emissions at the vehicle level to Well-to-Wheel greenhouse gas emissions based on existing studies;
- Review of options to include WTW-aspects in policy measures promoting the use of CNG to reach 120 gCO_2/km;

- Delivery of input data to TML, to be used in of TREMOVE (with CNG-vehicles separately modelled), and to Task B;

6.3 Relevant aspects and considerations

- Due to the more favourable H/C ratio LPG and CNG have a CO_2-benefit compared to petrol with regard to the direct (Tank-to-Wheel) exhaust emissions. A full comparison should, however, also include the emissions in the fuel chain (Well-to-Tank + Well-to-Wheel = Well-to-Tank). Especially for CNG it should be noted that the CO_2 benefits strongly depend on the origin of the natural gas. With increasing transport distances the WTW greenhouse gas emissions increase due to energy demand for transport and possible methane leakage [Concawe 2006].
- WTW-analyses for CNG are included in [Concawe 2006] and [GM 2002]. In these studies various technical options are assessed relating to the origin of the natural gas and the technologies used. A selection is made of the option(s) appropriate for this study. This study mainly relies on data from [Concawe 2006] as this is the most recent an comprehensive WTW-analysis available.
- Fuel chain (WTT) emissions are not included in the present Strategy. Instead the CO_2 emission target solely relates to direct (TTW) emissions from the vehicle. It needs to be assessed whether the industry, as a consequence of the possible extension of the Strategy to 120 gCO_2/km or in the context of the advocated "Integrated Approach", can be expected to produce and market vehicles on CNG in serious quantities. The industry should be consulted on this issue. WTT-aspects do need to be included in the overall impact assessment in any case as alternative fuels are expected to play a role in many or all possible scenarios to be evaluated. Possibilities to include WTT-aspects in the monitoring mechanism for a follow-up of the voluntary agreements will also need to be reviewed.
- The use of alternative, fossil energy based fuels such as LPG and CNG offers the possibility to reduce well-to-wheel (WTW) greenhouse gas emissions of passenger cars, but may also help to improve Europe's energy security by lessening the dependence on imported oil. This aspect is not considered in this study.
- CNG is a well-established motor fuel, and vehicles running on CNG are available in various EU-countries. Although their CO_2 reduction potential is smaller than that of biofuels, the availability of fuels and vehicle technology in principle allows a rapid market introduction throughout the EU-25.
- Tailpipe emissions of CH_4 are to be included in the assessment. Representative data for Euro 3 OEM-equipped passenger cars are available from [TNO 2003].
- The assessment of fuel costs is based on existing studies and does not involve own calculations based on costs of distribution infrastructure and filling stations. [Concawe 2006] supplies estimates of the costs of CNG as supplied at the filling station, assuming a sufficiently dense network capable of supporting the use of these fuels at a large scale.
- For the assessment of costs of NGVs, data on existing vehicles and projections for future vehicles have been collected from literature and through the questionnaire sent to vehicle manufacturers. The collected data are assumed valid for the situation of sufficiently large volume production (> 100,000 p.a.). Evaluation of the possible development of technology costs as a function of time or production volume was beyond the scope of this review.

6.4 Energy consumption and Tank-to-Wheel CO_2-emissions from NGVs

Table 6.1 presents Type Approval CO_2-emissions (NEDC-cycle) of a number of OEM-equipped NGVs currently on the market, compared to equivalent petrol vehicles of the same brand and model [GVR 2005]. The average difference in CO_2-emission is 44 g/km, or about 22%.

Table 6.1 Type Approval CO_2-emissions of NGVs and comparable petrol vehicles currently on the market [GVR 2005]

brand	model	petrol [g/km]	NGV [g/km]	difference [g/km]	% diff.
Opel	Zafira	190	144	-46	-24,2%
Citroen	Berlingo	176	146	-30	-17,0%
Volvo	S60	209	159	-50	-23,9%
Volvo	V70	214	169	-45	-21,0%
Volvo	S80	212	164	-48	-22,6%
Fiat	Multipla	205	162	-43	-21,0%
average difference in CO_2-emission				-44	-21,6%

In [TNO 2003] a comparison is made of the environmental performance of comparable Euro 3 passenger cars on petrol, diesel, LPG and CNG based on extensive laboratory testing. For each of the fuels petrol, diesel and LPG 7 different vehicle models were tested. For natural gas a total of 3 vehicles were tested. Tests included measurement of the emissions of regulated components and a wide range of unregulated components on the NEDC and the urban / rural / highway parts of the CADC cycle, with and without a cold start. From the results on the various tests emission profiles can be calculated which are representative for typical “urban drivers”, “business drivers” and for the “average driver”. Average results of the direct CO_2 and other GHG-emissions for the “average driver profile are presented in the Table 6.2. This study finds that under real-world conditions the direct CO_2-emissions of NGVs are about 19% lower than for comparable petrol vehicles.

Table 6.2 Direct greenhouse gas emissions from passenger cars on petrol, diesel, LPG and CNG under real-world driving conditions [TNO 2003]

direct / tailpipe emissions		**petrol**	**diesel**	**LPG**	**CNG**
CO_2	g/km	208.1	180.5	189.3	168.6
	%	100%	87%	91%	81%
CH_4	g/km	0.009	0.004	0.007	0.074
	%	100%	45%	82%	841%
N_2O	g/km	0.003	0.007	0.003	0.001
	%	100%	233%	100%	33%
total GHG	gCO2-equiv./km	209.2	182.7	190.4	170.6
	%	100%	87%	91%	82%

Table 6.3 presents TTW data from [Concawe 2006]. According to this study the TTW greenhouse gas emissions of NGVs are 23% lower than those of comparable petrol vehicles and even 17% lower than those of comparable diesel vehicles. This includes the relatively small contributions of CH_4 and N_2O.

Table 6.3 Direct greenhouse gas emissions from 2010 passenger cars on petrol, diesel and CNG on the NEDC test cycle [Concawe 2006]

	TTW energy consumption	CO_2	CH_4	N_2O	total TTW emissions	
	[MJ/km]	[g/km]	[gCO_2eq./km]	[gCO_2eq./km]	[gCO_2eq./km]	[%]
PISI petrol	1.90	139.4	0.5	0.5	140.3	100%
PISI CNG bi-fuel	1.88	105.9	1.8	0.5	108.2	77%
PISI CNG dedicated	1.87	105.3	1.8	0.5	107.6	77%
DICI diesel with DPF	1.76	129.4	0.2	1.5	131.1	93%

In the questionnaire sent to all manufacturer association under Task 1.1 also questions were included on natural gas vehicles. ACEA has submitted data to this questionnaire which have been taken into account in the analysis. As these data are confidential, they are not presented in this report. Further improvement of the fuel efficiency of NGVs compared to petrol vehicles is expected by ACEA. This is in line with the TNO's own vision that DI-technology and associated technical measures have a higher efficiency improvement potential when applied to natural gas engines than to petrol engines.

From Table 6.2 and the ACEA data it is clear that the tailpipe CH_4-emissions are well below 0.1 g/km. As also indicated in Table 6.3, with the GWP of 23 for CH_4 this corresponds to around 2 gCO_2eq./km or about 1.5% of the TTW CO_2-emissions of the average passenger car in 2008. Methane emissions thus only marginally reduce the overall CO_2-benefit of NGVs.

Similarly, despite the high GWP of 296, the TTW N_2O emissions of all fuels are below 2 gCO_2eq./km, and for petrol, LPG and CNG even around or below 1 gCO_2eq./km. This contribution is thus also marginal and the differences between fuels do not significantly impact the comparison on overall TTW greenhouse gas emissions.

For the purpose of this study we will assume that in the 2008 – 2012 timeframe the TTW GHG-emissions of NGVs, expressed in CO_2-equivalents, are 22% lower than those of their petrol-based equivalents. This value is chosen slightly lower than the numbers provided by [Concawe 2006] and ACEA, to account for the fact that the reduction on the type approval test is higher than in real-world driving. The real-world value is of relevance for assessing abatement costs and CO_2-reduction potential[28].

6.5 Well-to-Tank CO_2-emissions of natural gas

For the Well-to-Tank analysis of natural gas this study relies on [Concawe 2006]. The report has been made available by Europia, and its results have been discussed. The WTT energy consumption and CO_2-emissions and the factor between WTW CO_2-emissions and WTT CO_2-emissions according to [Concawe 2006] are given in Table 6.4. It can be seen that the WTT CO_2-emissions associated with the use of CNG is strongly dependent on the origin of the natural gas. The table summarises results for three different origins:

- EU-mix, being the existing mix of locally produced and imported natural gas;
- imported gas, transported over a distance of 4000 km from the Middle East or South-West Asia;

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[28] In hindsight this could also have been accounted for by combining a higher reduction value on the TA test with a higher translation factor between RW and TA CO_2-emissions than the value used for petrol and diesel vehicles (see section 2.3). Including NGVs in a regulation of CO_2-emissions based on the TA test would thus lead to a somewhat higher apparent benefit of NGVs than reflected in this study.

- imported gas, transported over a distance of 7000 km from Western Siberia.

Various groups (a.o. the Alternative Fuels Contact Group) have stated that the 4000 km option is the most likely origin of additional gas used in Europe in the next decades. This option will be used for further calculations.

Table 6.4 WTT energy consumption and CO_2-emissions and factor between WTW CO_2-emissions and WTT CO_2-emissions according to [Concawe 2006].

	TTW			**WTT**			**WTW**
	CO_2-content [gCO_2/MJ_fuel]	lower heating value (LHV) [MJ/l_fuel]	lower heating value (LHV) [MJ/m^3_fuel]	WTT energy consumption [MJ/MJ_fuel]	WTT CO_2-emission [gCO_2/MJ_fuel]	WTT CO_2-emission [gCO_2/gCO_2_TTW]	WTW CO_2-emission [gCO_2/gCO_2_TTW]
petrol	73.40	32.2		0.14	12.5	0.170	1.170
diesel	72.80	35.8		0.16	14.2	0.195	1.195
CNG EU-mix	56.20		32.0	0.12	8.4	0.149	1.149
CNG 4000 km	56.20		32.0	0.19	14.0	0.249	1.249
CNG 7000 km	56.20		32.0	0.30	21.7	0.386	1.386

As is clear from Table 6.4, [Concawe 2006] states that expressed per MJ final output the petrol chain is slightly more efficient than the diesel chain. This seems counterintuitive, as diesel is a more direct product of crude oil, but is in fact the result of the high share of diesel in present fleet. Meeting the increased diesel demand requires additional fuel processing which lowers the system efficiency of refineries. This leads to higher marginal WTT CO_2-emissions[29] for diesel than for petrol. The difference in WTT efficiency, however, is smaller than the opposite difference in TTW efficiency between the petrol and the diesel vehicle, so that expressed per km driven diesel has the best WTW efficiency and the lowest CO_2-emissions.

Combination of the data from Table 6.4 and the assumed TTW CO_2-reduction of 22% as motivated in section 6.4 yields the WTW CO_2-reduction potential for the various origins of the natural gas as depicted in Table 6.5. As a reference example a 2008 petrol vehicle is taken which is assumed to emit 148 g/km in the Type Approval test. The CO_2-emission of a comparable 2008 diesel vehicle is assumed 15% lower than that of the petrol vehicle. The CO_2-reduction potential expressed in relative terms does not depend on the CO_2-emission of the reference vehicle. For use in TREMOVE and Task B the absolute values of the TTW emissions of NGVs in the period 2008 – 2012 will be calculated on the basis of the results of Task 1.1 in which the technical development of conventional petrol and diesel vehicles is assessed.

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[29] For existing fuel chains the WTT results in [Concawe 2006] are expressed as marginal emissions and energy consumption.

Table 6.5 Calculation of WTW CO_2-emissions of NGVs

	TTW		WTT	WTW	
	CO_2-emissions [gCO_2/km]		WTT CO_2-emission [gCO_2/gCO_2_TTW]	WTW CO_2-emission [gCO_2/km]	
petrol	148.0	100%	0.170	173.2	100%
diesel	125.8	85%	0.195	150.3	87%
CNG EU-mix	115.4	78%	0.149	132.7	77%
CNG 4000 km	115.4	78%	0.249	144.2	83%
CNG 7000 km	115.4	78%	0.386	160.0	92%

6.6 Costs of NGVs

Table 6.6 presents retail prices of a number of NGVs currently on the market, compared to equivalent petrol vehicles of the same brand and model [GVR 2005]. The average difference in retail price is around € 2900. Assuming a translation factor of 1.67 (for whole-vehicle cost break-down, see section 2.1 and Annex A), this corresponds to additional (ex factory) costs to the manufacturer of € 1740. Using the factor of 1.44 ((for the cost break-down of marginal costs for additional technology, see section 2.1 and Annex A) manufacturer costs would be € 2015. In the case of current NGVs the factor of 1.44 may actually be too low. Due to the small sales volumes the share of distribution and dealer costs in the retail price may be higher than the value assumed in Annex A for the marginal additional costs for new technology applied to conventional passenger cars in high volumes.

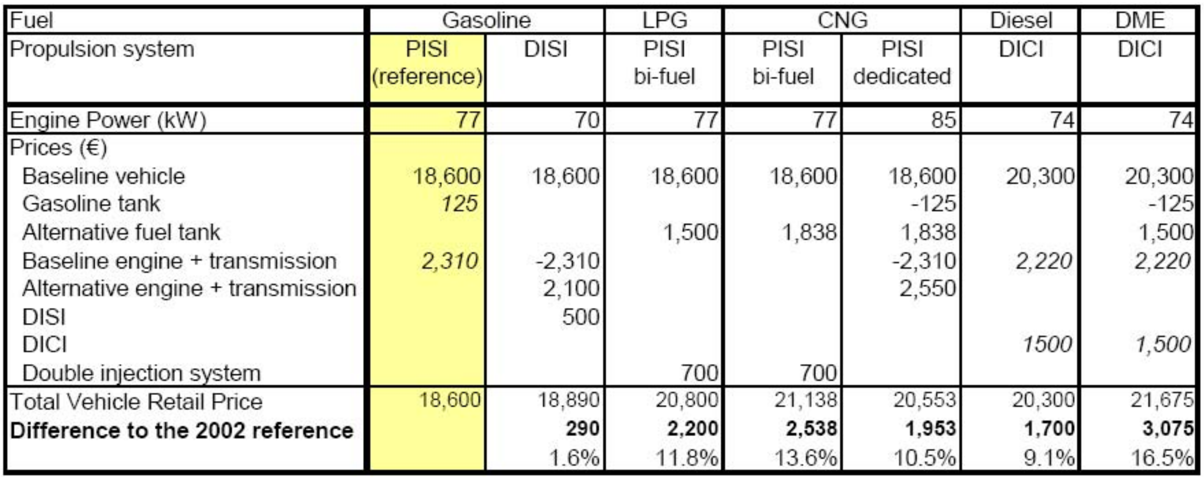
Table 6.6 Retail prices of NGVs and comparable petrol vehicles currently on the market [GVR 2005]

brand	model	petrol [Euro]	NGV [Euro]	difference [Euro]	% diff.
Opel	Zafira	18425	20975	2550	13,8%
Ford	Focus 5 doors	17890	20640	2750	15,4%
Ford	Focus wagon	18765	21472	2707	14,4%
Citroen	Berlingo	16240	19200	2960	18,2%
Volvo	S60	26470	29620	3150	11,9%
Volvo	V70	30570	33720	3150	10,3%
Volvo	S80	31150	34360	3210	10,3%
average additional retail price				2925	13,5%

ACEA has provided input data on the additional costs to the manufacturer of a NGV compared to an equivalent petrol vehicle for the 2008 – 2012 period. These data are derived under the assumption of sufficiently large production volumes (> 100,000 p.a.). The value derived from the data on existing vehicles presented in Table 6.6 is roughly the same as data provided by ACEA for 2008 – 2012, while one would expect costs to drop compared to the present situation. The reason ACEA provides for this is that under the present market circumstances NGVs are offered with a price that includes a (profit) margin that is below average in order to stimulate sales. If NGVs would become a successful technology in the longer run, profit margins should return to “normal”. NGVs have indeed been market ready and “on the shelve” for several years while the market is still lingering. It seems likely that manufacturers are trying to increase sales by offering vehicles with reduced margins, so that they at least earn back some of their investments. On the other hand, costs may be expected to go down compared to the present situation as a result of increased production volumes (assuming significant market growth) so that the future price difference would not necessarily be higher than the present even if profit margins are increased.

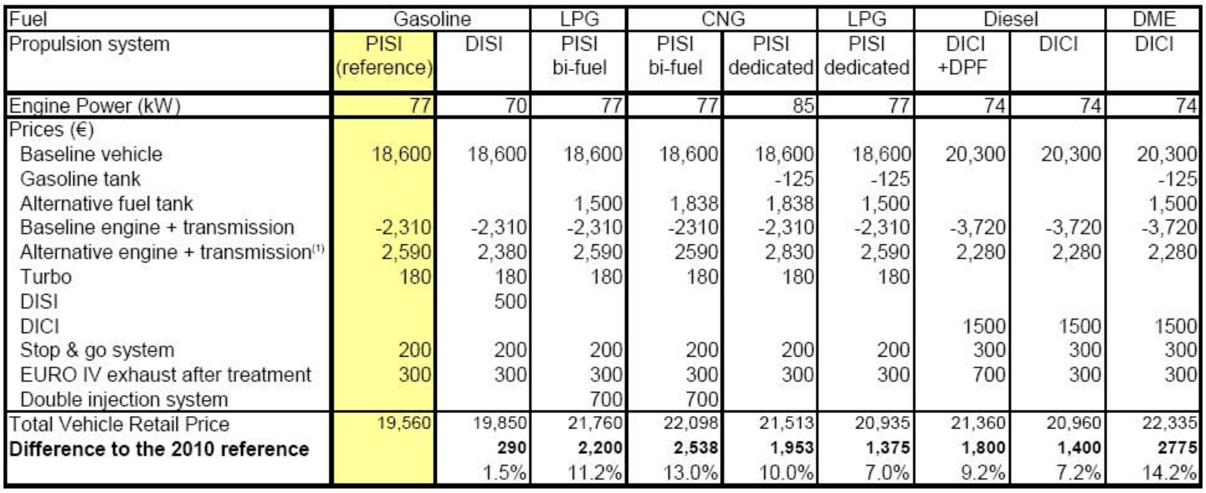
According to [Concawe 2006] the additional retail price for NGVs compared to equivalent petrol vehicles includes the costs of a CNG-tank (retail price: €1838), a double injection system for bi-fuel vehicles (retail price: €700) or additional engine costs for dedicated CNG engines (retail price: €240). For dedicated NGVs the price of the petrol tank can be subtracted (retail price: €125). The final retail price estimates for NGVs compared to other ICEVs are depicted in Table 6.7. A similar comparison for 2010 vehicles is presented in Table 6.7. These data are slightly lower than the retail price data for present day vehicles as presented in Table 6.6. Using a translation factor of 1.67 (see Annex A) these retail price estimates can be translated into manufacturer costs of €1525 resp. €1172 for bifuel NGVs and dedicated PISI NGVs. Using the factor of 1.44 for marginal costs of additional technology the values would be €1760 resp. €1355 for bifuel NGVs and dedicated PISI NGVs.

Table 6.7 Retail prices of 2002 NGVs and other comparable ICE vehicles [Concawe 2006]



Fuel	Gasoline		LPG	CNG		Diesel	DME
Propulsion system	PISI (reference)	DISI	PISI bi-fuel	PISI bi-fuel	PISI dedicated	DICI	DICI
Engine Power (kW)	77	70	77	77	85	74	74
Prices (€)							
Baseline vehicle	18,600	18,600	18,600	18,600	18,600	20,300	20,300
Gasoline tank	*125*				-125		-125
Alternative fuel tank			1,500	1,838	1,838		1,500
Baseline engine + transmission	*2,310*	-2,310			-2,310	*2,220*	*2,220*
Alternative engine + transmission		2,100			2,550		
DISI		500					
DICI						*1500*	*1,500*
Double injection system			700	700			
Total Vehicle Retail Price	18,600	18,890	20,800	21,138	20,553	20,300	21,675
Difference to the 2002 reference		**290**	**2,200**	**2,538**	**1,953**	**1,700**	**3,075**
		1.6%	11.8%	13.6%	10.5%	9.1%	16.5%

Table 6.8 Retail prices of 2010 NGVs and other comparable ICE vehicles [Concawe 2006]



Fuel	Gasoline		LPG	CNG		LPG	Diesel		DME
Propulsion system	PISI (reference)	DISI	PISI bi-fuel	PISI bi-fuel	PISI dedicated	PISI dedicated	DICI +DPF	DICI	DICI
Engine Power (kW)	77	70	77	77	85	77	74	74	74
Prices (€)									
Baseline vehicle	18,600	18,600	18,600	18,600	18,600	18,600	20,300	20,300	20,300
Gasoline tank					-125	-125			-125
Alternative fuel tank			1,500	1,838	1,838	1,500			1,500
Baseline engine + transmission	-2,310	-2,310	-2,310	-2310	-2,310	-2,310	-3,720	-3,720	-3,720
Alternative engine + transmission(1)	2,590	2,380	2,590	2590	2,830	2,590	2,280	2,280	2,280
Turbo	180	180	180	180	180	180			
DISI		500							
DICI							1500	1500	1500
Stop & go system	200	200	200	200	200	200	300	300	300
EURO IV exhaust after treatment	300	300	300	300	300	300	700	300	300
Double injection system			700	700					
Total Vehicle Retail Price	19,560	19,850	21,760	22,098	21,513	20,935	21,360	20,960	22,335
Difference to the 2010 reference		**290**	**2,200**	**2,538**	**1,953**	**1,375**	**1,800**	**1,400**	**2775**
		1.5%	11.2%	13.0%	10.0%	7.0%	9.2%	7.2%	14.2%

Based on the above information, information from ACEA, as well as in-house expert judgement, and assuming large scale production and a mature market position, we estimate that the additional manufacturer costs of NGVs in the 2008 – 2012 timeframe will be between €1500 and €2000. For abatement cost calculations we will assume a average value of €1750 for medium sized vehicles. The assumed additional costs for the three vehicle size segments is shown in Table 6.9, where the ratio between the costs as given by ACEA is used for the differentiation over segments. In this cost estimate furthermore the following considerations have played a role:

- The majority of NGVs in the timeframe considered are assumed to be bi-fuel vehicles. In the period of building up market and infrastructure these vehicles are expected to be more attractive to consumers than mono-fuel vehicles;
- In the present market prices for NGVs are expected to be under pressure. Many manufacturers have the technology on the shelve but the market is not growing according to expectations. In an attempt to create market and to achieve some return on investments NGVs are expected to be sold with relatively low margins or incomplete cost pass-through.

The effect of assuming a lower value for the additional manufacturer costs is further explored in section 6.8.

Table 6.9 Data for additional manufacturer costs, additional retail price and relative TTW CO2-reduction for NGVs compared to equivalent petrol vehicles used for the assessment of CO_2-abatement costs.

	NGVs compared to petrol vehicles		
	small	medium	large
add. manufacturer cost [€]	1450	1750	2050
add. retail price [€]	2090	2520	2950
TTW CO_2-reduction	22%	22%	22%

6.7 The cost of natural gas

The cost of natural gas for use in vehicles are in principle determined by:

- the price at which natural gas is bought at the source;
- costs for long distance transport;
- costs for distribution, e.g. through public filling stations, including compression to the required pressure level.

In the latter two infrastructure costs have a high share.

In principle the scope of this study should not be to make a bottom-up assessment of the future price of natural gas at the filing station. Instead the study should build on already available literature on this issue. For this reason the assessment of CO_2-abatement costs, as presented in the next section, is based on price data for natural gas and petrol derived from scenarios as presented in [Concawe 2006].

Table 6.10 Relation between oil price and the cost (price minus taxes) of petrol and natural gas based on [Concawe 2006].

oil price [€/bbl]	petrol/diesel cost [€/l]	gas cost [€/m^3]
25	0.21	0.32
36	*0.30*	*0.40*
50	0.41	0.49
74	*0.60*	*0.65*

Table 6.10 presents the assumed relation between oil price and the costs of petrol/diesel and natural gas. The data in the first and third row originate from [Concawe 2006] in which two scenarios are assessed, one with a petrol price of 0.21 €/l (oil price = 25 €/bbl) and one with 0.41 €/l (oil price = 50 €/bbl). The value of 0.30 €/l in the third row was the fuel price as used in [IEEP 2004]. The 0.60 €/l value is added as a high price scenario. For the second and fourth row the oil price and natural gas price (depicted in italic) have been calculated based on assumed linear relations between oil price and

petrol/diesel cost and between petrol/diesel cost and natural gas cost which can be derived from the [Concawe 2006] data.

6.8 CO_2-abatement costs

In Table 6.11 a comparison is presented of the estimated abatement costs for achieving a CO_2-emission reduction compared to a 2008 medium sized petrol baseline vehicle by means of NGVs. The comparison is made for different levels of the petrol and natural gas price, the latter varying between 0.32 and 0.65 €/m^3 (see section 6.7), for different additional manufacturer costs and for different origins of the natural gas (regarding WTW GHG emissions). Calculations are made for two values of the additional manufacturer costs, namely €1500 and €2000 to show the impact of variation in additional costs on CO_2-abatement costs. WTT data from [Concawe 2006] have been used to assess the CO_2-abatement costs for the three origins of the natural gas that is used (EU-mix, transport distance 4000 km and 7000 km, see section 6.5). The results indicate the sensitivity of the abatement cost calculations to a realistic spread in input values.

*Table 6.11 Comparison of the abatement costs for reaching a CO_2-emission reduction compared to a 2008 medium sized **petrol baseline vehicle** by means of NGVs, for oil prices varying from 25, 36, 50 to 74 €/bbl and petrol and natural gas costs varying accordingly.*

		petrol, M 2008-base	NGV EU-mix	NGV 4000km	NGV 7000km	NGV EU-mix	NGV 4000km	NGV 7000km	gas cost [€/m^3]	petrol cost [€/l]
TTW CO_2-reduction	[%]		22.0%	22.0%	22.0%	22.0%	22.0%	22.0%		
NEDC CO_2-emission	[g/km]	148	115	115	115	115	115	115		
real-world CO_2-emission	[g/km]	177	138	138	138	138	138	138		
WTW CO_2-emission	[g/km]	207	159	172	191	159	172	191		
WTW CO_2-reduction	[%]		23.4%	16.7%	7.6%	23.4%	16.7%	7.6%		
add. ret. price minus tax	[€/veh.]	0	1740	1740	1740	2320	2320	2320		
CO_2 abatement costs	[€/tonne]	--	240	335	737	298	416	914	0.32	0.21
	[€/tonne]		209	292	641	266	372	818	0.40	0.30
	[€/tonne]		171	238	524	228	319	701	0.49	0.41
	[€/tonne]		105	146	322	162	227	499	0.65	0.60

CO_2-abatement costs in Table 6.11 are calculated with the following assumptions:

- a reference vehicle emitting 148 gCO_2/km on the NEDC, derived from the 2008 assessment of Task 1.1 (section 3.9.2);
- 22% lower TA CO_2-emissions for a NGV with similar engine technology comparable to the reference petrol vehicle;
- translation from TA to real-world CO_2-emissions by means of a factor 1.195 (see Annex B)
- translation of RW TTW CO_2-emissions and fuel consumption by means of the WTW/WTT factors given in Table 6.5;
- additional manufacturer costs of €1500 resp. €2000.
- translation of additional manufacturer costs to additional investment costs (retail price excl. tax) using a factor of 1.16 (see Annex A);
- annual mileage 16,000 km;
- vehicle lifetime 13 years;
- interest rate for the calculations is 4%.

For the overall assessment of CO_2-abatement costs NGVs should be compared to the average conventional vehicle of 2008. In that year the shares of petrol and diesel in the new vehicle sales are expected to be both 50%. Table 6.12 presents the results of this comparison.

Table 6.12 Comparison of the abatement costs for reaching a CO_2-emission reduction compared to an average medium sized 2008 ***average baseline vehicle (50% petrol / 50% diesel)*** *by means of NGVs, for oil prices varying from 25, 36, 50 to 74 €/bbl and petrol/diesel and natural gas costs varying accordingly.*

		average, M 2008-base	NGV EU-mix	NGV 4000km	NGV 7000km	gas cost [€/m^3]	petrol cost [€/l]
TTW CO_2-reduction	[%]		20.1%	20.1%	20.1%		
NEDC CO_2-emission	[g/km]	145	115	115	115		
real-world CO_2-emission	[g/km]	173	138	138	138		
WTW CO_2-emission	[g/km]	204	159	172	191		
WTW CO_2-reduction	[%]		22.4%	15.6%	6.4%		
add. ret. price minus tax	[€/veh]	0	1450	1450	1450		
CO_2 abatement costs	[€/tonne]	--	243	347	852	0.32	0.21
	[€/tonne]		218	312	765	0.40	0.30
	[€/tonne]		187	268	658	0.49	0.41
	[€/tonne]		135	193	473	0.65	0.60

CO_2-abatement costs in Table 6.12 are calculated with the following assumptions:

- a reference vehicle emitting 145 gCO_2/km on the NEDC being the sales weighted average for medium sized petrol vehicles (148 g/km) and diesel vehicles (141 g/km), derived from the 2008 assessment of Task 1.1 (section 3.9.2;
- 50%/50% shares of petrol and diesel in 2008 new vehicle sales;
- 22% lower TA CO_2-emissions for a NGV with similar engine technology comparable to the petrol vehicles that constitute part of the reference average new vehicle;
- translation from TA to real-world CO_2-emissions by means of a factor 1.195 (see Annex B)
- translation of RW TTW CO_2-emissions and fuel consumption by means of the WTW/WTT factors given in Table 6.5:
  - for the case of the average conventional vehicle the WTW/WTT values are weighted over the share of petrol and diesel in the 2008 sales;
- translation of additional manufacturer costs to additional investment costs (retail price excl. tax) using a factor of 1.16 (see Annex A);
- additional manufacturer costs of a diesel vehicle are assumed €1000 compared to petrol, while the additional manufacturer costs of NGVs are assumed €1750 compared to petrol
- annual mileage 16,000 km;
- vehicle lifetime 13 years;
- interest rate for the calculations is 4%.

For the purpose of this study it is assumed that the natural gas consumed by additional NGVs used in Europe after 2008 will be imported with a transport distance of on average 4000 km.

In Table 6.13 a direct comparison is made of the CO_2-abatement costs of NGVs with the CO_2-abatement costs for reaching various 2012 targets by means of technical measures applied to conventional vehicles. For the NGV it is assumed that conversion to natural gas is applied to a 2012 petrol vehicle with a TA CO_2-emission value of 140 g/km. Compared to the 2008 baseline technical measures are assumed to have been applied to the petrol vehicle to compensate for autonomous weight increase between 2008 and 2012. However, as was done in Task 1.1 (section 3.9.3), the CO_2-abatement costs for reaching a net reduction compared to 2008 are calculated by excluding the costs of maintaining 140 g/km between 2008 and 2012, as these are attributed to the existing EU policy. To make the additional vehicle cost data for NGVs in the table (expressed as retail price excl. tax) comparable with the costs for reaching different targets wit conventional vehicles, the average costs of maintaining the 2008 CO_2-emission level in petrol cars are added to the additional costs of NGVs[30].

Table 6.13 Comparison of the CO_2-abatement costs of NGVs with the CO_2-abatement costs for reaching various 2012 targets by means of technical measures applied to conventional vehicles.

		average 2008-base	2012 conventional vehicles reaching targets between 140 and 120 g/km					NGV EU-mix	NGV 4000km	NGV 7000km	gas cost [€/m^3]	petrol cost [€/l]
TTW CO_2-reduction	[%]							20.1%	20.1%	20.1%		
NEDC CO_2-emission	[g/km]	140	140	135	130	125	120	112	112	112		
real-world CO_2-emission	[g/km]	167	167	161	155	149	143	134	134	134		
WTW CO_2-emission	[g/km]	198	198	191	184	177	170	154	167	185		
WTW CO_2-reduction	[%]		0.0%	3.6%	7.1%	10.7%	14.3%	22.4%	15.6%	6.4%		
additional vehicle costs (retail price excl. tax)	[€]	0	244	569	955	1408	1936	2001	2001	2001		
yearly fuel cost savings	[€/tonne]	--	0	8	16	24	32	-83	-83	-83	0.32	0.21
	[€/tonne]		0	11	23	34	46	-60	-60	-60	0.40	0.30
	[€/tonne]		0	16	31	47	63	-32	-32	-32	0.49	0.41
	[€/tonne]		0	23	46	69	92	17	17	17	0.65	0.60
CO_2 abatement costs	[€/tonne]	--	--	166	187	209	233	248	354	870	0.32	0.21
	[€/tonne]			143	164	186	210	223	319	782	0.40	0.30
	[€/tonne]			114	135	157	181	192	275	675	0.49	0.41
	[€/tonne]			65	86	108	132	140	200	490	0.65	0.60

It can be concluded from Table 6.13 that NGVs provide about the same level of CO_2-reduction per unit of additional vehicle costs as CO_2-reducing technical measures that can be applied to conventional vehicles. The CO_2-abatement costs of NGVs, however, are significantly higher. This is due to the fact that the yearly fuel cost savings for NGVs are lower than for conventional vehicles reaching the same CO_2-reduction and are even negative for petrol costs below roughly 0.50 €/l. The reason behind this is that the fuel price excluding taxes per unit of energy is higher for natural gas than for petrol and diesel, as is also illustrated in Table 6.14. Given the price assumptions as used in this study, natural gas is cheaper than petroleum based fuels only for high oil and resulting fuel prices (> 60 €/bbl, resp. > 0.50 €/l).

Table 6.14 Fuel costs per unit of energy for the fuel cost values as listed in Table 2.2

oil price [€/bbl]	petrol/ diesel cost [€/MJ]	gas cost [€/MJ]
25.0	0.0062	0.0081
36.3	0.0088	0.0101
50.0	0.0120	0.0124
73.8	0.0176	0.0165

The above conclusion is illustrated in a different way in Figure 6.1. This graph is based on the cost curve for medium size petrol vehicles as presented in Figure 3.5 and Table 3.11 and on the cost data developed in this chapter for NGVs. For the four different oil price levels as used in this report the CO_2-abatement costs for reducing the CO_2-emissions of petrol cars are plotted as a function of the achieved 2012 level of WTW GHG emissions[31]. This level includes the effects of autonomous weight

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[30] These additional costs are based on Table 3.16. The value depends on the target-measure combination. Average additional manufacturer costs are calculated of € 475 (retail price excl. tax = € 551) and used for this comparison.

[31] WTW value = (TA value) x (real world correction factor) x (WTW/TTW factor)

increase on CO_2-emissions. These abatement costs are based on the difference in vehicle costs between a medium size petrol vehicle with the given level of WTW GHG emissions and a medium size petrol vehicle in a scenario in which a new vehicle sales weighted average TA CO_2-emission of 140 g/km is maintained. The grey bar in the graph displays the levels of WTW GHG emissions that are required for medium size petrol vehicles in the various scenarios in which a new vehicle sales weighted average TA CO_2-emission of 120 g/km is achieved in response to the different target-measure combinations as studied in chapter 3. Also indicated in the graph (by the coloured markers) is the WTW GHG emission level that is achieved by conversion to natural gas of a medium size petrol vehicle with the level of CO_2-reducing technology that is required in a scenario in which a new vehicle sales weighted average TA CO_2-emission of 140 g/km is maintained, together with the abatement costs for this technology as assessed for different levels of the oil price and for different levels of the additional manufacturer costs associated with NGVs. For the latter the 1750 €/vehicle, as determined in this chapter, is compared to a fictitious alternative value of 1250 €/vehicle to demonstrate the effect of vehicle costs on the comparison of abatement costs. In short the graph compares the CO_2-abatement costs for reaching a certain level of WTW GHG emission reduction compared to the scenario in which 140 /km is maintained between 2008 and 2012 either by improving the fuel efficiency of petrol cars or by applying natural gas.

Figure 6.1 shows that converting a “140 g/km TA” petrol vehicle to natural gas results in roughly the same WTW GHG emission reduction as applying efficiency improving technologies to the petrol vehicle to achieve the level of CO_2-emission reduction as required under a 2012 overall target of 120 g/km. The abatement costs for the natural gas option, however, are significantly higher than the abatement costs for the efficiency improvement options. Assuming lower additional costs for NGVs (e.g. 1250 €/vehicle) than the value determined in this study (1750 €/vehicle) leads to significantly lower abatement costs, which in the case of a high oil price may even be lower than those for improving petrol vehicles.

Natural gas is thus not a cost effective alternative for efficiency improvement of petrol vehicles as means to reach a 2012 TA CO_2-target between 140 and 120 g/km. As natural gas can also be applied to petrol vehicles to which technical measures are applied in order to reach an overall 2012 goal between 140 and 120 g/km, NGVs may play a role in extending the potential for CO_2-reduction beyond 120 g/km or as an alternative for the expensive technologies that need to be applied for the last steps towards reaching targets around or beyond 120 g/km. This is further explored on the basis of a comparison of marginal abatement costs in Figure 6.2 and Figure 6.3. In these graphs the dotted lines represent the marginal CO_2-abatement costs for model year 2012 medium sized petrol cars as a function of the TA CO_2-emission reduction relative to the 2002 baseline (same axis as the cost curve graph in Figure 3.5), plotted for different levels if the oil price. These marginal abatement costs thus correspond to the costs per avoided tonne of GHG resulting from further TA CO_2-emission reduction by e.g. 1 g/km (“moving further up the cost curve”). The solid lines represent the CO_2-abatement costs associated with converting a 2012 petrol vehicle with the level of TA CO_2-emission reduction compared to the 2002 baseline as indicated on the x-axis into a natural gas vehicle. The point where the dotted and solid line of the same colour cross is the break-even point where conversion to natural gas becomes more cost effective for further CO_2-emission reduction than additional technical measures to improve the fuel efficiency of the petrol vehicle. Figure 6.2 presents the results on the basis of additional manufacturer costs for NGVs equal to 1750 €/vehicle. To assess the impact of vehicle costs Figure 6.3 presents a similar comparison using a fictitious value for the additional manufacturer costs of 1250 €/vehicle.

Figure 6.2 shows that, for additional manufacturer costs of 1750 €/vehicle, conversion to natural gas only becomes an alternative to further efficiency improvement on the petrol vehicle for 2012 targets beyond 120 g/km, for all values of the oil price considered here. Figure 6.3 indicates that, if the additional manufacturer costs could be significantly reduced, conversion to natural gas could become a viable alternative to further efficiency improvement for 2012 targets of 120 g/km or less depending on the oil price. Obviously, if conversion to natural gas is applied to avoid costly last steps in efficiency improvement, then the resulting natural gas vehicles yield WTW GHG-emission reductions that can go beyond the required levels to meet the 2012 target.

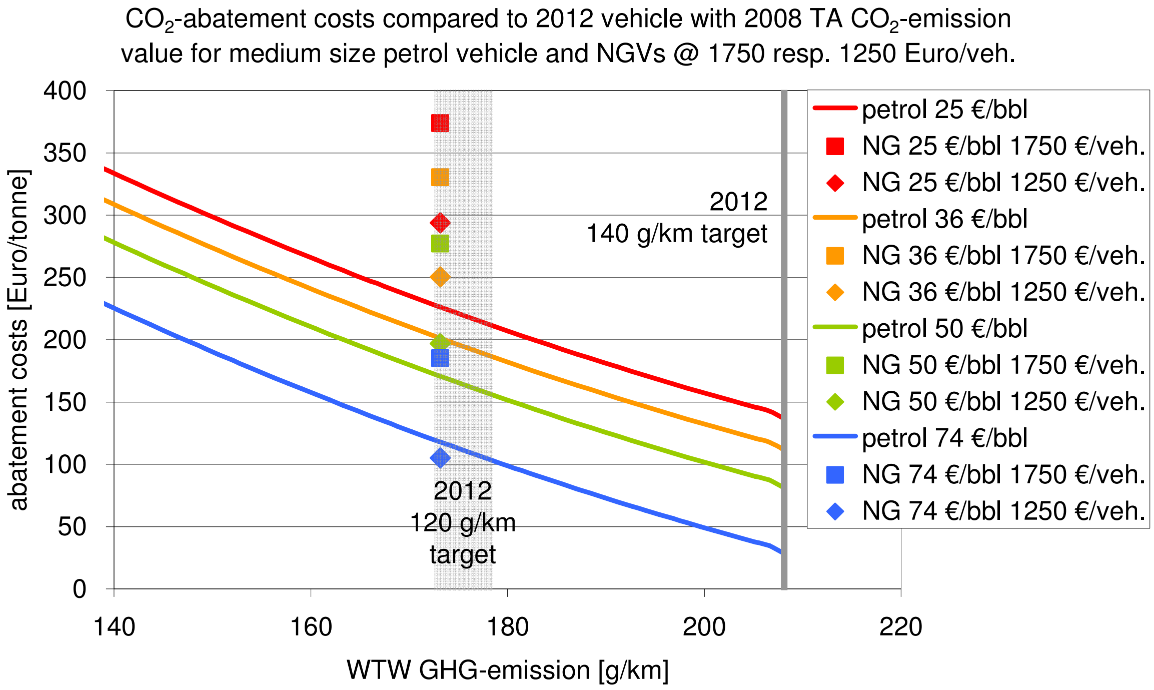

Figure 6.1 Comparison for the case of medium sized petrol vehicles of the CO$_2$-abatement costs for reducing CO$_2$-emissions below the level required for maintaining a sales weighted average of 140 g/km between 2008 and 2012 with the CO$_2$-abatement costs associated with natural gas vehicles based on a 2012 petrol vehicle with a CO$_2$-emission compatible with the scenario of maintaining a sales weighted average of 140 g/km between 2008 and 2012. For the NGVs additional manufacturer costs of 1750 €/vehicle are used as well as an alternative value of 1250 €/vehicle to demonstrate the effect of vehicle costs on the comparison.

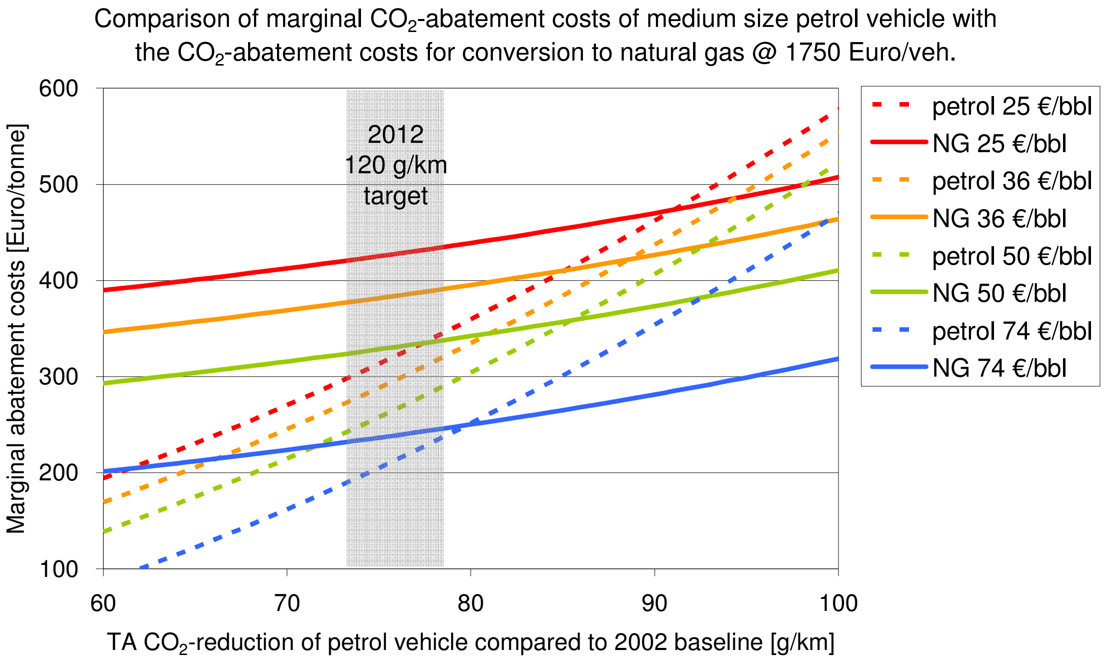

Figure 6.2 Comparison of the marginal CO$_2$-abatement costs for medium sized petrol cars as a function of the TA CO2-emission reduction relative to the 2002 baseline with the CO$_2$-abatement costs associated with converting a petrol vehicle with the same level of TA CO$_2$-emission reduction compared to the 2002 baseline into a natural gas vehicle involving additional manufacturer costs of 1750 €/vehicle as estimated in Table 6.9.

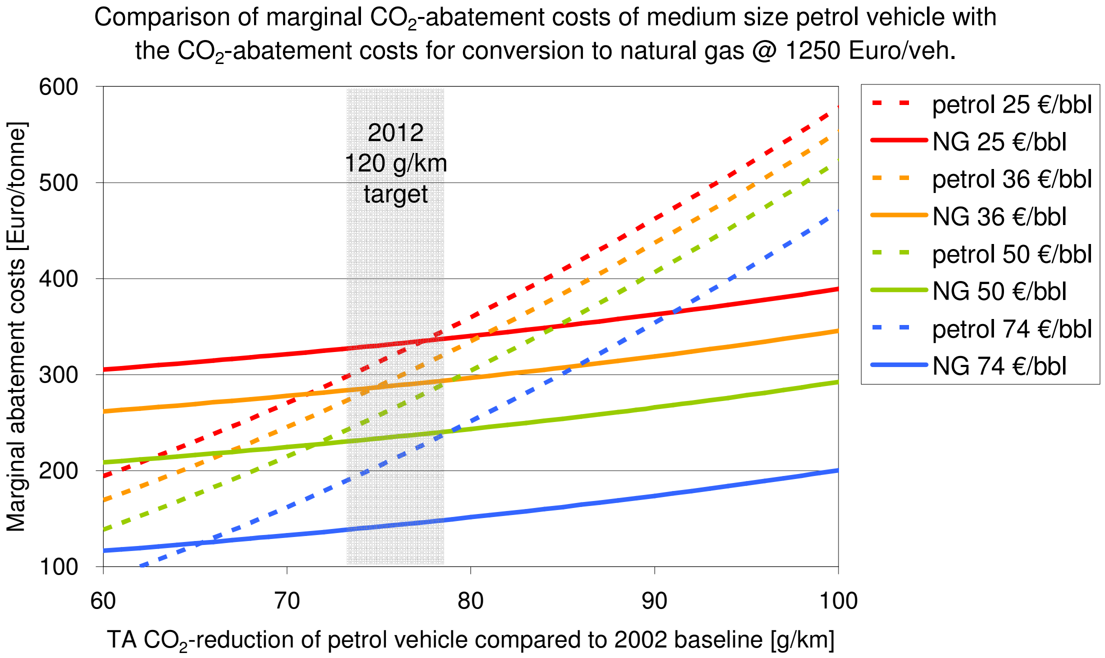

Figure 6.3 Comparison of the marginal CO$_2$-abatement costs for medium sized petrol cars as a function of the TA CO2-emission reduction relative to the 2002 baseline with the CO$_2$-abatement costs associated with converting a petrol vehicle with the same level of TA CO2-emission reduction compared to the 2002 baseline into a natural gas vehicle using a fictitious value for the additional manufacturer costs of 1250 €/vehicle to assess the impact of vehicle costs on the comparison.

Important conclusions from this exercise are:

- The WTW GHG penalty associated with importing natural gas over long distances strongly increase the CO_2-abatement costs of natural gas vehicles;
- The additional manufacturer costs have a significant impact on CO_2-abatement costs;
- Even at a petrol price of 0.60 €/l the abatement costs associated with NGVs are higher than those for efficiency improvement. At the assumed level of additional manufacturer costs, NGVs therefore are not a cost effective solution for reducing CO_2-emissions to the levels foreseen for the 2008 – 2012 timeframe;
- The higher abatement costs for NGVs, compared to technical measures that can be applied to conventional vehicles, are partly due to the high additional manufacturer costs and partly due to the higher fuel price excluding taxes per unit energy for natural gas.
- As natural gas can also be applied to petrol vehicles to which technical measures are applied in order to reach an overall 2012 goal between 140 and 120 g/km, NGVs may play a role in extending the potential for CO_2-reduction beyond 120 g/km. NGVs can be an alternative for the expensive technologies that need to be applied for reaching targets beyond 120 g/km. For the levels CO_2-reduction as foreseen for the 2008 – 2012 timeframe NGVs can only become an interesting alternative if the costs could be reduced significantly below the level estimated in this chapter. When these costs are assumed to be € 1250 instead of € 1750 then NGVs still only become cost effective in the case of high oil prices and 2012 targets below 130 g/km.

6.9 Total reduction potential

The total CO_2-reduction potential (in Mtonnes in a given year or total over a given period) can not be estimated in a simple way, as it depends on the share of NGVs that is assumed in the new vehicle sales in the time period under consideration.

In general the market penetration of NGVs will depend on the type, target and effectiveness of policies employed to stimulate the use of NGVs. The effectiveness of policies influencing the costs of NGVs relative to petrol an diesel vehicles can be assessed in TREMOVE. This would require assumptions on e.g. the levels of tax or subsidy on vehicles and fuel. In this report only a back-of-the-envelope calculation will be given of the total CO_2-reduction potential that can be achieved at different levels of assumed market penetration.

For estimating the overall reduction potential for NGVs two scenarios are assumed for the additional use of NGVs compared to the TREMOVE baseline. In both scenarios NGVs are assumed to replace 10% of the total sales of new conventional vehicles on petrol and diesel in 2012 and beyond. Policies to promote the use of NGVs are assumed to be implemented from 2008 onwards. A linear increase of this additional share[32] is assumed from 0% in 2007 to 10% in 2012. In scenario 1 NGVs are assumed to replace only petrol vehicles, while in scenario 2 NGVs are assumed to replace 10% of new petrol vehicle sales and 10% of new diesel vehicle sales.

Starting point for the calculations is the TREMOVE 2.42 baseline for EU-15. The real-world Tank-to-Wheel CO_2-emissions of NGVs are calculated from the baseline values in the TREMOVE 2.42 baseline using the emission reduction percentage as given in Table 6.9. Calculations of the overall reduction also include well-to-tank emissions based on [Concawe 2006] as given in Table 6.5. It should be noted here that the petrol / diesel shares in the TREMOVE 2.42 baseline are inconsistent with data as used in our report. In this study a 50% / 50% share of petrol / diesel is assumed in the

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[32] Additional sales of NGVs in response to an assumed new policy promoting the use of NGVs, on top of the autonomous development of the market share of NGVs resulting from existing market drives and policies

2008 new vehicle sales and 45% / 55% in 2012. In TREMOVE 2.42 the petrol/diesel share is around 66% / 33% in 2008 and thereafter[33].

Table 6.15 Total annual well-to-wheel GHG-emission reduction (in Mtonnes CO$_2$-eq. p.a.) for EU-15 which can be reached by an additional share of NGVs in new vehicles sales (compared to baseline) ranging from 2% in 2008 to 10% in 2012 and beyond[32].

	WTW GHG emission reduction [Mtonnes/y]	
	2012	**2020**
scenario 1	2.4	7.3
scenario 2	2.1	6.4

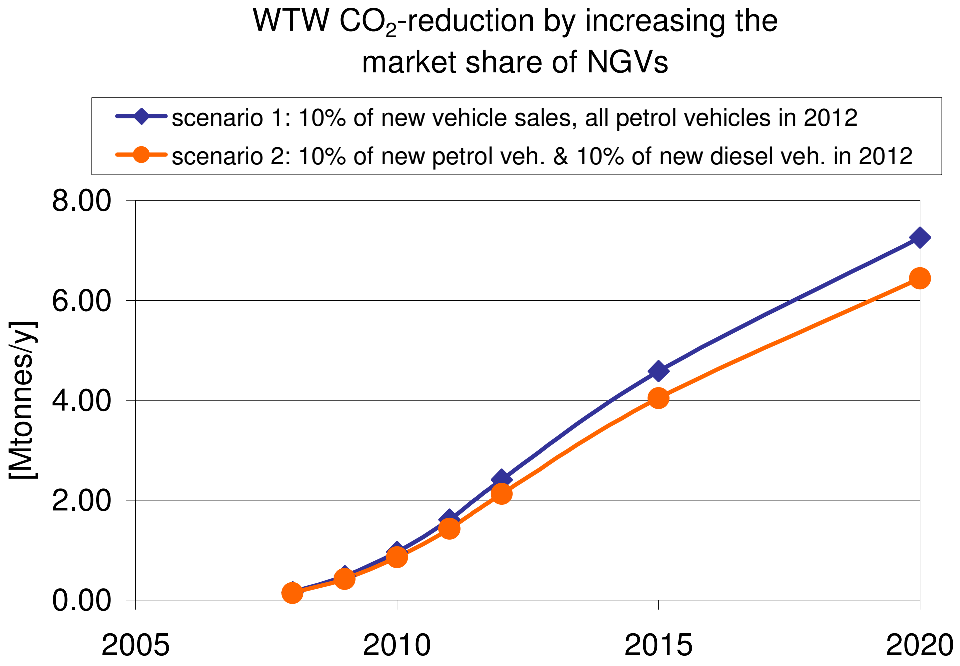

Figure 6.4 Total annual well-to-wheel GHG-emission reduction (in Mtonnes CO$_2$-eq. p.a.) for EU-15 which can be reached by an additional share of NGVs in new vehicles sales (compared to baseline) ranging from 2% in 2008 to 10% in 2012 and beyond[32].

The resulting overall GHG emission reduction for EU-15 is presented in Table 6.15 and Figure 6.4. Due to the relatively low share of diesel vehicles in the TREMOVE 2.42 baseline the difference between scenario 1 and scenario 2 is rather limited. Similar to the case of technical measures applied to petrol and diesel vehicles as presented in section 3.10, the overall reduction resulting from increasing the share of NGVs in new vehicle sales between 2008 and 2012 still increases after 2012 as the share of NGVs in the fleet is still increasing after 2012.

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[33] In a TREMOVE update expected to be released in August 2006 the petrol / diesel shares will be amended to better reflect the historic trend over the past decade and expectations for the future.

6.10 Policy options to promote the use of NGVs

Possible policy measures to promote the use of natural gas in passenger cars (and possibly vans) include:

- a European Natural Gas Vehicle Directive prescribing a minimum percentage of natural gas to be used as transport fuel in Europe (in analogy to the Biofuels Directive);
- fiscal incentives for market development:
    - tax reduction for natural gas vehicles;
    - a long-term tax exemption of natural for use in vehicles;

    Here it should be noted that in the long term NGVs should generate the same tax revenue per vehicle as petrol and diesel vehicles;
- subsidies on natural gas vehicles;
- financial stimulation of the construction of a natural gas distribution infrastructure for transport purposes (pipelines and filling stations);
- national public procurement initiatives or a European Directive;
- incorporation of NGVs in a regulatory policy aimed at reducing the sales weighted average CO_2-emission of passenger cars beyond 2008/9, e.g. by setting legislative targets and applying these to vehicles or to "manufacturer bubbles".

As the WTW/TTW factor for natural gas imported from outside the EU over transport distances of 4000 km or more is actually higher than the WTW/TTW factor for petrol or diesel, the net relative WTW benefit of NGVs driving on such imported natural gas is lower than the relative TTW reduction achieved in direct CO_2-emissions as measured on the type approval test. Including the benefits of NGVs (and possibly also other alternative fuels, specifically biofuels) in a monitoring scheme accompanying legislative or other policy measures aimed at reaching a defined CO_2-emissions reduction would thus preferably include a methodology for dealing with the WTT greenhouse gases for all fuels.

6.11 Output supplied to TREMOVE and Task B

For the output to TREMOVE results are summarised in Table 6.16. The results for CO_2-emission are expressed in relative terms compared to a petrol vehicle with the same level of engine technology.

Table 6.16 Assumed additional costs, additional retail price and CO_2-emission reduction of natural gas vehicles in the 2008 – 2012 timeframe, compared to petrol vehicles in the same size class

	NGVs compared to petrol vehicles		
	small	medium	large
add. manufacturer cost	1450	1750	2050
add. retail price	2090	2520	2950
add. retail price excl. tax	1682	2030	2378
TTW CO_2-reduction	22.0%	22.0%	22.0%
WTW CO_2-reduction	16.7%	16.7%	16.7%

Detailed output for use in TREMOVE, including a calculation of absolute CO_2-emission factors for NGVs in relation to the development of the CO_2-emissions of petrol vehicles under various scenarios and the interpolation of values for years between 2008 and 2012, is specified in a separate spreadsheet delivered to TML and the European Commission.

6.12 Conclusions

- The additional manufacturer costs of medium sized natural gas vehicles (NGVs) compared to equivalent petrol vehicles is estimated at around €1750 per vehicle. Compared to equivalent petrol vehicles the direct (exhaust or Tank-to-Wheel (TTW)) CO_2-emissions of NGVs are about 22% lower;
- Emissions of methane (CH_4) only marginally reduced the greenhouse gas reduction potential of NGVs. Including CH_4 and other greenhouse gases (mainly N_2O) in the comparison between petrol, diesel and natural gas does not significantly influence the outcome of the assessment;
- The abatement costs of reducing CO_2-emissions from passenger cars by means of natural gas depend strongly on the price of oil and the costs of natural gas at the filling station, as well as on the origin of the natural gas. Longer transport distances incur relatively high Well-to-Tank (WTT) emissions that counteract the TTW benefits to some extent. For this study it is assumed that most of the additional natural gas consumed between 2008 and 2012 by NGVs will be imported from outside Europe with an average transport distance of 4000 km. Using the WTW-assessment made in [Concawe 2006] for this fuel chain the net WTW CO_2-emission reduction compared to petrol vehicles is about 17% for this case;
- Including the benefits of NGVs (and possibly also other alternative fuels, specifically biofuels) in a monitoring scheme accompanying legislative or other policy measures aimed at reaching a defined CO_2-emissions reduction would thus preferably include a methodology for dealing with the WTT greenhouse gases for all fuels;
- Even at a petrol price of 0.60 €/l (oil price = 74 €/bbl) NGVs are not a cost effective solution for reducing CO_2-emissions given the level of additional manufacturer costs as estimated in this study. CO_2-abatement costs range from around 350 €/tonne at an oil price of 25 €/bbl to 190 €/tonne at 74 €/bbl;
- Compared to technical measures that can be applied to conventional vehicles, NGVs are a less cost effective option for reaching a 2012 target of e.g. 120 g/km, are partly due to the high additional manufacturer costs and partly due to the higher fuel price excluding taxes per unit energy for natural gas. As a result of the latter NGVs have higher fuel costs (excl. taxes) than baseline petrol vehicles to which the natural gas technology is applied, while more efficient petrol vehicles have a net fuel cost reduction compared to the same baseline;
- As natural gas can also be applied to petrol vehicles to which technical measures are applied in order to reach an overall 2012 goal between 140 and 120 g/km, NGVs may play a role in extending the potential for CO_2-reduction beyond 120 g/km. NGVs can be an alternative for the expensive technologies that need to be applied for reaching targets beyond 120 g/km. For the levels CO_2-reduction as foreseen for the 2008 – 2012 timeframe NGVs can only become an interesting alternative if the costs could be reduced significantly below the level estimated in this chapter. When these costs are assumed to be € 1250 instead of € 1750 then NGVs still only become cost effective in the case of high oil prices and 2012 targets below 130 g/km.
- Assuming a linear increase of the additional share of NGVs in new vehicle sales from 0% in 2007 to 10% in 2012 and a constant share of 10% after 2012, the total GHG reduction potential for EU-15 is estimated at 2.1 – 2.4 Mtonnes/y in 2012 growing to 6.4 – 7.3 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

6.13 Literature

[TNO 2003]	*Evaluation of the environmental performance of modern passenger cars running on petrol, diesel, automotive LPG and CNG*, P. Hendriksen et al., TNO-report 03.OR.VM.055.1/PHE, TNO Automotive, December 2003
[Concawe 2003]	*Well-to-Wheels analysis of future automotive fuels and powertrains in the European context*, Concawe / Eucar / JRC, December 2003.
[Concawe 2006]	*Well-to-Wheels analysis of future automotive fuels and powertrains in the European context*, Concawe / Eucar / JRC, update of the 2003 study, January 2006.
[GM 2002]	*GM Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study*, L-B-Systemtechnik GmbH, September 2002
[GVR 2005]	*Gas Vehicle Report* (GVR), issue December 2005

7 Review of options to promote application of biofuels

7.1 Goal of Task 1.9

The goal of this Task is to assess the likely contribution of a range of biofuels to future passenger car fuelling arrangements over the study period, and to give indications of the CO_2 and broader GHG emissions implications, and costs, of these developments.

As agreed, the assessment on this topic should be quantitative, not qualitative as originally suggested. The consortium should take account of different levels of subsidies and different expected level of biofuel penetration in different EU-countries in the cost assessment of this option. This should be able to be based largely on reports under the Biofuels Directive and the questionnaire responses.

7.2 Approach

- Review the literature on the state of play (technical and policy) on biofuels, and likely future developments.
- Technical review of the emissions implications of biofuels (e.g. moving to WTW assessment; reflecting sources, growing regimes and processes as well as products, including non-CO_2 emissions balance, etc.).
- Collect recent information from Member States by means of a questionnaire.
- Outline possible developments in this area, both policy and technical.
- Analyse evidence relating to costs of infrastructure, fuel sources, production, etc., based on existing literature.
- Review subsidies and other incentives, in order to provide indicative cost incidence of such programmes.

7.3 Technical description

There are a range of biofuels used in transport, with varying degrees of current uptake and future potential. Most common are biodiesel, bioethanol and bio-ETBE. Box 2 presents a summary of the key fuels. The difference between 1st and 2nd generation biofuels is explained in Box 1.

This wide range of products can be derived from various feedstocks via a range of processes. Currently the main feedstocks are crops grown for oil (such as rape, soya and sunflower) that is esterified to biodiesel, and crops high in sugar or starch (including sugar beet and cane, various grain crops, etc) from which ethanol is produced. Ethanol can be further modified through chemical processes to produce ETBE as a fuel additive.

Box 1: First and Second Generations

In the box below, biofuel options are characterised as 'first generation' – i.e. those available now using a range of relatively simple processes (esterification, fermentation, digestion) – and a 'second generation' of those that may become available in future from more advanced processes (gasification, enzyme treatment, Fischer-Tropsch process, etc). It is important to stress that this designation refers primarily to the production process rather than the end result – for example, bioethanol could be produced through both 1st and 2nd generation processing routes, whereas biodiesel as currently understood is primarily a 1st generation fuel, while new and more advanced synthetic fuels are expected to emerge only under 2nd generation processes.

Broadly speaking, while first generation processes (for liquid biofuels) rely mainly on crops usually grown for food, second generation processes offer the prospect of using a wider range of feedstocks including woody (lignocellulosic) materials. The latter offers the prospect of using most or all of the source plants (e.g. wood and straw as well as seeds, nuts or pulses) and a wider range of waste materials (e.g. forestry waste, biodegradable municipal solid waste). As well as more efficient utilisation of resources, these processes tend to be more efficient in energy terms and may also reduce agricultural inputs, and for these reasons it is expected that they will typically offer greater greenhouse gas savings at lower unit costs.

However, none of these processes has yet advanced beyond the stage of demonstration plants, so they are unlikely to make a significant contribution during the period covered by this study. As an indicator, however, some indications of future costs and benefits of biomass-to-liquid (BTL) technology is included.

It should be stressed that even the list of Box 2 is not the full range of possibilities, but this report focuses on those currently available. Therefore most second generation pathways are excluded from detailed analysis, and it has been agreed to focus further work on the following (mainly first generation) fuels:

- Bioethanol
- Biodiesel (also known as RME, FAME, VOME, as appropriate)
- ETBE
- BTL (2nd generation – primarily for comparative purposes)

At current levels of blending, in most EU countries ethanol is being utilised in the form of ETBE. Note however that ETBE is a by-product produced in some refineries; and there is a limit to the scale of production available, so it is difficult to predict what the future ratio will be. Outside Europe, in contrast, use of ethanol already predominates over ETBE. National plans do not address this point, but if the prevalence of ETBE were to remain high then the greenhouse gas savings would be somewhat lower than those reported in the literature for ethanol; otherwise, if ethanol takes a growing overall share of fuel penetration, then it is likely that more will need to be used as pure ethanol rather than ETBE. For the purposes of this exercise, however, ETBE is therefore treated as part of the ethanol stream. Biomass-to-Liquids (BTL) is included for comparative purposes; it is not implied that it will contribute significantly to total fuel supplies until well after 2010.

Note also that the cost and WTW greenhouse gas emissions characteristics of ethanol produced in Europe and that imported from Brazil are sufficiently different that they are treated separately below.

Box2: Biofuel types

What follows is not a complete list of biofuels, but the most likely options either now or in the future are as follows:

Biodiesel: a methyl-ester produced from vegetable or animal oil, of diesel quality - produced from oily seeds such as rape seeds, sunflower seeds, etc. The full technical terms for biodiesel include fatty acid methyl ester (FAME) or vegetable oil methyl ester (VOME). The most common form of biodiesel in Europe is RME (rapeseed oil methyl ester)[34]. This is a *1st generation* process.

Bio dimethyl ether: dimethyl ether (DME) produced from biomass can be used in heavy duty diesel engines with some modification. However these are then dedicated to DME and a separate refuelling infrastructure is needed, so DME is most likely to be used in captive fleets. This is a *2nd generation* process.

Bioethanol: ethanol produced currently mainly from crops containing sugar or starch such as sugar cane, sugar beet, maize, wheat, etc.)[35] Alternative methods using biomass and/or the biodegradable fraction of waste are also expected . This can be produced by both *1st and 2nd generation* processes.

Biogas: a fuel gas produced from biomass and/or from the biodegradable fraction of waste, that can be purified to natural gas quality and used in adapted spark-ignition engines. This is a *1st generation* process.

Bio hydrogen: hydrogen produced from biomass, and/or from the biodegradable fraction of waste. This is a *2nd generation* process.

Bio methanol: methanol produced from biomass. This is likely to be a *2nd generation* process.

Bio-ETBE (ethyl-tertio-butyl-ether): ETBE produced by chemical reactions from a feedstock of bioethanol. This is used primarily as an additive to petrol to improve performance. The percentage by volume of bio-ETBE that is calculated as biofuel is 47%.

Bio-MTBE (methyl-tertio-butyl-ether): a fuel produced on the basis of bio methanol, similar to the above. The percentage by volume of bio-MTBE that is calculated as biofuel is 36%.

Pure vegetable oil: oil produced from oil plants through pressing, extraction or comparable procedures, crude or refined but chemically unmodified. It can be used in some suitable heavy duty diesel engines, but otherwise is likely to cause damage; more commonly used as a feedstock for VOME.

Synthetic biofuels: synthetic hydrocarbons or mixtures of synthetic hydrocarbons which have been produced from biomass. This is a *2nd generation* process.

Based on http://europa.eu.int/comm/research/energy/nn/nn_pu/renews/003/article_2275_en.htm

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[34] The European standard EN 590 allows up to 5% (vol.) RME in diesel. This is equivalent to 4.6% of energy content.

[35] Under the EU Fuels Directive and CEN standard EN 228, the maximum amount of ethanol which may be mixed with petrol is 5% (vol.). Petrol mixed with far higher proportions of ethanol may be sold, but in this case no reference may be made to EN 228. Such petrol is usually used in special engines, and a CEN Workshop Agreement (CWA) exists for E85 and is considered adequate for the current level of use. Under the ongoing review of the Fuels Directive, an increase in the level of ethanol in standard blends to 10% is under consideration; if this occurs, it will automatically lead to a review of EN 228.

7.4 Assessment of effectiveness for CO_2 emission reduction

As they are composed mainly of organic carbon compounds, biofuels emit carbon dioxide from the vehicle exhaust in significant quantities when they are burned as fuel. However they offer benefits over mineral fuels because this carbon was absorbed from the atmosphere as the source plants grew, rather than being released from underground storage as is the case with fossil fuels. However few if any biofuels are truly 'carbon neutral' because additional greenhouse gas emissions are generally incurred in their production, e.g. through use of machinery, heating, emissions from soils; but most do offer a net greenhouse gas (GHG) benefit relative to fossil fuels.

However, the range of GHG savings is very significant, with savings of above 80 per cent relative to fossil fuels possible in some cases (currently this would be sugarcane ethanol from Brazil, which benefits from very high growth rates, high sugar content, and the use of the waste bagasse for process heat, thereby minimising inputs from fossil fuels). Against this the worst case examples can actually be worse than their fossil counterparts. The first generation options that can be produced in Europe tend to fall in the middle of this range, with methyl esters typically giving 40 to 60 per cent reductions in carbon. Ethanol is typically at or below the bottom end of this range, but better performance is possible, and the result varies significantly according to what method is used to provide process heat in particular.

As noted above, second generation biofuels seem likely in general to offer greater GHG benefits and greater cost-effectiveness, but are not yet commercially available.

Notwithstanding reservations expressed by eBio [eBio 2006] on the value of using WTW analysis in this study, this approach is essential and unavoidable if real GHG savings are to be meaningfully balanced between a range of policy options under the Integrated Approach. For the purposes of modelling in Task B, it is proposed therefore that the GHG savings arising from a representative range of biofuels available in Europe might be within the following ranges. Note that these values are not intended to represent the full or extreme range of possible GHG outcomes, but a representative range of values found in the literature for the technological options typically used or likely to be used in Europe.

Table 7.1 Indicative Percentage WTW reductions in CO2eq for a range of Biofuels

Fuel	High	Central	Low
Brazilian sugarcane or lignocellulosic bioethanol	90	80	70
European bioethanol	60	50	40
Biodiesel	60	50	40
BTL	95	85	75

The range of results found in the literature reflects in part differences in methodological approaches between different studies, but also to a large extent the genuine differences in GHG outcomes between different combinations of feedstock and production process. Section 7.7 addresses *inter alia* options for certification of biofuels to reduce uncertainty ranges regarding the levels of GHG reduction that will actually be achieved.

Biofuels can be burned in dedicated vehicles with modified engines to accommodate their slightly different physical and chemical properties. Thus far these vehicles are largely confined to captive fleets, however, as it would be very expensive to install a new fuelling infrastructure on a wide scale. Instead a larger share of the total biofuel currently being consumed in Europe is blended into conventional fuels, as upwards of 5 per cent by volume can be added without any effect on a conventional internal combustion engine, and produces an equivalent level of GHG saving, typically at lower cost. In either case, this replaces some demand for fossil fuel and thereby saves carbon and possibly other GHGs. In either case, this replaces some demand for fossil fuel and thereby saves carbon. Currently the proportion in blended fuels is limited to 5 per cent owing to both specifications in fuel standards and the limitations on warranties for use of biofuel offered by car manufacturers; but it should be possible in future to offer higher proportions than this.

7.5 Assessment of CO_2-abatement costs

Biofuels have historically been relatively expensive, around €0.5/litre for biofuels, compared with €0.2 to €0.25 per litre pre-tax cost for oil-based fuels at US$30/barrel. The current high oil price reduces, but in most cases does not eliminate, this cost gap. Feedstock prices may also change over time to reflect growing global demand for both fuel and food.

Fulton (2004) argues that, of the conventional biofuels currently available, ethanol from Brazilian sugar cane is by far the most competitive in terms of cost, with an incremental cost relative to petrol of only 5-15 US cents per litre, giving CO_2 savings at abatement costs of US$25-50 per tonne. Grain ethanol is considerably more expensive to produce – he estimates it at between $200 and $500 per tonne of CO_2 abatement, reflecting both the higher unit costs and a significantly lower net CO_2 reduction per unit. Cost estimates from the Concawe/JRC/Eucar study are of the same order of magnitude.

In the near term, he estimates that lignocellulosic ethanol could produce CO_2 reductions at abatement costs of $200 per tonne, becoming cheaper than ethanol from most conventional crops, and even eventually becoming competitive with petrol 'if world oil prices remain in the US$30/barrel range' – which seems a very low figure at the time of writing. In the medium term he argues that, owing in part to much lower feedstock costs, production either of ethanol from hydrolysis or synthetic fuels via the Fisher-Tropsch process should fall below $100 per tonne of CO_2 abatement post-2010.

However, a wide range of costs is quoted in the literature, and these vary substantially according to the economics and yield of the feedstock chosen, costs and efficiency ratings of the various stages in the transformation process, and the prices available for co-products. The table below presents the cost ranges reported in three recent studies that are deemed to be relatively authoritative and to reflect these ranges – [Ecofys 2003], [Concawe 2006] and [Sheffield Hallam 2003], plus a further recent review of the evidence [VIEWLS 2005].

The Concawe/Eucar/JRC (2003) study illustrated a wide range in costs per tonne of CO_2 abated relative to conventional fuel costs. This study has now been fully updated [Concawe 2006] and estimates improved in some areas. As a result the ranges have narrowed, but still reflect some uncertainty as to future costs, and more importantly, variations between different feedstock and production methods. All the current biofuel options show positive costs relative to oil at the lower cost range assumed for oil (€25 per barrel) – less than half of that which prevails at the time of writing. However the figures are much more favourable with oil at €50 per barrel, with some second generation options now appearing positively cost-effective against conventional fuels, and hence saving CO_2 at zero or negative cost. Thus there remain cost barriers to biofuels, and these are large in some cases once various subsidies as well as direct costs are taken into account – but some options are significantly closer to economic viability if high oil prices persist.

For ethanol, the VIEWLS figures (and to a lesser extent Ecofys) appear high in the table above, while CONCAWE and Sheffield Hallam give quite good agreement. For biodiesel Ecofys and VIEWLS present a wider range, but all estimates centre on values around 15-20€/GJ.

Table 7.2 Range of Estimated Production Costs of Biofuels

Fuel	[Ecofys 2003]	Concawe/Eucar/JRC [Concawe 2006]	[Sheffield Hallam 2003]	[VIEWLS 2005]
	Cost in €/litre	Cost in €/GJ	Cost in GB£/litre	Cost in €/GJ
Ethanol	0.59-0.63 [25.7-27.4]	13.8-20.0	0.16-0.37 [10.2-23.7]	29-67 (best estimate 40)
ETBE	0.45-0.48 n/a			28-72 (best estimate 45)
Biodiesel	0.49-0.95 [15.8-30.6] (best estimate 0.73 [23.5])	16.4-18.5	0.44-0.47 [20.9-22.3]	9-26 (best estimate 17)
Petrol/Diesel @ €25/bbl		6.2		
Petrol/Diesel @ €50/bbl		12.3		

Notes: Figures in square brackets translate estimates into €/GJ
Low end Hallam ethanol figure is production cost for Brazil – not considered by Ecofys
Concawe/Eucar/JRC costs are 2005 data

Note that, as biofuel products are already traded globally and are likely to be more so, no studies suggest a strong supply constraint or conversely that substantial additional economies of scale are available relative to the current position for first generation fuels. Major price fluctuations are therefore not expected. However, some countries that are increasing biofuel production are apparently doing so primarily or at least in part to provide domestic supplies as a hedge against high oil prices [WorldWatch 2006]. It is also extremely difficult to estimate what share of the global market in future will be accounted for by European demand, as it is unclear what proportion of future national plans will be fulfilled by ethanol as opposed to biodiesel or other options; or what part of this will be supplied from domestic production rather than imported; or how rapidly global supply will expand to meet any future demand. The latest Biofuels Barometer [EurObserver 2006] notes that currently the EU’s biofuel production capacity is significantly underutilised on average, and projects significant annual growth in coming years. This is expected to reach nearly 10Mtoe in 2010, which can be set against the 5.75% target in the Biofuels Directive that equates to approximately 18Mtoe. However, given that this target is unlikely to be met, the projections suggest that around 70% of EU-25 biofuel demand could be met from domestic production sources in 2010. The European Environment Agency [EEA 2006] has also estimated that agricultural feedstock sufficient to produce around 47Mtoe of bioenergy could be available from sustainable European sources by that date; and while not all of this would be available for first generation biofuels, this indicates that the available domestic resource could be more than sufficient for projected production plans.

With this in mind, and reflecting the ‘balanced approach’ that is envisaged between domestic production and imports, an indicative estimate suggests that European demand for imports of biofuels or feedstocks by the end of the decade might constitute around 10 per cent of the total world trade, or at most up to 20%. Bearing in mind that there are active plans to increase feedstock and fuel production in many areas worldwide, although subject to the uncertainties noted above, this seems to represent a significant share, but probably not enough to result in major shortages or price shocks.

As a result, price is not expected to rise significantly with respect to demand, so the cost curve is a flat line for each fuel. Prices would on the other hand be expected to rise partly in line with oil price, partly as this pushes up production and transport costs, but also because biofuel prices have shown a tendency to track the price of oil. [Worldwatch 2006] in particular emphasises that internationally traded ethanol is currently a 'price taker' that follows the price of oil, although this is partly a reflection of the very small size of the international market relative to that of petroleum products. Thus this effect may diminish in the future; but a sensitivity analysis is included below to consider the impact of the possibility that biofuel prices will continue to track the price of oil.

However the abatement cost of carbon-equivalent savings reduces as oil price rises. As the global market for ethanol is still developing and its price relationship to oil has been volatile in recent years, it is not possible to predict the nature of this relationship reliably for the future; but the 'high' and 'low' estimates offer some indication of this effect. A sensitivity analysis is also included below to illustrate the effect on abatement costs if biofuels track the price of oil.

From the figures above, the following range of biofuel prices is proposed for cost-effectiveness analysis. Again, this illustrates an indicative range of the most likely outcomes expected from the literature. The Biomass Action Plan noted EU ethanol costs at around 22 Euro per GJ and biodiesel at around 18 Euro per GJ. The latter is in full agreement with the values in the literature as reflected in Table 7.3, while the former is slightly above the mid-point of the rather wider range of estimates for European ethanol, and outside the range quoted by Concawe/Eucar/JRC [Concawe 2006] for the main options. These differences are not great enough to have a significant impact upon the conclusions, however.

Table 7.3 Indicative production costs in €/GJ for a range of biofuels

Fuel	**High**	**Central**	**Low**
Brazilian sugarcane bioethanol	14	12	10
European bioethanol	25	19	13
Biodiesel	22	18	15

As noted above, Fulton [2004] anticipated that costs would fall as second generation fuels were developed. CONCAWE [2005/6] also indicates lower costs for the best second generation options, with ethanol from wheat straw estimated at below the cost of conventional fuels with oil at €50 per barrel.

Combining the figures in Table 7.3 above with the estimates of potential carbon equivalent savings percentages from the previous section, it is now possible to produce estimates of the cost of GHG abatement set against a range of oil price assumptions (which is the main external variable that needs to be considered). For each of the two main fuels, it incorporates high, medium and low estimate cases of CO_2-abatement costs. In each case, the central estimate is a combination of the central estimates with respect to both cost and CO_2 abatement percentage. Also for each abatement case, the high abatement cost case reflects the high end of the cost range combined with the low end of the CO_2 abatement estimate range; and vice versa for the low abatement cost case.

The results of this calculation are shown in Figure 7.1 below. This graph illustrates that the net cost of CO_2 equivalents avoided is quite strongly dependent upon the price of oil assumed, as the cheaper biofuel options in particular become much more attractive commercially as fuel price rises. Indeed in this illustration, the cost of CO_2 equivalents avoided falls below zero on the assumption of a high oil price and even the most pessimistic assumptions around Brazilian bioethanol cost, and is significantly negative on high oil price assumptions. It should be stressed, however, that these assumptions (particularly with respect to price) do not apply to current European bioethanol production, which only approaches the lowest costs on optimistic price assumptions, and the net abatement cost does not fall below €50/tCO_2eq avoided even at the high oil price. European biodiesel falls between these two extremes, falling to near zero abatement cost with the highest oil price modelled.

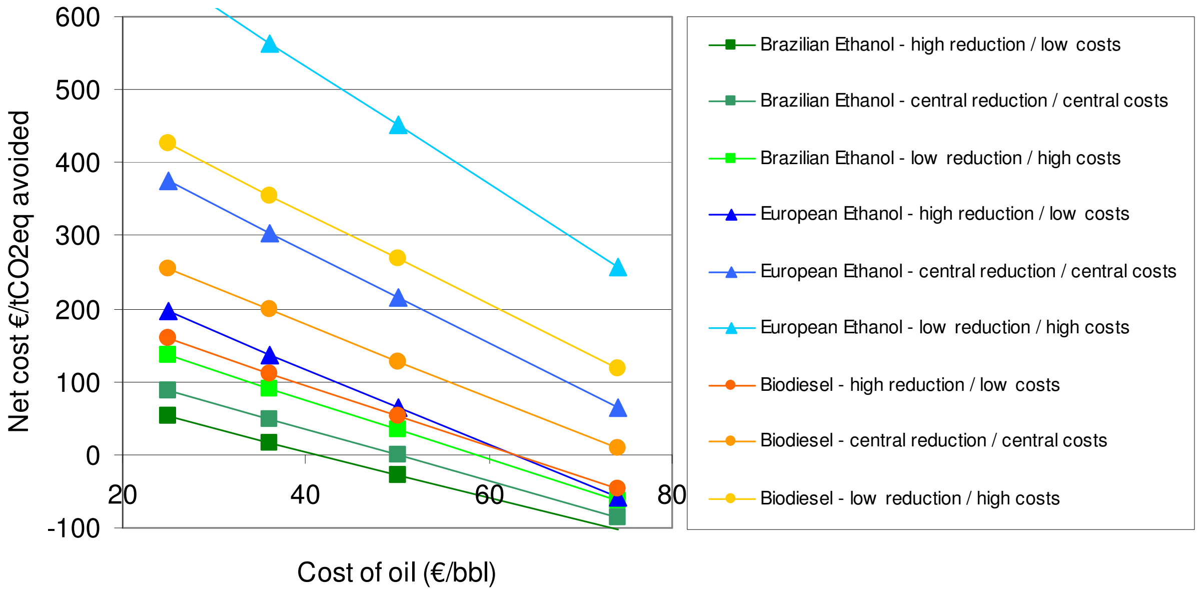

Figure 7.1 CO_2-abatement costs of biofuels as a function of oil price (base case)

Looking at the figures in greater detail (Table 7.4) it can be seen that all the options have a positive avoidance cost at the lowest oil price assumptions – although this cost varies by an order of magnitude from some tens of euros per tonne of carbon dioxide equivalent avoided up to several hundreds. For all options the cost falls as the oil price rises, with Brazilian ethanol becoming negative in net cost at around €50/bbl on the central cost-effectiveness range, or even lower if its cost-effectiveness turns out to be high. That is, at these conditions it not only saves carbon, but is also cheaper than the conventional fuel that it displaces. With oil at €74/bbl, Brazilian ethanol has significant negative abatement costs on even the most pessimistic cost-effectiveness assumptions (but note also the alternative case below). Only at the highest oil prices and on optimistic cost-effectiveness assumptions do European biofuels reduce CO_2 at a negative cost per tonne, however, but the cost per tonne is reasonably low on central assumptions at €50/bbl or above for biodiesel. European ethanol remains relatively expensive under most cost assumptions. Biodiesel falls between the two ethanol cases, falling to around €50/tCO_2eq avoided only with oil at more than €50/bbl at the high end of its cost-effectiveness range, and it only becomes significantly cost-competitive with conventional diesel on the most optimistic cost assumptions and with the highest oil price.

Table 7.4 Net cost in €/tCO_2eq avoided

Fuel	CO_2-abatement costs range	Assumed cost of oil (€/bbl) 25	36	50	74
Brazilian Ethanol	High	51.9	16.0	-27.7	-103.3
	Central	88.8	48.5	-0.7	-85.8
	Low	136.3	90.3	34.0	-63.2
European Ethanol	High	195.6	137.0	65.4	-58.3
	Central	374.5	302.9	215.4	64.1
	Low	655.6	563.6	451.0	256.6
Biodiesel	High	158.5	111.0	53.0	-47.2
	Central	254.9	197.9	128.2	7.9
	Low	426.3	355.1	268.0	117.7

To address the possibility that biofuel prices will continue to track the price of oil, a sensitivity analysis was undertaken in which European biofuel prices never fall below that of oil, and Brazilian ethanol never falls below 90% of the price of that produced in Europe. The results of this exercise are illustrated in Figure 7.2 below.

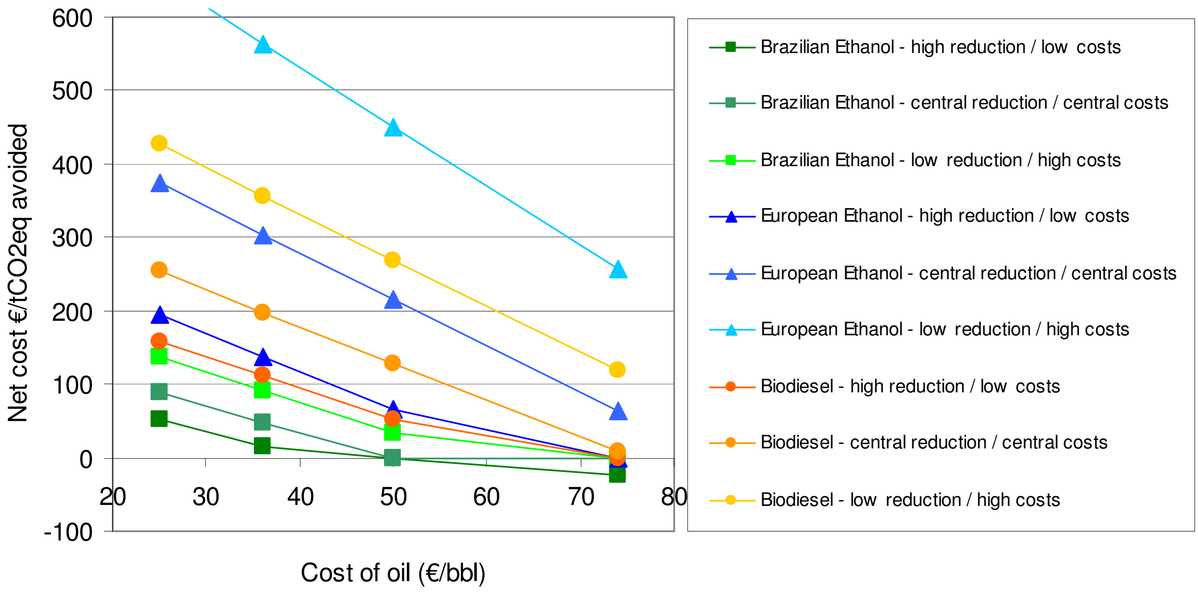

Figure 7.2 Cost effectiveness of biofuels as a function of oil price ('price taker' case)

These alternative 'price taker' assumptions have very little impact on the price or abatement costs of European biofuels, because only with the highest oil price and optimistic cost assumptions do they ever reach equivalence with the price of oil-based fuels. In these cases, however, the impact is that their abatement costs never achieve negative values and only ever fall to zero no matter how high the oil price. For Brazilian ethanol, however, these alternative assumptions pose a rather greater constraint, in that only under very specific and limited conditions does their abatement cost now become negative; otherwise their abatement cost falls to zero with oil price at around €50/bbl, but does not become negative if the oil price goes above this threshold.

Note that, in principle, if biofuel prices rise for reasons other than production costs this does not affect the overall societal costs if the fuel is produced in Europe – because extra cost for some is balanced by extra profit for others – but it is a cost to 'EU Inc' if the fuel is imported from outside the EU. This however is likely to be rather a simplification if the market for biofuels becomes more global and more profitable. That is, European companies are likely to invest increasingly in biofuel production plant and plantations outside Europe, and vice versa, so profits will be shared. Also, oilseed crops from outside Europe are quite likely to be imported and then processed in plants inside the EU, in which case a significant share of the value added will be in Europe.

7.6 Methodological issues

Extending the current approach based on tailpipe CO_2 emissions to include biofuels gives rise to three separate, but related, issues:

- *The consideration of WTW emissions.* For conventional fuels and vehicles, not only do tailpipe CO_2 emissions form the largest part of the total 'well-to-wheel' (WTW) emissions, but also the relationship between the two figures is similar for petrol and diesel fuels. As a result, tailpipe emissions of CO_2 are a good and easy-to-measure proxy for full WTW emissions and are, therefore, an appropriate focus of policy for a fleet that primarily uses conventional fuels. However, when moving towards a greater use of biofuels, this is no longer the case, as there is no fixed relationship between tailpipe emissions and WTW emissions. Furthermore, the latter can vary enormously between two apparently similar fuels derived from different sources or produced by different methods.
- *The consideration of other greenhouse gas emissions.* Similarly, the CO_2 emissions of conventional fuels are the dominant element of total greenhouse gas emissions arising from fuel combustion. With biofuels, however, other greenhouse gases such as nitrous oxide from soils can be a major component of the total greenhouse gas balance in some cases, so a weighted average reflecting the global warming potential (GWP) of each gas is needed for a true comparison.
- *Reflecting whole life and whole fleet emissions.* One advantage of biofuels is that they can be used (in certain forms notably low-level blends) in existing as well as new cars, and for other vehicle types as well that are currently outside the scope of the passenger car strategy. For this reason a different metric is needed to express the amount of carbon saved.

Thus an expansion of the Integrated Approach to reflect the use of biofuels used would have important implications for the metric used and possibly the method of monitoring; most likely the total emissions would need to be calculated in terms of total CO_2-equivalent emissions, or a net saving relative to conventional fuel.

Note: It has been suggested that the contribution of biofuels might instead be reflected in the CO_2 performance of new car models – i.e. reducing the measured tailpipe emissions in terms of g/km by a given percentage to reflect the WTW benefits of biofuels. However, this approach is not particularly meaningful for a number of reasons. (i) Biofuels (say) might be blended into fuels used at differential levels in all types of vehicles (and not just new ones), so it makes little sense to translate the benefit into figures for new cars alone. (ii) In spite of the reference levels in the Biofuels Directive, it is clear that levels of biofuel use will vary significantly from one Member State to another, and this will mean that the WTW emissions from a similar vehicle will differ from place to place. (iii) Even with a dedicated vehicle (and hence known level of biofuel use), the WTW emissions will also vary according to the source of the biofuel and the process used to make it.

7.7 (Enhanced) policy measures

Thus far the main Community measure to promote biofuels in transport has been the Biofuels Directive 2003/30/EC, setting indicative 'reference levels' for biofuel use in each Member State. The Directive requires Member States to ensure that a 'minimum proportion' of biofuels is put on the market and in order to do these national indicative targets should be set. A reference values for the targets are set at 2 per cent at the end of 2005, rising to 5.75 per cent in 2010 – if Member States targets differ from these reference values they must provide justification to the Commission. Fuels covered by the Directive include: pure biofuels or at high concentration in mineral oil derivatives; biofuels blended in mineral oil derivatives; and liquids derived from biofuels, such as ETBE.

A wide range of policies has been, and is being, put in place to encourage uptake of biofuels in the various Member States and some municipalities. These include direct market measures and quotas, supplemented by a large and various range of supporting measures, including direct subsidies for crops and production plants. Fuel duty reductions reflecting the biofuel content of blended fuel, and in some cases for pure biofuels, are also quite widespread. Some countries are also developing dedicated biofuel fleets through public procurement – e.g. an ethanol bus fleet in Stockholm.

Box 3: National Measures in support of Biofuels

A substantial body of information on national policy measures is now emerging. Some Member States are vigorously supporting transport biofuel use, and intend to reach or even exceed the indicative targets of the Biofuels Directive. Others in contrast are doing very little and do not anticipate coming even close to the target. Initial support measures were largely in the form of reductions in fuel duty for biofuels and biofuel blends, but an increasing number of Member States are now actively considering supply obligations or other forms of quotas for the supply of biofuels. Incentives and subsidies are also being offered to encouraged fuel production. The Annex includes a table with examples of recent and planned national measures.

The Commission's Biomass Action Plan was issued in December, and a Strategy in February. These place much more emphasis than previously on second generation biofuels, but recognise that these will not be commercially available until after 2010. The Commission therefore reasserts the need to press ahead with first generation fuels in the interim, but notes that the reference values of the Biofuels Directive are unlikely to be achieved. Therefore mandatory targets might be considered in future, but the Member States might block this as they did when the measure was first proposed.

In a public consultation document prepared by DG TREN, a range of Community-level policy options is set out to enhance the penetration of biofuels in the EU market.

- *Option A*: The biofuels directive is amended to fix targets for each Member State. These targets are mandatory – that is, failure to achieve them automatically places the Member State in breach of Community law.

- *Option B*: The system of fixing national indicative targets is retained. The biofuels directive is amended to state explicitly that, once fixed by Member States, these targets are mandatory.

- *Option C:* The system of fixing national indicative targets is retained. The biofuels directive is amended to define more precisely the circumstances under which these targets may differ from the reference value.

- *Option D*: The biofuels directive is amended to require Member States to use biofuel obligations (requiring fuel suppliers to incorporate a given percentage of biofuel in the total amount of fuel they place on the market) as a tool to achieve national targets.

- *Option E*: A biofuel obligation is imposed at Community level on each fuel supplier.

- *Option F*: The fuel quality directive is amended to permit Member States to impose mandates on fuel suppliers (laying down a minimum proportion of biofuel to be contained in each litre of fuel sold).[36]

- *Option G*: The fuel quality directive is amended to require all fuel sold in the EU to contain minimum proportions of biofuel (a European mandate).

- *Option H*: The Commission attempts to negotiate with the oil and car industries a voluntary agreement to achieve the 5.75% reference value.

- *Option I*: A forecast is made of the likely share of biofuels in each year between 2008 and 2012. Biofuel use above these forecast levels is counted towards objectives for the CO_2 performance of new cars, permitting this to improve less rapidly than would otherwise be the case.

- *Option J*: All fuel is labelled to show the proportion of biofuel it contains.

- *Option K*: A campaign is organised to inform consumers of the benefits of biofuels.

Some of these measures are mutually exclusive – for example options *A, B* and *C*. Others can co-exist or may indeed be mutually supportive – for example, option *D* is compatible with all these three options, and options J and K are likely to reinforce the effectiveness of other options. Also, mandatory standards, targets or obligations are likely to be more effective than the voluntary approach, provided that they are sufficiently flexible and fair to be accepted by the Member States. It will therefore be important that future analysis should identify the best measure or package of measures available. However, any of the above measures could be associated with any particular level of ambition in relation to the level of biofuel to be used beyond 2008, so the choice of measures is not strongly relevant to the main task of this study – i.e. to quantify the possible impacts of a range of options.

However, some particular observations on certain policy options from the list above are as follows:

- As biofuels and some of the issues surrounding their use become more widely understood, there is now growing emphasis on the desirability of being able to certify that particular biofuels both deliver a given level of greenhouse gas reductions and are ‘sustainably’ produced. These developments are potentially important in ensuring the sustainability of the biofuels used in Europe in the future. Greenhouse gas certification could have the effect of driving up the net carbon benefit of the fuels brought to market by allowing these to achieve some sort of benefit such as a premium price or preferential treatment under a biofuels obligation. However, in the absence of further detail as to the likely speed or effectiveness of the implementation of such measures, it is uncertain whether this initiative will deliver concrete benefits during the study period, and so its effect cannot be reflected in the analysis at this stage. ‘Sustainability’ certification would also be valuable in ensuring the environmental credibility of biofuels as a policy option, as they risk being undermined if it is believed that feedstocks for imported biofuels are being grown on cleared land that was formerly rainforest, for example. In this sense certification would serve two purposes; both to minimise the risk of unsustainable biofuels or feedstocks being imported, and to bolster the sustainability credentials of imports that were allowed.

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[36] In 2005, the Commission consulted stakeholders on the reform of the fuel quality directive, including options for easing the constraints on the level of bioethanol allowed to be incorporated in petrol.

- Addressing the supply side, the Communication notes the important implications of CAP reform for both grain and sugar beet production, the possibility of using Community funding to subsidise processing plant construction, and the need for further work to raise the current limits on blending of biofuels in petrol and diesel. However it is as yet too early to make detailed further assessment of such possibilities.
- One of the options (Option H) envisages a voluntary agreement or understanding between car manufacturers and the oil industry. As noted above, current fuel specifications limit the percentage of biofuel in mainstream road fuels to 5%, and many new cars are only warranted to run on blends at this level, although it is understood that many new car models can or easily could use higher blends. As a result the oil industry is also not motivated to consider plans for higher blends, and this stalemate inhibits Member States' ability to reach the target set in the Biofuels Directive, far less to go beyond it. One suggestion, therefore, would be for a voluntary agreement whereby all carmakers would design and warrant their cars as capable of running on higher blends of 10% or more (as some are already doing). In exchange, the oil industry would indicate the specifications of higher-blend fuels, and commit to making these available to an agreed plan and timetable to reflect the potential growth in demand. However, experience with the current VA on passenger car CO_2 suggests that, for this to be achieved effectively, a strong engagement and commitment from the main companies involved would be needed. Also, as such an arrangement would necessitate coordinated action from two major industrial groups with differing and sometimes conflicting interests, it can be argued that a clear 'road map' of future actions would need to be developed and agreed, specifying what actions would be taken by which parties at certain milestones in the lifetime of the agreement. Such milestones would need to include specific and verifiable targets, and be accompanied by an agreed monitoring mechanism such that progress by all parties could be clearly verified. Arrangements for technical cooperation and a work programme to clarify outstanding technical issues might also be needed.

7.8 Output to be supplied to TREMOVE and Task B

To define the level of biofuel use for Task B, we need first to set out the approach to be used to define both a baseline and an alternative policy scenario for biofuel use.

The Biofuels Directive (2003/30/EC) set indicative 'reference levels' for biofuel use in each Member State. The Directive requires Member States to ensure that a 'minimum proportion' of biofuels is put on the market and in order to do this, national indicative targets should be set. Reference values for the targets are set at 2 per cent at the end of 2005, rising to 5.75 per cent by the end of 2010. If Member States' targets differ from these reference values they must provide justification to the Commission. Fuels covered by the Directive include: pure biofuels or biofuels at high concentration in mineral oil derivatives; biofuels blended in mineral oil derivatives; and liquids derived from biofuels, such as ETBE. For the purpose of this exercise, we will model all of these together to reflect the approach in TREMOVE and in most national reports under the Directive.

In addition, it should be borne in mind that the Green Paper on the Security of Energy Supply COM(2000)769 refers to a possible objective of 20 per cent substitution of road transport fuels with alternative fuels (though not all of this is expected to be biofuel) by 2020. Future developments should also be seen in the light of the Commission's developing strategy on alternative fuels for vehicles i.e. the Action Plan of 2005 and the more recent Strategy; and reflecting this, the Spring Summit in March also gave tentative support for an 8% share of biofuels by 2015.

7.8.1 The Current Position

The TREMOVE model currently incorporates as a baseline a linear increase in biofuel average blend level from 2 per cent by the *end of 2005* to 5.75 per cent by the *end of 2010*. This profile was chosen to reflect the requirements of the Biofuels Directive – although this specification based year end implies, if the increase in percentage is assumed to be linear and incremental, slightly lower averages for the full year specified than is specified in the Directive – i.e. 1.625 and 5.375 per cent respectively for the years specified. Alternative values could however be modelled if it were agreed to change the baseline.

It has been acknowledged in the Action Plan that these levels will not be fully met as some countries have indicated that they do not plan to meet the targets in full. Table 7.5 below illustrates the Directive targets and our estimates of projected proportions of total biofuel use in milestone years. These projections are based on a fairly conservative interpretation of the national reports under the Biofuels Directive, supplemented by data supplied by DG TREN and cross checked against our own records. In addition, the last row illustrates a possible non-linear implementation of the Biofuels Directive scenario as recently proposed by DG Enterprise.

Table 7.5 Projections of Biofuel Shares

	2005	**2008**	**2010**
Projected Average %	1.3	3.3	4.5
Directive Target (year end)	2	4.25	5.75
Directive Target (year average)	1.625	3.875	5.375
Directive Target (non-linear progress)	1.3	3.5	5.75

7.8.2 The Baseline for 2008-2012

As explained above, the policy baseline in TREMOVE is set to reflect the reference levels in the Directive up until the end of 2010, but the purposes of this exercise is to determine a baseline and alternative policy scenario for the period from 2008 to 2012 for input to Task B, in order to assess the possible impact of additional measures.

The most straightforward option for the baseline is to accept the existing policy baseline to 2010 and assume that this level is maintained through 2011 and 2012. It is difficult to justify proposing a higher value in the alternative scenario in this case for the years 2008-2010, as we have no basis for supposing that additional measures might be applied during the period covered by the existing Directive, or what such measures might be, or how we could quantify their impact. However, any of the three variants illustrated in the table above could reasonably form the basis for this baseline, and the differences are not expected to make a substantial difference to the conclusions of the modelling. The variant chosen should therefore reflect the practicalities of the modelling, and no firm recommendation is made here.

A difficulty arises in this case, however, because, as discussed, the policy baseline is not likely to be achieved, but to model an alternative scenario that falls below the baseline is irrational. The alternative is to supplement the agreed baseline with projections on Member States' actual expectations to 2010 as summarised in the first row of the table above, assuming no further increase thereafter. In the modelling, actual MS estimates could in this case be used for each country.

In either case, the alternative scenario would be to model further increases in 2011 and 2012 to reflect such additional measures as are outlined in the Strategy. Using the current baseline, this would mean extrapolating from the Directive's target levels for 2011 and 2012, to reach just above 8% by 2012;

with the alternative baseline this would be an alternative scenario that reached just above the original target of the Directive for the years 2011 and 2012 (5.9% in the latter). In neither example does there seem to be a rational case for a scenario that exceeds the baseline in years prior to 2011.

In practice the choice of baseline is not likely to be very important in the sense that it will affect the results materially. In neither case is there a great deal of 'freedom of movement' with respect to the alternative scenario to be modelled, in that both will differ from the baseline only for years 2011 and 2012, and will simply imply different rates of increase in biofuel penetration in those years. The two alternative baselines and policy scenarios are illustrated in the graph below.

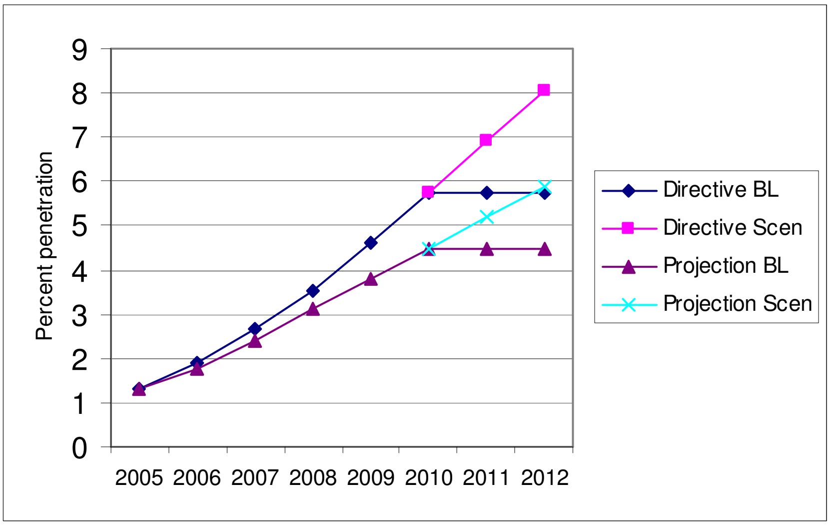

Figure 7.3 Market penetration of biofuels for different scenarios

7.8.3 Average CO_2 Reduction Projections

Note that the proposal above for the baseline and scenario relates to a combination of bioethanol, biodiesel and (probably limited) ETBE. Our expectation is that this will continue to be primarily from first generation processes, although we could envisage limited introduction of demonstrations of second generation plant before 2012. We cannot support ACEA's 'ambition' as set out in its recent paper on the Integrated Approach [ACEA, 2006] that we might in addition to the foregoing see a 5% share of synfuels from second generation biomass, or that biogas might make a significant contribution to a 4% gas target, by 2012. Our judgement is that biomass synfuels will not be sufficiently well developed at a commercial scale up to 2012 to merit separate modelling.

As argued above, neither of these projected levels is likely to make sufficient inroads into world production as to have significant impacts on availability or price of biofuels; the future price of oil is a more significant factor.

Neither the reporting under the Biofuels Directive nor the modelling input to TREMOVE makes a distinction between the different biofuels in the fuel mix. It is therefore necessary here to make assumptions about the shares of the different biofuels contributing to the total mix, and from these to produce an average figure for the level of CO_2 reduction to be achieved.

From this illustration, it can be seen that the percentage split of the biofuels burned could materially affect the effectiveness of the policy in terms of CO_2 savings per unit of biofuel consumed, with the saving ranging from two-thirds of the carbon saved in the event of high levels of import, but closer to

50% as the share of imports falls. However, for the purposes of the modelling input, we have proposed a central case of 58% savings.

Table 7.6 Illustration of Impact of Biofuel Split on CO_2 savings

Fuel mix	**% split of biofuels**			**Average CO_2 saving**
	Brazilian ethanol	**European ethanol**	**Biodiesel**	
High biodiesel, low imports	5%	30%	65%	52%
High biodiesel, high imports	30%	5%	65%	59%
Central case	25%	25%	50%	58%
Low biodiesel, low imports	5%	55%	40%	52%
Low biodiesel, high imports	55%	5%	40%	67%

7.9 Total reduction potential

This review only considers application of biofuels through blending with conventional fuels. The overall GHG-reduction potential of the increased use of biofuels (in addition to the results of the EU Biofuels Directive) is then determined by the amount of conventional fuel that is additionally replaced and the Well-to-Wheel GHG-emission reduction percentages of the biofuels compared to their conventional counterparts. As an example the impact of an additional 1% substitution of conventional fuel with biofuels over and above the effects of the Biofuels Directive has been assessed.

In general the impact depends on the types and origins of the biofuels that are blended into petrol and diesel. Average WTW GHG-saving figures for 5 different scenarios are given in Table 7.6. Multiplying these with 1% of the WTW GHG-emission of the entire fleet in a given year (according to the TREMOVE 2.42 baseline or the fleet that results under scenarios from chapter 3 in which a 2012 target between 135 and 120 g/km is reached for the sales average TA CO_2-emissions of new passenger cars) yields the total reduction potential associated with a 1% replacement of conventional fuels by biofuels. For the five different scenarios this reduction ranges from 3.1 to 4.0 Mtonnes/y WTW GHG emission reduction, as can be seen from Table 7.7.

Table 7.7 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) resulting from the additional replacement of 1% of conventional fuels with biofuels in the EU-15 passenger car fleet.

	WTW GHG emission reduction [Mtonnes/y]	
	2012	**2020**
High biodiesel, low imports	3.11	3.13
High biodiesel, high imports	3.57	3.58
Central case	3.48	3.49
Low biodiesel, low imports	3.11	3.13
Low biodiesel, high imports	4.02	4.04

Whether the 1% biofuels replacement is applied to the baseline situation (140 g/km sales averaged TA CO_2-emissions for new vehicles from 2008/9 onwards) or to a scenario with further reduction to a 2012 TA value of 120 – 135 g/km does not strongly influence the total reduction. For the scenario in which 120 g/km is reached in 2012 the overall reduction is 9% smaller than for the baseline scenario. As the blended biofuels and the associated WTW GHG-reduction are applied to the entire fleet the resulting GHG-emission reduction remains more or less constant over time and only scale with changes in the overall fleet fuel consumption.

7.10 Conclusions

- Currently the biofuels most commonly available as transport fuels are biodiesel and bioethanol (with the latter often converted to bio-ETBE to be used as an additive in petrol). The main feedstocks are crops grown for oil (such as rape, soya and sunflower) for biodiesel, and crops high in sugar or starch (including sugar beet and cane, various grain crops, etc) for ethanol. In future, 'second generation' processes should be able to produce a range of synthetic fuels from a wider range of biomass sources, including bio-wastes, woody crops and grasses, but these are unlikely to contribute significantly up to 2012.
- Biofuels offer CO_2 reduction benefits relative to mineral fuels because their carbon was absorbed from the atmosphere as the source plants grew, rather than being released from underground storage as with fossil fuels. However few if any biofuels are truly 'carbon neutral'; those grown in Europe typically offer around a 50% greenhouse gas reduction, although the benefits of ethanol imported from Brazil are typically much greater (around 80% reduction).
- Current biofuels are produced at a cost premium relative to conventional fuels, but this is reduced significantly if oil prices remain high. For the cheaper biofuel options (particularly Brazilian ethanol) the cost of CO_2-equivalent avoided falls to or below zero on the assumption of a high oil price ($\geq$ €50/bbl), but more expensive European sources continue to have a cost premium under most reasonable assumptions, although this varies substantially according to both the cost and greenhouse gas reduction impact of the biofuel in question, and the anticipated price of oil.
- The current biofuels policy framework sets indicative targets for biofuel percentages to the year 2010; it is proposed to model the greenhouse gas benefits of a linear extrapolation of the agreed trend for the years 2011 and 2012.
- The additional replacement of 1% of fossil fuel use (in energy terms) by the use of biofuels over and above the effects of the Biofuels Directive is estimated to result in an overall GHG emission reduction for EU-15 of 3.1 to 4.0 Mtonne/y. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

7.11 References

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8 Review of options for CO_2-reduction in N_1 vehicles

8.1 Goal of Task 1.10

This task reviews the technical potential and policy options for reducing CO_2 emissions from light commercial (i.e. N_1) vehicles and assesses the extent to which these can be developed in parallel to, complementary to or separate from measures aimed at passenger cars.

8.2 Approach

- Review of literature that has assessed the technical options for reducing CO_2 emissions from N_1 vehicles (notably [RAND 2003],[TNO 2004],[ADAC 2005]).
- Update of the assessment of CO_2-reduction potential, costs and CO_2-abatement costs as carried out in [TNO 2004], using updated input from Task 1.1.
- Results will be compared to the marginal costs for CO_2-reductions through technical measures in M_1 vehicles and through the other options studied in this project.
- Review the literature on policy options that are currently applied to N_1 vehicles in relation to encouraging a reduction in their CO_2 emissions.
- Delineate most important policy options, plus costs and benefits.

8.3 General considerations

Thus far, in relation to reducing CO_2 emissions from the transport sector, EU policy has focussed on passenger cars, or M_1 vehicles, as these vehicles are the biggest single source of such emissions from the sector. The EU's passenger car CO_2 strategy has three strands – the manufacturers' self-commitments, the fuel efficiency/CO_2 emissions label, and fiscal incentives. The setting of the CO_2 reduction target for new passenger cars, which is the objective of the manufacturers' self-commitments, is made possible as:

i) Emissions of CO_2 from new passenger cars are measured in the course of the EU-approved, and EU-wide, test cycle at the type approval stage (as set out in Directive 80/1268/EEC); and

ii) Manufacturers' progress towards meeting these targets is monitored at the European level as Member States are required to supply the Commission with data relating to the number of cars sold and their respective CO_2 emissions (under Decision 1753/2000/EC). In order to monitor progress, manufacturers supplied data for the first two years, after which the data was supplied by Member States in the last three, with at least two years where both data sets where available and cross checked. The responsibility for data provision has moved towards the Member States, as the confidence in this data increased.

As a result, specific CO_2 emissions data could be gathered; monitored and reported on for passenger cars with some level of confidence, but for no other type of road vehicle. Hence, policy targeted at reducing CO_2 emissions from other vehicles (including light commercial, or N_1, vehicles) is not as fully advanced as that targeting CO_2 emission from passenger cars. In some areas (particular for the lighter class I N_1s) similar issues apply, but there are also important differences in technology, market, fleet structure, etc.

The Commission was subsequently asked by both the Council and the European Parliament to explore the possibility of developing policies to reduce CO_2 emissions from N_1 vehicles. The first step in doing this was an amendment to Directive 80/1268 to extend the measurement of CO_2 emissions during the test cycle to LCVs, which was achieved by Directive 2004/3/EC. As a result, CO_2

emissions for all new types of light commercial vehicles will be available from 2009. Currently the European Commission has a contract running which investigates how N_1-vehicles can best be incorporated in the monitoring Decision 1753/2000/EC.

8.4 Input from manufacturers

The subject of N_1-vehicles was included in the questionnaire sent out to manufacturer associations. Only ACEA has provided input. Detailed data are considered confidential and are not included in this report. Some general aspects of the data as submitted by ACEA can be summarized as follows:

- Data on CO_2-reduction and additional manufacturer costs are taken over from the data supplied on M_1-vehicles with the following relation between M_1 and N_1 categories:
  - petrol small → Class I petrol
  - petrol medium → Class II petrol
  - petrol large → Class I petrol
  - diesel small → Class I diesel
  - diesel medium → Class II diesel
  - diesel large → Class III diesel
- The following modifications are applied:
  - The CO_2-reduction potential of engine down-sizing is smaller for N_1-vehicles than for M_1-vehicles. Due to sensitivity on payload the 1st and 2nd gear ratio must be shorter for take-off performance, resulting in a lower value for the CO_2-reduction potential;
  - Medium and strong down-sizing are not considered to be viable solutions for Class III N_1-vehicles on diesel;
  - The costs of start-stop systems with regenerative braking, mild hybrid and full hybrid powertrains are higher for Class III N_1-vehicles than for large M_1-vehicles. This is due to the performance demands related to operating with full payload (GVW up to 3500 kg).

8.5 Methodology for assessing investment costs and CO_2-abatement costs

A cost assessment for N_1 vehicles could follow the same approach as that taken in Task 1.1, i.e. developing suitable cost curves, identifying a range of possible targets, estimating gaps in specific CO_2 emissions for the various vehicle types / market segments and hence what needs to be done, and then calculating the associated average and marginal costs for each vehicle type. The approach followed in this chapter is a somewhat simplified version of the approach taken in Task 1.1. It is essentially an update of the assessment performed in [TNO 2004], with the exception that the calculation of CO_2-abatement costs is not based on a complex scenario approach, but on more straightforward comparisons at the level of average vehicles.

The approach contains the following steps:

- translation of data on CO_2-reduction potential and manufacturer costs of various technical options derived in Task 1 for the various types of M_1-vehicles (petrol small / medium / large, diesel small / medium / large) to a dataset valid for the various categories of N_1-vehicles (petrol Class I, II and III, diesel Class I, II and III);
- determination of a limited number of possible packages of technical options that could likely be applied to the various categories of N_1-vehicles for reaching increasing levels of CO_2-reduction, including a “business as usual” (BAU) package of options that are expected to be applied by 2012 in the absence of policy targeting the CO_2-emission of N_1-vehicles;
- calculation of the overall CO_2-reduction and additional manufacturer costs of the various packages, using the approach outlined in section 3.8.1.1;

  - a correction factor is introduced to correct for the possible overestimation of reduction potentials inherent to the approach outlined in section 3.8.1.1[37];
- determination of continuous cost curves for the various categories of N_1-vehicles describing the costs of reaching various levels of CO_2-reduction compared to the 2002 baseline vehicle;
- determination of scenarios in terms of ways in which CO_2-reductions are shared over the different categories of N_1-vehicles for reaching an overall level of CO_2-reduction for the average N_1-vehicle in 2012;
  - basically two types of scenarios are considered:
    - "equal level of technology": to each category of N_1-vehicles a technically comparable package of CO_2-reducing measures is applied;
    - "least cost solution": using a solver function the CO_2-reductions are divided over the different categories of N_1-vehicles in such a way that a desired level of average CO_2-reduction is achieved at least costs.
- calculation of CO_2-abatement costs for the different scenarios as a function of fuel price.

Details of the approach will be explained in the following sections.

In the assessment the following data are taken from [TNO 2004]:
- TA CO_2-emission values of the 2002 baseline vehicles;
- distribution of new vehicle sales over petrol Class I, II and III and diesel Class I, II and III.

Contrary to the assessment for M_1-vehicles the possible impacts of autonomous trends concerning a shift from petrol to diesel or autonomous weight increase are neglected in the assessment for N_1-vehicles.

8.6 The 2002 baseline vehicles

Similar to the case for M_1-vehicles (Task 1.1) also for N_1-vehicles the reduction potentials and costs of CO_2-reducing technologies are specified relative to the 2002 baseline vehicles in the various segments. The baseline for N_1-vehicles is taken from [TNO 2004] and is described in Table 8.1

Table 8.1 2002 baseline technologies

	Class I, Gasoline	**Class II, Gasoline**	**Class III, Gasoline**	**Class I, Diesel**	**Class II, Diesel**	**Class III, Diesel**
Engine layout:	4 cylinder in-line	4 cylinder in-line	4/6 cylinder in-line	4 cylinder in-line	4 cylinder in-line	4/6 cylinder in-line
Fuel system:	Multi-point indirect fuel injection	Multi-point indirect fuel injection	Multi-point indirect fuel injection	Common rail direct injection, turbo	Common rail direct injection, turbo	Common rail direct injection, turbo
Gearbox:	5 speed manual	5 speed manual	5 speed manual	5 speed manual	5 speed manual	5 speed manual

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[37] For M_1-vehicles this is intuitively accounted for in the way the cost curves are drawn through the cloud of data points by using a margin with respect to the lower envelope of the cloud.

8.7 Technological options for reducing TA CO_2-emissions from N_1-vehicles

In section 3.8 a data set is presented of CO_2-reduction potentials and costs for technological measures that can be applied to passenger cars. As the technology for N_1-vehicles closely follows that for M_1-vehicles, these data serve as input of the analysis of N_1-vehicles also.

Based on an analysis of the average cylinder content and mass of N_1 vehicles of Class I, II and III the following basic translation of the results from Task 1.1 is defined:

- petrol small → Class I petrol
- petrol medium → Class II petrol
- petrol large → Class I petrol
- diesel small → Class I diesel
- diesel medium → Class II diesel
- diesel large → Class III diesel

This translation is the same as the one proposed by ACEA, but is different from the one used in [TNO 2004]. In that study the data for Class I vehicles were taken from medium M_1-vehicles, data for Class III vehicles were taken from large M_1-vehicles, while data for Class II were derived by means of interpolation.

Based on the input provided by ACEA the following modifications are applied:
- The CO_2-reduction potential of engine down-sizing for N_1-vehicles is assumed to be smaller than for M_1-vehicles;
- The costs of start-stop systems with regenerative braking, mild hybrid and full hybrid powertrains for Class III N_1-vehicles are assumed to be a factor of 1.3 higher than for large M_1-vehicles. This factor is somewhat smaller than the one assumed by ACEA.
- Some options such as strong downsizing and dual clutch transmission are considered not applicable to N_1-vehicles. For strong downsizing (in combination with (twin) turbo) this is due to the relatively high engine loads, that would cause problem with durability of the turbo, and the high torque requirements at low rpm that may not be fulfilled by this system.

The resulting datasets for N_1-vehicles on petrol and diesel are presented in Table 8.2 resp. Table 8.3. Costs in these tables are manufacturer costs.

Also in the case of N_1-vehicles applied technologies may serve more than one purpose. However, in this application aspects such as driveability and comfort play a less prominent role. For this reason the costs of hybridisation of N_1-vehicles are fully attributed to CO_2-reduction.Only for variable valve timing and variable valve control 25% of the costs is attributed to the role of these technologies in achieving future exhaust gas emission limits.

8.8 Technology packages

From the 2002 technology baseline N_1 vehicles will develop to a 2012 technology level. This level will be determined by external factors, such as consumer preferences, fuel price and legislation. In this paragraph, some typical technical pathways for short to medium term CO_2-emission reduction are described for each N_1 class in the form of technology packages. The basic assumption here is that the technology packages are considered technically feasible in 2012. The economic viability is in part a result from this assessment and should be discussed also in relation to the definition of a time horizon for an EU policy aimed reducing CO_2-emissions from N_1-vehicles. The outcome of this exercise in terms of cost increase and CO_2-emission reduction will indicate to which extent CO_2-emissions can be reduced what the involved costs per vehicle are.

Compared to the analysis for M_1-vehicles in chapter 3, for N_1-vehicles a somewhat simplified approach is used. Instead of calculating CO_2-reduction potentials and costs for (almost) all possible packages of technological options, for N_1-vehicles the number of technology packages to be assessed has been limited to four. This does not mean that other possible combinations are excluded, or are considered less feasible. A 'Business As Usual' (BAU) package has been added as well, to indicate the autonomous development of the CO_2 emissions of N_1 vehicles under the circumstance that no external factors are present to initiate a further reduction of CO_2-emissions.

The technology packages that have been used in this study are summarised in Table 8.4 and Table 8.5 for respectively petrol and diesel engines. The packages represent increasing levels of technical effort and complexity to reduce CO_2-emissions from N_1-vehicles.

Using the approach as described in section 3.8.1.1 the overall CO_2-reduction and additional manufacturer costs of the various packages have been calculated. The results are given in Table 8.6. For package 1 to 4 the CO_2-reduction and additional manufacturer costs is specified relative to the BAU-package. For each packages the direct results of the calculation is given as well as a corrected CO_2-reduction figure. This figure is derived by applying a correction factor to compensate for the possible overestimation of combined efficiency improvements of options targeting the same energy losses which is inherent to the followed methodology. The correction factors are given in the first column of Table 8.6, and have been estimated based on expert judgement and are not based on any form of modelling. The corrected ΔCO_2-figures will be used for the assessment in this chapter. In the approach for M_1-vehicles a similar correction is applied by drawing the cost curves through the cloud of data points using a margin with respect to the lower envelope of the cloud. A direct comparison between the two corrections can not be made. In the case of M_1-vehicles the spread of CO2-reduction values of all possible packages was know. In the simplified approach used for N_1-vehicles it has not been analysed where the packages assessed here are positioned with respect to the overall cloud of data points for different possible packages. A more in-depth analysis could be carried out using detailed modelling of the powertrains resulting from the packages 1 to 4 and simulation of vehicles with these powertrains over representative driving cycles. Such calculations, however, were not possible within the budgetary constraints of this project.

Table 8.2 CO_2-reduction potential and additional manufacturer costs of technological options for reducing the CO_2-emission of N_1-vehicles on petrol

Technology options for N1 petrol cars		**Class I**					**Class II**					**Class III**				
Description		CO2 red. [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 red. [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 red. [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]
Engine	Reduced engine friction losses	3.0	40	100%	40		4.0	50	100%	50		5.0	60	100%	60	
	DI / homogeneous charge (stoichiometric)	3.0	125	100%	125		3.0	150	100%	150		3.0	175	100%	175	
	DI / Stratified charge (lean burn / complex strategies)	10.0	320	100%	320		10.0	400	100%	400		10.0	480	100%	480	
	Medium downsizing with turbocharging	7.0	225	100%	225		8.5	300	100%	300		8.5	375	100%	375	
	Strong downsizing with turbocharging	9.5	390	100%	390		9.5	450	100%	450		9.5	510	100%	510	
	Variable Valve Timing	3.0	100	75%	75		3.0	150	75%	113		3.0	200	75%	150	
	Variable valve control	7.0	300	75%	225		7.0	350	75%	263		7.0	400	75%	300	
	Optimised cooling circuit	1.5	35	100%	35		1.5	35	100%	35		1.5	35	100%	35	
	Advanced cooling circuit+ electric water pump	3.0	120	100%	120		3.0	120	100%	120		3.0	120	100%	120	
Trans-mission	Optimised gearbox ratios	1.0	50	100%	50		1.5	60	100%	60		1.5	70	100%	70	
	Piloted gearbox	4.0	300	100%	300		4.0	350	100%	350		4.0	400	100%	400	
Hybrid	Start-stop function	4.0	220	100%	220		4.0	250	100%	250		4.0	280	100%	280	
	Start-stop + regenerative braking	7.0	515	100%	515		7.0	600	100%	600		7.0	891	100%	890.5	
	Mild hybrid (motor assist)	11.0	1200	100%	1200		11.0	1600	100%	1600		11.0	2600	100%	2600	
	Full hybrid (electric drive)	22.0	2800	100%	2800		22.0	3500	100%	3500		22.0	5460	100%	5460	
Body	Improved aerodynamic efficiency	1.5	75	100%	75		1.5	75	100%	75		1.5	75	100%	75	
	Mild weight reduction	0.9	22	100%	22	-14	1.0	28	100%	28	-19	0.9	34	100%	34	-22
	Medium weight reduction	2.2	57	100%	57	-34	2.3	90	100%	90	-45	2.2	115	100%	115	-54
	Strong weight reduction	5.5	212	100%	212	-86	5.8	294	100%	294	-113	5.4	418	100%	418	-135
Other	Low rolling resistance tyres	2.0	25	100%	25		2.0	30	100%	30		2.0	35	100%	35	
	Electrically assisted steering (EPS, EPHS)	3.0	100	100%	100		2.5	100	100%	100		2.0	100	100%	100	
	Advanced aftertreatment	1.0	0	100%	0		1.0	0	100%	0		1.0	0	100%	0	

Table 8.3 CO_2-reduction potential and additional manufacturer costs of technological options for reducing the CO_2-emission of N_1-vehicles on diesel

Technology options for N1 diesel cars		**Class I**					**Class II**					**Class III**				
Description		CO2 red. [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 red. [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]	CO2 red. [%]	Costs [Euro]	Attribution to CO2 [%]	Attributable Costs [Euro]	Weight [kg]
Engine	Reduced engine friction losses	3.0	40	100%	40		4.0	50	100%	50		5.0	60	100%	60	
	Mild downsizing	2.0	120	100%	120		2.0	150	100%	150		2.0	180	100%	180	
	Medium downsizing	4.0	160	100%	160		4.0	200	100%	200		4.0	240	100%	240	
	Optimised cooling circuit	1.5	35	100%	35		1.5	35	100%	35		1.5	35	100%	35	
	Advanced cooling circuit+ electric water pump	3.0	120	100%	120		3.0	120	100%	120		3.0	120	100%	120	
	Exhaust heat recovery						1.5	45	100%	45		1.5	45	100%	45	
Transmission	6-speed manual/automatic gearbox															
	Piloted gearbox	4.0	300	100%	300		4.0	350	100%	350		4.0	400	100%	400	
Hybrid	Start-stop function	3.0	180	100%	180		3.0	200	100%	200		3.0	220	100%	220	
	Start-stop + regenerative braking	6.0	475	100%	475		6.0	550	100%	550		6.0	813	100%	812.5	
	Mild hybrid (motor assist)	10.0	1200	100%	1200		10.0	1600	100%	1600		10.0	2600	100%	2600	
	Full hybrid (electric drive capability)	18.0	2800	100%	2800		18.0	3500	100%	3500		18.0	5460	100%	5460	
Body	Improved aerodynamic efficiency	1.5	75	100%	75		1.5	75	100%	75		1.5	75	100%	75	
	Mild weight reduction	1.0	23	100%	23	-15	1.0	31	100%	31	-20	1.0	38	100%	38	-25
	Medium weight reduction	2.4	65	100%	65	-37	2.5	101	100%	101	-49	2.4	136	100%	136	-61
	Strong weight reduction	5.9	231	100%	231	-93	6.3	333	100%	333	-123	5.9	538	100%	538	-152
Other	Low rolling resistance tyres	2.0	25	100%	25		2.0	30	100%	30		2.0	35	100%	35	
	Electrically assisted steering (EPS, EPHS)	3.0	100	100%	100		2.5	100	100%	100		2.0	100	100%	100	
	DeNOx catalyst	0.0	0	100%	0		0.0	0	100%	0		0.0	0	100%	0	
	Particulate trap / filter	1.5	0	100%	0		1.5	0	100%	0		1.5	0	100%	0	

Table 8.4 Packages of CO_2-reducing technologies for N_1-vehicles on petrol (BAU = business as usual scenario without policy aimed at N_1-vehicles)

		Class I					Class II					Class III				
Petrol	technology	BAU	Pk1	Pk2	Pk3	Pk4	BAU	Pk1	Pk2	Pk3	Pk4	BAU	Pk1	Pk2	Pk3	Pk4
Engine	Reduced engine friction losses	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	DI / homogeneous charge (stoichiometric)		x	x				x	x				x	x		
	DI / Stratified charge (lean burn / complex strategies)				x	x				x	x				x	x
	Medium downsizing with turbocharging				x	x										
	Strong downsizing with turbocharging															
	Variable Valve Timing			x	x				x	x				x	x	
	Variable valve control					x					x					x
	Optimised cooling circuit				x					x					x	
	Advanced cooling circuit+ electric water pump					x					x					x
Transmission	Optimised gearbox ratios		x	x	x	x		x	x	x	x		x	x	x	x
	Piloted gearbox			x	x	x			x	x	x			x	x	x
Hybrid	Start-stop function			x					x					x		
	Start-stop + regenerative braking															
	Mild hybrid (motor assist)				x					x					x	
	Full hybrid (electric drive)					x					x					x
Body	Improved aerodynamic efficiency	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Mild weight reduction			x					x					x		
	Medium weight reduction				x					x					x	
	Strong weight reduction					x					x					x
Other	Low rolling resistance tyres		x	x	x	x		x	x	x	x		x	x	x	x
	Electrically assisted steering (EPS, EPHS)															
	Advanced aftertreatment				x	x				x	x				x	x

Table 8.5 Packages of CO_2-reducing technologies for N_1-vehicles on petrol (BAU = business as usual scenario without policy aimed at N_1-vehicles)

		Class I					Class II					Class III				
Diesel	technology	BAU	Pk1	Pk2	Pk3	Pk4	BAU	Pk1	Pk2	Pk3	Pk4	BAU	Pk1	Pk2	Pk3	Pk4
Engine	Reduced engine friction losses	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Mild downsizing		x	x					x	x	x			x	x	x
	Medium downsizing				x	x										
	Optimised cooling circuit				x					x					x	
	Advanced cooling circuit+ electric water pump					x					x					x
	Exhaust heat recovery					x					x					x
Transmission	6-speed manual/automatic gearbox															
	Piloted gearbox			x	x	x			x	x	x			x	x	x
Hybrid	Start-stop function			x					x					x		
	Start-stop + regenerative braking															
	Mild hybrid (motor assist)				x					x					x	
	Full hybrid (electric drive capability)					x					x					x
Body	Improved aerodynamic efficiency	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Mild weight reduction			x					x					x		
	Medium weight reduction				x					x					x	
	Strong weight reduction					x					x					x
Other	Low rolling resistance tyres		x	x	x	x		x	x	x	x		x	x	x	x
	Electrically assisted steering (EPS, EPHS)															
	DeNOx catalyst															
	Particulate trap / filter	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 8.6 Overall (initial and corrected) CO_2-reduction values and additional manufacturer costs calculated for the various packages compared to the 2012 BAU package.

			correction factor	Class I		Class II		Class III	
				petrol	diesel	petrol	diesel	petrol	diesel
2002 baseline CO2-emission		[g/km]		179	160	184	175	283	227
2012 BAU CO2-emission		[g/km]		171	152	174	163	265	209
package 1	ΔCO2	[g/km]		10.1	6.0	11.1	3.3	16.9	4.2
	ΔCO2 corrected	[g/km]	1.00	10.1	6.0	11.1	3.3	16.9	4.2
	Δcosts	[€]		200	145	240	30	280	35
package 2	ΔCO2	[g/km]		28.5	17.3	29.8	18.8	45.1	24.0
	ΔCO2 corrected	[g/km]	0.93	26.5	16.1	27.7	17.4	42.0	22.3
	Δcosts	[€]		817	648	981	761	1144	873
package 3	ΔCO2	[g/km]		53.0	28.1	54.7	33.1	82.9	42.3
	ΔCO2 corrected	[g/km]	0.86	45.6	24.2	47.0	28.5	71.3	36.4
	Δcosts	[€]		2287	1785	2677	2266	3885	3386
package 4	ΔCO2	[g/km]		76.6	44.8	78.8	52.7	119.2	67.1
	ΔCO2 corrected	[g/km]	0.79	60.5	35.4	62.3	41.6	94.2	53.0
	Δcosts	[€]		4277	3636	5016	4528	7283	6778

8.8.1 Determination of cost curves

The results for the various packages are also plotted in Figure 8.1 and Figure 8.2. Using a least squares approach continuous cost curves can be fitted on the basis of the results for the 4 different packages. As in section 3.8.1.1 cost curves are defined as 3rd order polynomials expressed as:

$$y = a\,x^3 + b\,x^2 + c\,x$$

with x the CO_2-reduction in [g/km] and y the additional manufacturer costs in [Euro], in this case both relative to the BAU package. The values for the coefficients a, b and c, as determined for the various vehicle classes are listed in Table 8.7.

Table 8.7 Coefficient values for cost curves (manufacturer costs)

	Class I		Class II		Class III	
	petrol	diesel	petrol	diesel	petrol	diesel
a	0.0102	0	0.0114	0	0.0035	0
b	0.2848	2.951	0.2944	2.5394	0.4491	2.6029
c	16.123	-1.1384	18.081	3.9186	3.9946	-8.4561

For class I and II the cost curves for N_1-vehicles are very close together an for the case of petrol vehicles even reversed compared to intuition in the sense that the curve for Class II vehicles is above the curve for Class I vehicles. This basically results from the fact that the costs for reaching a relative CO_2-reduction in class II are significantly higher than in Class I, while the 2002 baseline CO_2-emission, and hence those of the BAU packages, are very close together.

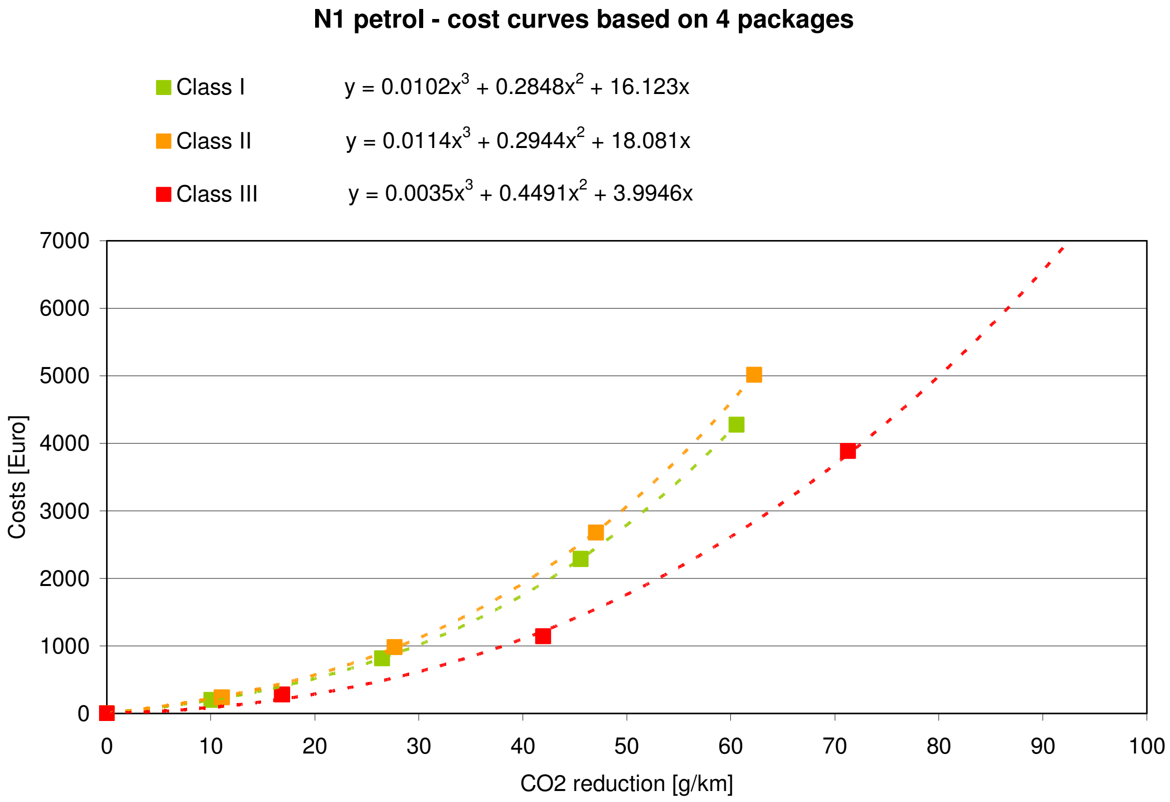

Figure 8.1 Cost curves for N_1-vehicles on petrol

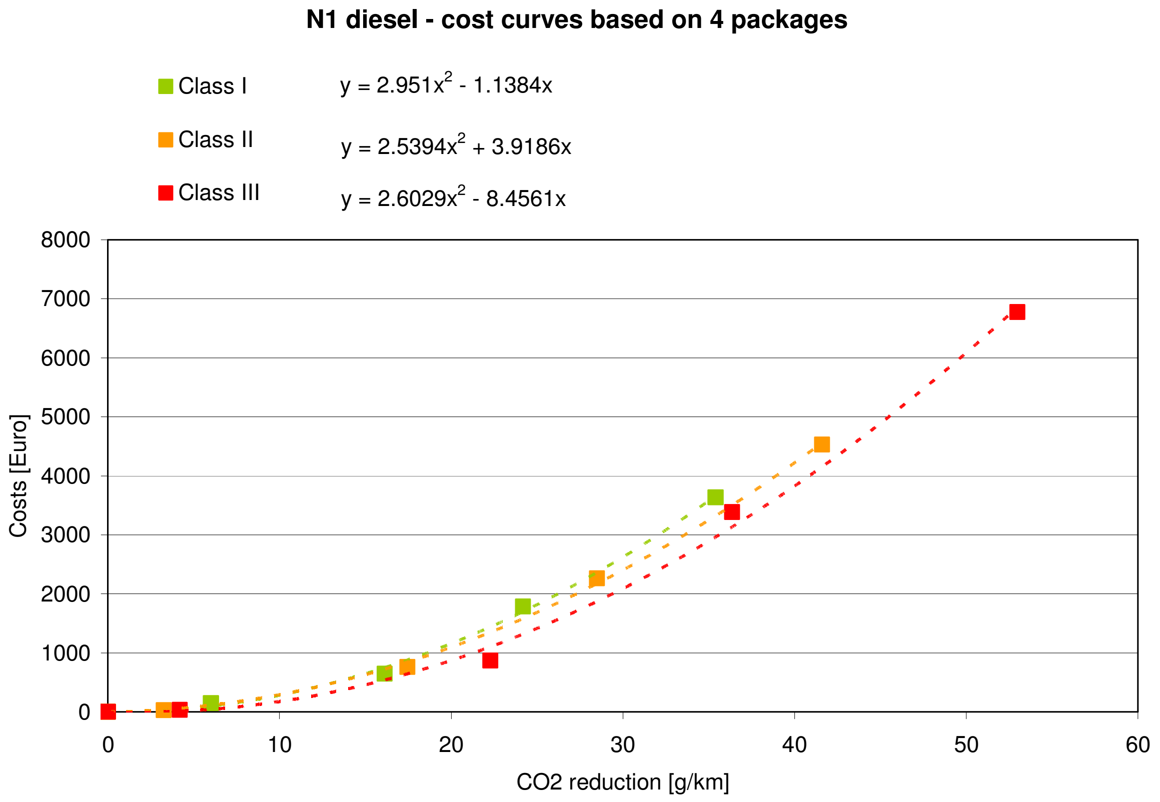

Figure 8.2 Cost curves for N_1-vehicles on diesel

8.9 CO_2-abatement costs for N_1-vehicles

For assessing the overall abatement costs for CO_2-reduction in N_1-vehicles assumptions have to be made on the type of policy measure that is applied and how manufacturers respond to this in terms of the division of required CO_2-emission reductions over the various vehicle segments in their product range. At this point no detailed assumptions can be made yet regarding policy measures. To explore possible variations in CO_2-abatement costs the assessment is carried out for two basic types of scenarios.

"Equal level of technology" scenario
Manufacturer are assumed to apply technically comparable packages of CO_2-reducing measures to each category of N_1-vehicles. In this case a scenario is the application of the same package # to all segments.

"Least cost solution" scenario
It is assumed that manufacturers have the freedom to apply CO_2-reducing measures to the various N_1-vehicle segments in such a way that a required overall CO_2-emissions reduction (expressed as a reduction of the sales-weighted average CO_2-emissions) is reached at least costs. For the purpose of this assessment the calculation of the least cost solution is performed for the entire N1-market, rather than for individual manufacturers as applied for M_1-vehicles in Task 1.1. The least cost solution is calculated using a solver function in Excel and is characterised by the fact that for the resulting CO_2-reductions per segment the derivative of the cost curves is equal for each segment.

CO_2-abatement costs are calculated using the methodology as described in section 2.2 of this report. The results of this exercise are presented in Table 8.8. For this calculation the following assumptions have been made:

- CO_2-abatement costs are calculated on the basis of the sales-weighted average CO_2 and cost data for the average vehicle sold in 2012;
- 2012 sales distributions over the various segments are taken from vehicle stock sheets underlying [TNO 2004];
- Fuel consumption benefits and CO_2-reductions are calculated for real-world figures, using the same factor of 1.195 as fro M_1-vehicles to translate TA data as determined in the assessment to RW data. Figure 4.12 of [TNO 2004] shows that the ration between TA and RW CO_2-emission for N_1-vehiles depends strongly on the road type / cycle and can even be smaller than 1. However, for lack of data on the division of kilometres driven over different road types [TNO 2004] does not give an overall weighted average value. As this problem has not been solved for this study it is preferred to use the same factor as is derived for M_1-vehicles in Annex B;
- Lifetime CO_2-emissions are further corrected to WTW greenhouse emission using a WTW/WTT factor of 1.186 based on a sales weighted average of the WTW/WTT factors for the petrol and diesel energy chain as presented in Table 2.3;
- Annual mileage data are taken form [TNO 2004] and correspond to:
  - 19336 km/y for petrol vehicles
  - 23579 km/y for diesel vehicles
  - 21993 km/y for average vehicles based on a sales weighted average;
- Average vehicle lifetime is assumed to be 15 years, based on data from [TNO 2004];
- For calculating the net present value of fuel savings an interest rate of 4% is assumed;
- Additional manufacturer costs are translated into marginal investment costs by multiplying with a factor of 1.16 in accordance with the methodology as outlined in section 2.1 and Annex A.

Table 8.8 Results of the assessment of manufacturer costs and CO_2-abatement costs of reaching various levels of CO_2-reduction in N_1-vehicles

				Class I		Class II		Class III		average	abatement costs [€/tonne]			
				petrol	diesel	petrol	diesel	petrol	diesel		0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
	2002 new vehicle sales			9%	19%	10%	23%	12%	27%					
	2008 new vehicle sales			10%	18%	12%	21%	14%	25%					
	2012 new vehicle sales			10%	17%	12%	21%	15%	25%					
	2002 baseline CO2-emission		[g/km]	179	160	184	175	283	227	200.9				
	2012 baseline CO2-emission		[g/km]	171	152	174	163	265	209	189.7				
equal technology - 2012	package 1	ΔCO2	[g/km]	10.1	6.0	11.1	3.3	16.9	4.2	7.6	-9	-32	-59	-106
		CO2	[g/km]	161	146	163	160	248	205	182				
		Δcosts	[€]	200	145	240	30	280	35	131				
	package 2	ΔCO2	[g/km]	26.5	16.1	27.7	17.4	42.0	22.3	24.2	36	13	-14	-61
		CO2	[g/km]	145	135	146	146	223	187	165				
		Δcosts	[€]	817	648	981	761	1144	873	859				
	package 3	ΔCO2	[g/km]	45.6	24.2	47.0	28.5	71.3	36.4	40.1	118	96	69	22
		CO2	[g/km]	125	127	127	135	194	173	150				
		Δcosts	[€]	2287	1785	2677	2266	3885	3386	2752				
	package 4	ΔCO2	[g/km]	61	35	62	42	94	53	55.6	188	165	138	91
		CO2	[g/km]	110	116	112	121	171	156	134				
		Δcosts	[€]	4277	3636	5016	4528	7283	6778	5372				
least costs - 2012	15 g/km reduction	ΔCO2	[g/km]	22.3	7.6	20.2	7.9	32.3	10.1	15.0	6	-16	-44	-91
		CO2	[g/km]	149	144	154	155	232	199	175				
		Δcosts	[€]	613	164	581	189	717	179	352				
	30 g/km reduction	ΔCO2	[g/km]	43.0	16.6	40.2	18.3	60.6	20.3	30.0	63	41	14	-34
		CO2	[g/km]	128	135	134	145	204	189	160				
		Δcosts	[€]	2027	798	1945	926	2675	898	1394				
	45 g/km reduction	ΔCO2	[g/km]	60.0	27.4	56.5	30.8	86.5	32.4	45.0	131	108	81	34
		CO2	[g/km]	111	124	118	132	178	177	145				
		Δcosts	[€]	4192	2178	4011	2530	5977	2463	3315				
	60 g/km reduction	ΔCO2	[g/km]	74.9	39.2	70.7	44.6	110.2	45.9	60.0	206	184	156	109
		CO2	[g/km]	96	112	103	118	155	163	130				
		Δcosts	[€]	7090	4498	6769	5226	10573	5093	6239				

8.10 Total reduction potential

Similar to the case of passenger cars in section 3.10, also for N_1-vehicles a first indication of the overall reduction potential in Mtonnes/y for the EU-15 is assessed using a vehicle stock spreadsheet containing time series of data on the number of vehicles of different years of construction in the fleet, their CO_2-emission and their annual mileage. This spreadsheet is based on output from the TREMOVE 2.42 baseline. The overall reduction will evolve over time and is calculated for the period 2002 to 2020. The general methodology for the “back-of-the-envelope” calculations of overall GHG-emission reductions made in this report is described in section 2.5. Outside the context of this project (Task A) TREMOVE calculations will be used to calculate the overall reduction in more detail, also taking into account impacts of changes in vehicle prices on sales of different vehicle types, modal split and transport volumes.

The annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) resulting from technical measures applied to N_1-vehicles is displayed in Figure 8.3. The overall reduction in 2012 and 2020 for the different 2012 target levels is listed in Table 8.9. Results are presented for four scenarios representing different levels in the average reduction of CO_2-emissions on the Type Approval test (resp. 15, 30, 45 and 60 g/km) of new vehicles sold in 2012 compared to the baseline situation in 2002. It is assumed that policies aiming at achieving these reductions are entering into force in 2008. As a consequence the CO2-emission figures between 2002 and 2008 are kept the same as in the TREMOVE 2.42 baseline. Type Approval values for intermediate years between 2009 and 2012 have been determined by means of linear interpolation. After 2012 the Type Approval CO_2-emission of new vehicles is assumed to remain constant at the 2012 level. Real-world CO_2-emissions in the policy scenarios for the different reduction levels have been determined using scaling factors based on the development of Type Approval values between 2008 and 2012 which are applied to the real-world CO_2-emission factors as included in the TREMOVE baseline data. Calculations of the overall reduction include well-to-tank emissions based on [Concawe 2006].

As can be seen from Figure 8.3 the overall reduction resulting from measures taken between 2008 and 2012 still increase after 2012 as the share of vehicles meeting the 2012 target in the fleet is still increasing after 2012. For the 15 g/km reduction target a decrease is visible after 2015. This is caused by the fact that the TREMOVE baseline includes some autonomous efficiency improvements between 2009 and 2020, while in the policy scenarios emissions of new vehicles are assumed constant after 2012. The motivation for the latter is that technical options that may be used in the autonomous developments assumed in the TREMOVE baseline scenario are used earlier in the policy scenario for reaching the 2012 target.

Table 8.9 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) for EU-15 resulting from technical measures applied to light duty commercial vehicles (N_1-vehicles) in order to reach an average 2012 Type Approval CO_2-emission value which is 15, 30, 45 or 60 g/km lower than the average for 2002

	WTW GHG emission reduction [Mtonnes/y]	
	2012	**2020**
15 g/km TA	1.2	2.2
30 g/km TA	2.4	7.0
45 g/km TA	3.7	11.7
60 g/km TA	4.9	16.5

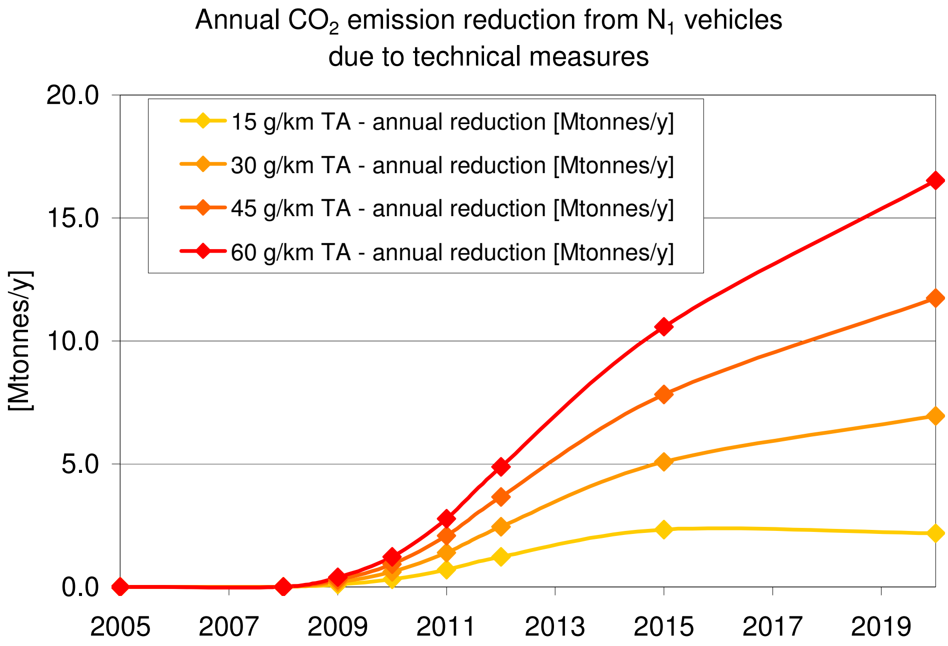

Figure 8.3 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) for EU-15 resulting from technical measures applied to light duty commercial vehicles (N_1-vehicles) in order to reach an average 2012 Type Approval CO_2-emission value which is 15, 30, 45 or 60 g/km lower than the average for 2002.

8.11 Policy measures

8.11.1 Monitoring

As noted above, in order that the self-commitments could be independently monitored, it was necessary to set up a mechanism to collate the information measured at the type approval stage. Such a mechanism has not yet been set up for N_1 vehicles. The first stage to development of any policy for reducing CO_2 emissions from N_1 vehicles, therefore, would be to set up a monitoring mechanism to collate emissions as measured in the course of the test cycle from these vehicles. This could either be an amendment to Decision 1753/2000, which currently focuses in passenger cars, or a separate, but parallel Decision focusing purely on N_1 vehicles. The data will be available from 2009, so it would make sense to have the necessary legislation in place to collate the CO_2 emission figures of new N_1 vehicles by the end of 2008. This would avoid the delay in collating information on CO_2 emissions from N_1 vehicles from Member States, which occurred in the course of monitoring CO_2 emissions reductions from passenger cars. In the meantime, there might be potential for an industry-led reporting exercise, as this would ensure that data becomes available sooner and, therefore, that informed decisions can be made as to potential policy options.

Similarly, there is not yet an EU-level label for light commercial vehicles. Again, this could not come into operation before 2009, but, if it were considered appropriate, it would make sense that this was ready by the end of 2008. As with the monitoring mechanism, it can be considered whether a new or different mechanism is needed, or whether N_1 vehicles (or N_1 Class I at least) might ‘piggy-back’ on the existing arrangements for passenger cars. [ADAC 2005] notes that energy efficiency labelling for Class I of N_1 vehicles could be introduced from 2005, as this is when Directive 2004/5 applies to the granting of the type approval for this class (the dates are delayed for other classes). They also note that, if the an energy efficiency rating system was used on the label, in line with the report’s recommendations for the passenger car label, then the different classes should be handled separately for this purpose.

The two policies mentioned above facilitate monitoring and provide information to the consumer. Both of these were also highlighted as possible actions in the earlier report [TNO 2004]. That report also suggested that policy measures aimed at actually reducing emissions might include self-commitments, also along the lines of the ones in place for passenger cars, or even emission limit values. The latter are a more viable option for N_1s than for passenger cars, due to the relative homogeneity of technologies within classes.

8.11.2 Options for policy measures

Measures to promote the application of CO_2-reducing technology in N_1-vehicles can be aimed at vehicle buyers or at vehicle manufacturers. An extensive evaluation of policy measures applied in different countries and policy measures that could be adopted at the EU-level is given in chapter 6 of [TNO 2004]. A summary of the results is presented in Annex J.

The following general measures can be envisaged to promote CO_2-emission reduction in N_1-vehicles:

- Labelling of the TA fuel consumption or CO_2-emission of N_1-vehicles;
- Subsidies for fuel efficient N_1-vehicles, preferably in combination with a CO_2-labelling scheme;
- CO_2-based taxation of N_1-vehicles, preferably in combination with a CO_2-labelling scheme;
- Public procurement of low-CO_2 N_1-vehicles (limited overall impact but measure that creates initial market for new technology)
- A self-commitment from the industry along the lines of the self-commitment for passenger cars to reach 140 g/km in 2008/9;
- A legislative target for the CO_2-emission of N_1-vehicles in combination with a policy measure as also analysed for passenger cars in Task 1.1 and [IEEP 2004]. Targets could be a uniform target, a percentage reduction target or a utility based target and can be applied to all vehicles, per manufacturer without the option of trading or per manufacturer including the option of trading CO_2-emission credits among manufacturers. Targets could e.g. be differentiated for the three classes of N_1-vehicles;
- A legislative approach as described above could be applied to the combination of M_1 and N_1 vehicle sales. Translation factors might be necessary, e.g. on default annual mileage data, to make the average CO_2-emission data of M_1 and N_1 vehicles comparable. Under this approach manufacturers are allowed to “burden share” reduction efforts over the two vehicle categories and to divide CO_2-reduction efforts in such a way that a cost optimised solution is reached for reaching a combined CO_2-reduction target for the two classes;
- The CO_2-emissions of N_1 vehicles (together with M_1) could be included in a European emission trading scheme (ETS). This would require a methodology with default factors to translate TA CO_2-emissions in [g/km] into emission units that can be used for trading.

Considerations

Given that there are three classes of N_1 vehicles and that N_1 vehicles are used differently to passenger cars, it might be appropriate to use different policy instruments to reduce the emissions of the different classes (as noted above in relation to labelling). As the smaller N_1 vehicle models (class I) are often derived from passenger cars, it might make sense to address emissions from these vehicles in the same way as that for passenger cars, while utilising other measures for classes II and III.

One possibility that was suggested might be to create a mechanism to credit progress of N_1 technology to the level of M_1 vehicles. The potential for this depends on the development of suitable robust data. The potential option for this could usefully be developed as an incentive for better data provision, and if the data (and configuration of a potential link) leads to the conclusion that a credit mechanism would make sense then the practicability could usefully be looked at. The issue of links and implications is key, as some progress for N_1 will take place anyway given technological developments and concern for high fuel price bills. Simply, taking fuel use reduction developments that make sense in the market anyway and rewarding this by effectively giving credits (and reducing burdens on the passenger vehicles) will be giving a double reward and arguably inappropriately reduce the responsibility of manufacturers for passenger vehicles. Of course, if true additional reductions could be shown then the matter does become sensible, but proving this could be fraught with difficulties. The comparison of CO_2-abatement costs will be valuable to establish the relative merits of focusing efforts on passenger and light commercial vehicles. It is not an either or question, but one of where more effort can usefully be applied. It is most unlikely that no efforts are needed for light commercial vehicle, and more an issue of which instruments are suitable and what ambitions realistic, and also to highlight the potential benefits of combining the targets.

8.12 Output supplied to TREMOVE and Task B

TREMOVE only contains two overall categories of N_1-vehicles, being average N_1-vehicles on petrol and average N_1-vehicles on diesel. Output to TREMOVE for N_1-vehicles thus needs to be aggregated to this level by weighing per fuel type the results of the different classes over the sales distribution over these classes. Results are presented in Table 8.9 and Figure 8.4. All costs in this case are expressed as retail price excluding taxes, which is calculated from the manufacturer costs as presented above by means of a translation factor of 1.16 in accordance with the methodology as outlined in section 2.1 and Annex A. All CO_2-data are type approval data.

In Figure 8.4 also overall cost curves are derived for petrol and diesel vehicle describing additional retail price (excl. tax) as a function of the TA CO_2-reduction compared to the BAU reference case.

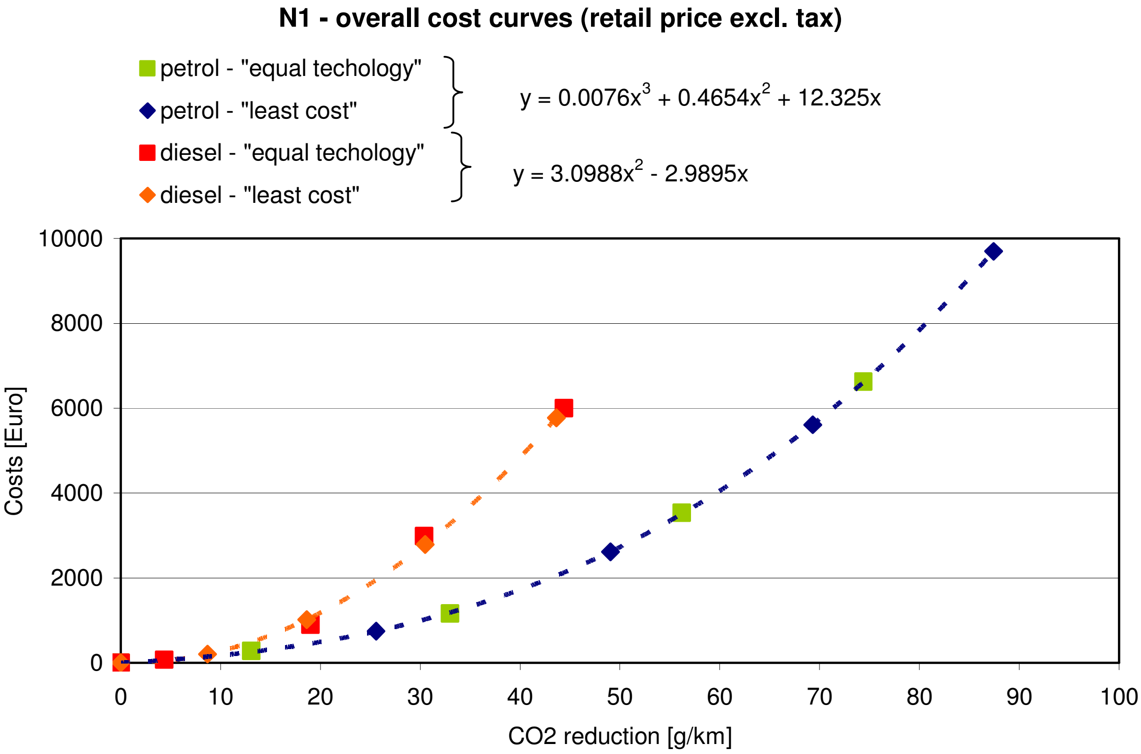

Figure 8.4 Output to TREMOVE: overall cost curves for N1-vehicles on petrol and diesel

Table 8.10 Output to TREMOVE: TA CO_2-emission data and increase of retail price excl. taxes.

				N1	
				petrol	diesel
	2002 baseline CO2-emission		[g/km]	222	191
	2012 baseline CO2-emission		[g/km]	209	178
equal technology - 2012	package 1	ΔCO2	[g/km]	13.1	4.4
		CO2	[g/km]	196	174
		Δcosts	[€]	284	74
	package 2	ΔCO2	[g/km]	33.0	19.0
		CO2	[g/km]	176	159
		Δcosts	[€]	1160	898
	package 3	ΔCO2	[g/km]	56.2	30.4
		CO2	[g/km]	153	148
		Δcosts	[€]	3535	2988
	package 4	ΔCO2	[g/km]	74.4	44.4
		CO2	[g/km]	135	134
		Δcosts	[€]	6622	5999
least costs - 2012	15 g/km reduction	ΔCO2	[g/km]	25.6	8.7
		CO2	[g/km]	183	169
		Δcosts	[€]	747	207
	30 g/km reduction	ΔCO2	[g/km]	49.0	18.6
		CO2	[g/km]	160	159
		Δcosts	[€]	2617	1021
	45 g/km reduction	ΔCO2	[g/km]	69.3	30.5
		CO2	[g/km]	140	148
		Δcosts	[€]	5611	2792
	60 g/km reduction	ΔCO2	[g/km]	87.4	43.6
		CO2	[g/km]	122	134
		Δcosts	[€]	9697	5769

8.13 Conclusions

- Cost and CO_2-reduction potentials of options to reduce CO_2-emissions form N_1-vehicles have been based on the results of Task 1.1 on passenger cars. For each fuel data from the M_1 categories small, medium and large have been used for the N_1 categories Class I, II and III. Based on the input provided by ACEA the following modifications are applied:
    - The CO_2-reduction potential of engine down-sizing for N_1-vehicles is assumed to be smaller than for M_1-vehicles;
    - The costs of start-stop systems with regenerative braking, mild hybrid and full hybrid powertrains for Class III N_1-vehicles are assumed to be a factor of 1.3 higher than for large M_1-vehicles. This factor is somewhat smaller than the one assumed by ACEA;
    - Some options such as strong downsizing and dual clutch transmission are considered not applicable to N_1-vehicles. For strong downsizing (in combination with (twin) turbo) this is due to the relatively high engine loads, that would cause problem with durability of the turbo, and the high torque requirements at low rpm that may not be fulfilled by this system;

- For each of the classes a business-as-usual package (BAU) has been defined of CO_2-reducing options that are assumed to be applied in the period 2002 – 2012 even in the absence of policy aimed at the CO_2-emissions of N_1-vehicles, as well as four packages with increasing levels of CO_2-reduction and technical complexity that may be applied by manufacturers in response to policy. For each of these packages the overall costs and CO_2-emission reductions have been assessed;

- The CO$_2$-abatement costs are found to depend strongly on the desired level of CO$_2$-reduction and on fuel costs. Small levels of CO$_2$-reduction compared to the BAU baseline (up to 15 g/km) are found to yield cost benefits for almost all levels of fuel costs;

Table 8.11 Abatement costs for CO$_2$-reduction in N$_1$-vehicles

				average	abatement costs [€/tonne]			
					0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
	2002 baseline CO2-emission		[g/km]	200.9				
	2012 baseline CO2-emission		[g/km]	189.7				
least costs - 2012	15 g/km reduction	ΔCO2	[g/km]	15.0	6	-16	-44	-91
		CO2	[g/km]	175				
		Δcosts	[€]	352				
	30 g/km reduction	ΔCO2	[g/km]	30.0	63	41	14	-34
		CO2	[g/km]	160				
		Δcosts	[€]	1394				
	45 g/km reduction	ΔCO2	[g/km]	45.0	131	108	81	34
		CO2	[g/km]	145				
		Δcosts	[€]	3315				
	60 g/km reduction	ΔCO2	[g/km]	60.0	206	184	156	109
		CO2	[g/km]	130				
		Δcosts	[€]	6239				

- Achieving an average 60 g/km TA CO$_2$-emission reduction in N$_1$-vehicles has about equal CO$_2$-abatement costs as reducing the average TA CO$_2$-emission from M$_1$-vehicles with 20 g/km form 140 to 120 g/km. Given the non-linear dependence of CO$_2$-abatement costs on the reduction target, an average 20 g/km TA CO$_2$-emission reduction in N$_1$-vehicles can thus be reached at significantly lower costs per ton than the same reduction in M$_1$-vehicles;
- CO$_2$-emission reduction in N$_1$-vehicles therefore is an interesting option to consider in the context of the Integrated Approach. Obviously this advantage of N$_1$-vehicles compared to M$_1$-vehicles is largely due to the fact that M$_1$-vehicles are subject to CO2-reducing policy until 2008, while such a policy does not exist for N$_1$-vehicles.
- A first assessment of the overall GHG reduction potential associated with reducing the TA CO$_2$-emissions of new N$_1$-vehicles compared to the business-as-usual baseline has been made for EU-15. For a 2012 reduction target of 15 g/km the overall GHG reduction potential grows from 1.2 Mtonne/y in 2012 to 2.2 Mtonne/y in 2020. These values increase with higher reduction targets reaching 4.9 Mtonne/y in 2012 and 16.5 Mtonne/y in 2020 for a reduction target of 60 g/km. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

8.14 Literature

[ADAC 2005]	*Study on the effectiveness of Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO_2 emissions in respect of the marketing of new passenger cars,* A report to DG Environment, ADAC, March 2005.
[IEEP 2004]	*Service contract to carry out economic analysis and business impact assessment of CO_2 emissions reduction measures in the automotive sector*, contract nr. B4-3040/2003/366487/MAR/C2, carried out by IEEP, TNO and CAIR on behalf of DG-ENV, 2004
[RAND 2003]	*Preparation of measures to reduce CO_2 emissions from N_1 vehicles*, A report to DG Environment by RAND Europe, FKA and TML, April 2003
[TNO 2004]	*Study contract on measuring and preparing reduction measures for CO2 emissions from N_1 vehicles*, study for DG Environment carried out by TNO, IEEP and LAT/AUTh, 2004.

9 Options for promoting fuel efficient driving

9.1 Goal of Task 1.5

The goal of this Task is to review the potential costs and benefits fuel efficient driving behaviour and of measures that can be taken to promote it. Two main options studied separately under this Task are:

- in-car equipment, and
- driver training, e.g. included in driving lessons for new drivers or lessons aimed at new car buyers, company car drivers or all drivers.

9.2 Approach

- Based on existing literature and insights estimates are made of the possible impacts of in-car equipment on the fuel economy of average cars in 2008, which reach the goal of 140gCO_2/km on the type approval test. Costs of this equipment will be estimated both for OEM-equipped new vehicles and for retrofit on existing vehicles.
- Based on existing literature and insights estimates are made of the possible impacts of fuel efficient driving styles on the fuel economy of average cars in 2008, which reach the goal of 140gCO_2/km on the type approval test. Driver training can be promoted and implemented by public authorities or by car manufacturers. It will be assessed how the two different forms of financing affect the vehicle price.
- Cost and CO_2-reduction data (with respect to real-world emissions) will be generated as input for the development of scenarios and assessments to be carried out with TREMOVE and in Task B.

9.3 Relevant aspects and considerations

- The fuel economy of a car is not only a function of the applied engine and vehicle technology, but is also strongly influenced by the behaviour of its driver. Aggressive driving styles result in high fuel consumption and high emissions. Smooth driving by anticipating other traffic and traffic situations and applying a shifting strategy appropriate for modern engines can reduce fuel consumption significantly. Besides through driver training, the implementation of this new driving style can be facilitated by driver assistance equipment (e.g. a gear shift indicator, GSI) or a semi-automatic gearbox.

- The essence of the new driving style is to reduce part-load operation of the engine. Technical measures to improve fuel economy, as reviewed in Task 1.1, are to a large extent aimed at improving the engine's efficiency at part load. It may thus be expected that the impacts of the new driving style will decrease with increasing engine efficiency. This relation will be assessed as far as possible based on available information.

- It is important to take into account the potential longevity of the impacts, e.g. drivers can be trained to drive differently, but can easily revert back to their former habits. This task, therefore, needs to underline the problems of this approach to manufacturers. Long-term benefits will need a long-term commitment to training to ensure that there are permanent changes in drivers' behaviour.

- In principle a differentiation of the estimated potential for different EU countries could be justified, as the driving style in Northern countries is known to be generally less dynamic / aggressive than in Southern European countries. The potential CO_2-reduction of eco-driving in Southern countries therefore may be higher. These possible differences are neglected in the present analysis.

- The fleet-wide effectiveness of measures relating to the "new driving style" can not really be modelled or predicted as they depend strongly on behavioural aspects. Assumptions will have to be made on the percentage of drivers that will adopt the driving style and the long-term impacts on average real-world CO_2-emissions.
- Like for the adoption of driving style, the overall impact of the use of a GSI on CO_2-emissions will have to be estimated too. It is not known what share of drivers will follow the instructions given by a GSI and how good and consistent they are in following the instructions. At the moment, such questions are under consideration for addressing in concrete research activities to be carried out by members of the FIA foundation and individual car manufacturers. The shifting points as determined by a GSI are determined in the same manner as for an Automated Manual Transmission. The shifting points are based on a balance between fuel economy, drive-ability and possibly emissions. An example can be given for the situation in which the driver demands a strong acceleration. In this case the GSI will not advise to shift up early at low engine revolutions, but to shift up at a higher engine speed to obtain the best response from the engine to accelerate as strong as the driver demands. This advice is to the detriment of fuel economy. In this way, however, dangerous situations are avoided in which too little engine power is available for catching up (adapting speed) with other traffic.
- Assessment of possible positive impacts of eco-driving on traffic safety and the associated societal benefits is considered beyond the scope of this project and is therefore not included.

9.4 Fuel efficient driving (eco-driving)

The fuel consumption of a car is influenced by the driving behaviour of the driver to a significant extent. Fuel consumption can be significantly reduced by means of a fuel efficient driving style, also referred to as eco-driving.

Fuel efficient driving is achieved by:
- Operating the engine in its most efficient range, i.e. in an area of the engine map (of torque and engine speed) where the fuel efficiency is highest, and example of an efficiency map is given in the picture below;
- Reducing the waste of kinetic energy by unnecessary braking and using the benefit of fuel cut off;
- Avoiding unnecessary energy demand by:
  - avoiding unnecessary (too strong) accelerations;
  - avoiding high speeds;
  - minimizing the use of auxiliary equipment;
  - minimizing driving resistance (tyre pressure).

In essence this comes down to:
- Reducing the energy needed at the wheels by influencing the driving pattern ($v(t)$);
- Optimising the efficiency with which the engine delivers it's energy to the wheels by reducing the amount of part or low load operation of the engine.

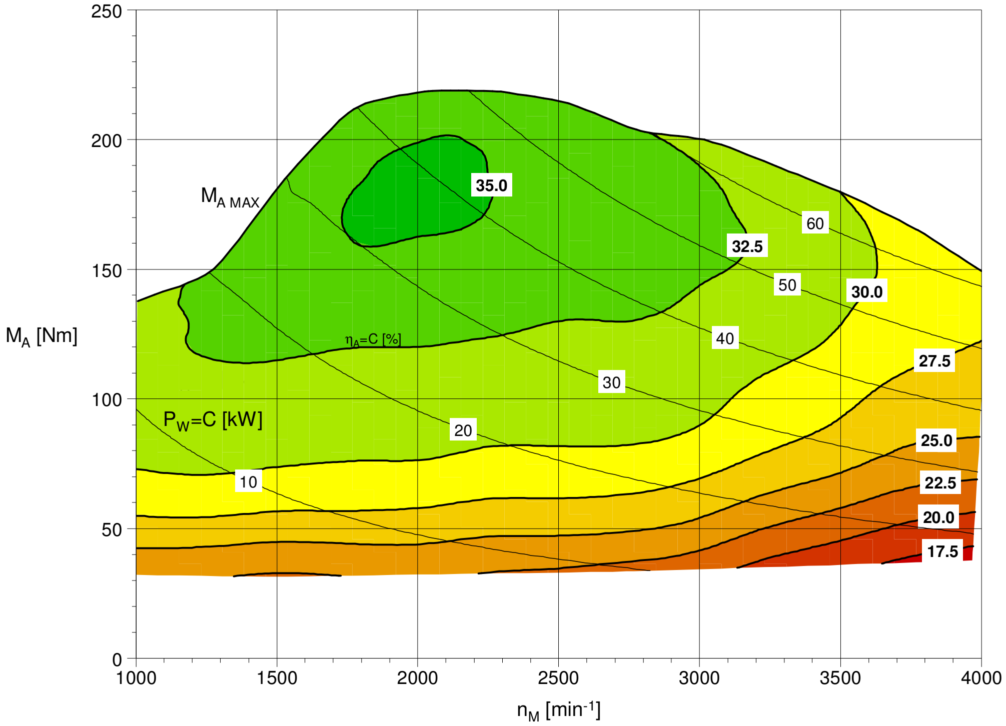

Figure 9.1 Example of an efficiency map of a diesel engine; efficiency vs. engine torque and engine speed. The dark green area represents the highest efficiency.

These rather physical explanations have been translated in more practicable and generally understandable tips, suitable for campaigns and driving courses, as for example in the Netherlands:

- Shift up as soon as possible at a maximum of 2500 rpm (for diesel a maximum of 2000 rpm) to a gear as high as possible;
- Press the throttle quickly and vigorously just as much so that you can keep up with the traffic;
- Do not shift down to a lower gear too early, and keep the car rolling without disengaging the clutch and in a gear as high as possible;
- Keep the speed as steady as possible, drive at low engine speeds in the highest gear as possible;
- Look ahead as much as possible and anticipate other traffic.

Depending on their driving style, drivers may save between 5 and 25% fuel directly after having received instructions or lessons. The average reduction in practice is more of the order of 5-10% and tends to reduce over time. A more detailed evaluation of the possible fuel consumption and CO_2-reduction is presented in section 9.6.

The application of eco-driving can be aided by the use of in-car devices such as a fuel economy meter and a gear shift indicator (GSI). In this chapter the CO_2-reduction and CO_2-abatement costs of eco-driving and the use of GSI are analysed separately and in combination.

As the costs of governments sponsored programmes to promote the application of eco-driving should be factored into the assessment of the CO_2-abatement costs of eco-driving, the following section first discusses various options to promote fuel efficient driving behaviour.

9.5 Options to promote fuel efficient driving

This fuel efficient driving behaviour can be stimulated by different means. In general it can be stated that fuel efficient driving is indirectly promoted by the costs of fuel and environmental awareness.

Next to options like ‘leaving the car home’ and public transportation, car owners will or need to be stimulated to seek for other measures to reduce fuel consumption. Applying a fuel efficient driving style saves costs and reduces CO_2 emissions. There are several options how to promote fuel efficient driving. Below, the most promising options are given.

Options to promote fuel efficient driving may require different levels of involvement of the driver and the authorities and involvement of different types of technical equipment, impacting different aspects of fuel efficient driving. Five typical levels can be distinguished:

1. Awareness campaign (including communication of tips);
2. Driver training course (theoretical and/or practical);
3. In-car information (on-board combined trip meter - fuel consumption computer)
4. In-car driving advise (Gear Shifting Indicator);
5. In-car driver assistance, overruling the driver (Automated transmissions, hybrid drivelines);

1. Awareness campaigns; make drivers aware of the fact that driving behaviour can influence (decrease) fuel consumption by promoting the fuel efficient driving style through advertisement campaigns and communication of the tips. To be effective, a high level of initiative from the side of the driver is required.

2. Training of the driver. There are 3 options:
   - Training could be given to voluntary drivers, e.g. in the form of an advanced driving course that focuses on fuel efficient driving. Recruiting drivers could be done by advertisement;
   - Training could be given compulsory, additional to the standard driving lessons that are needed for obtaining a drivers license;
   - Training could be given when one purchases a new car, the training e.g. to be looked after and promoted by the car manufacturer(s).

   This level of involvement of the driver is characterized by the fact that the driver in the end determines his driving style. This driving style is to a certain level affected by the training course. Willingness, acceptance and interpretation determine if the instructions keep well over time and determine how good the driving tips can be reproduced over time. Obviously, voluntary drivers will be better motivated and try harder to achieve good results. It is the question, however, how many of them can be recruited for a training.

3. In-car information: a combined trip - fuel consumption meter (on-board fuel consumption computer) helps to *make* the driver aware of his own impact, but probably also helps to *keep* him aware of his own impact. A trip - fuel consumption meter gives feedback on fuel consumption and enables a quick evaluation of the impact an adapted driving style has. Although during accelerations the meters presenting actual fuel consumption do not seem to give useful information (the instantaneous FC fluctuates to much during accelerations) they do show the benefit of driving in a higher gear at stable speeds. Meters having the ability to average fuel consumption over a trip (most do have this option today) also help to get insight in the *overall* impact an adapted driving style has on fuel consumption, thus including the obtained effects of shifting at lower engine speeds, avoiding unnecessary braking etc. because an onboard fuel consumption computer makes the comparison of individual trips very easy; a driver does not need to collect tickets and write down mileage to calculate eventual effects. A driver who uses the meter (computer) in combination with the driving style tips is able to learn about the impact of his driving style and by a certain amount of learning time knows how well he performs. This in the end could help to *keep* a driver aware as a change in fuel consumption would be noticed very easily.

4. In-car driving advice; advising the driver by means of some indicator on how to act. A Gear Shifting Indicator (GSI), for example, indicates appropriate shifting moments by means of two lights on the dash board, one for up-shifting and one for down-shifting, or indicates the preferred gear to drive in by the number of the gear presented on the dashboard. The application of a GSI is characterized by the involvement of an in-car instrument that gives advise on how to drive (when to change gears).

5. In-car driving assistance, overruling the driver; in-car systems that decide for the driver on how to operate. Examples are CVT (Continuous Variable Transmission), AMT (Automated Manual Transmission) and cruise control. An AMT is a conventional gear box where the gear lever and the clutch are operated by actuators, a CVT is a pulley – belt construction that allows the gear ratio to be adjusted continuously. Because both transmissions are operated by actuators and computer control the driver's interference isn't needed anymore. For both, the engines computer decides for the transmissions which gear or which gear ratio to adjust. Sometimes, these gear boxes come with the option for different driving modes (Economic / Sportive / Mountain) and most AMTs have the option to force shifting by buttons on the steering wheel or a push lever. Even the conventional automatic gear boxes (with planetary gears and a torque converter) use shifting strategies that are optimized for fuel consumption, but like for the GSI and the AMT shifting moments are not only adapted to fuel economy, but also to power demand. At a high power demand, for example needed for a strong acceleration, shifting up will be at higher engine speeds, while at a relatively low power demand shifting up will occur at low engine speeds, better optimized for fuel economy. Besides the AMT and CVT a hybrid power train is typical example of a system that is tuned to perform as efficient as possible under given driving conditions. It uses a battery to temporarily store energy which was generated at a high level of engine efficiency or from regenerative braking. Like the GSI and AMT, application of a hybrid driveline does not affect the driving itself, but only the efficiency at which the energy for driving is generated. Finally, a cruise control can be regarded as being 'driving assistance'. A cruise control only keeps the speed constant, however, and by no means assists on driving at a fuel efficient speed. This instrument is probably only profitable if its use drastically reduces driving dynamics, avoiding unnecessary strong accelerations and decelerations. For drivers already driving relatively steady the benefits are probably very low.

9.6 CO_2-emission reduction through eco-driving and GSI

The effects of two different options to reduce CO_2-emission will be discussed;

- The first option is training fuel efficient driving;
- The second option is application of an in-car instrument giving advice on when to shift, generally called a Gear Shifting Indicator (GSI).

Driving styles introduce large variations in fuel economy. Driver behaviour is complex and can be characterized by numerous independent parameters. A number of items can be recognized that altogether determine the effect that will be finally obtained. These items will be discussed hereafter.

9.6.1 Parameters that influence the effect

Human behaviour

The achievable effect of fuel efficient driving is determined by a lot of parameters. To start with, the base driving situation and the effectiveness of the trained driving tips for the driver in question for the car in question are the key parameters. The base situation determines how much improvement can be achieved, relative to that base situation. Drivers already driving fuel efficient to a certain extent have a smaller potential to reduce fuel consumption than for example 'sportive' drivers. Driving styles typical for regions in Europe may also be of significance. Drivers in Southern countries often have a more dynamic driving style than drivers of Northern countries and may thus have a larger potential of reducing fuel consumption. Next to the base situation, training quality, perception and ability / skill of the trainee also determine how good the driving style can be put into practice and thus determine the level of the attainable effect. Furthermore, acceptance, willingness, longevity, skill and stimulation are important and determine *if* the driving style is adapted, for *how long* it will be adapted, *how good* the driving style will be adapted and *how good it lasts* over time. Looking at these factors, it is not the question for how long a driving style will be adapted, it is mainly the question how many drivers are willing to adapt their driving style, how much they are willing it and how good they can put it to practice. These drivers may loose some of their skill over time, but not all of it. And they will probably not just quit applying the efficient driving style.

How many drivers will eventually adapt the driving style and to what extend is rather difficult to determine, because not much research has been performed on this issue and the research itself is rather complicated. As was already mentioned it is a matter of acceptance and willingness stimulated by parameters like fuel costs, environmental awareness, advertisement, feed-back and recurring advice how many drivers will eventually adapt their driving style and how good they will adapt it. Furthermore, it is obvious that fuel efficient driving will appeal to drivers that are already driving consciously. Sportive drivers may have the highest potential to reduce their fuel consumption, the efficient driving style may be less appealing for them and so they may be less willing to accept and adapt their driving style. Another group is the one containing drivers that are not very well aware of the possibility to reduce fuel consumption by adaptation of their driving style, although in principle they are willing to reduce costs and / or the environmental burden. This is probably a large group that may obtain good results regarding overall reduction of fuel consumption. Reliable figures were never established, however.

How good driving style tips were put into practice by a panel of 24 drivers, just after being informed in writing, was investigated in [TNO 2002, Interpretation of Driving Style Tips]. This study revealed a spread in how tips are interpreted. While fluent driving is accepted as evident for fuel efficient driving, some drivers had difficulties accepting and applying the tip to press the throttle quickly and vigorously. In some cases this even resulted in unwanted very strong accelerations. The communication of that tip was changed after finishing the investigation.

Driving conditions

Driving conditions in general and mainly traffic conditions may have a large impact on how well a driver is able to apply a fuel efficient driving style. For instance, other traffic may obstruct the fuel efficient driver applying his driving style. Likewise, weather conditions as well as traffic situations may obstruct a driver to adapt his driving style.

Car and equipment

A passenger car may affect the way a driver operates it by matters like driveability of the car (the availability of power over the range of engine speed, engine souplesse), noise and vibrations. The lack of souplesse and/or the presence of noise and vibration due to driving at low engine speeds may prevent a driver from shifting up early. Modern engines, however, are often very well optimized when it comes down to these matters. A difference might be found in the effects between low motorised cars and high motorised cars, because cars with low powered engines often already require deep throttle positions to catch up with traffic and may thus be more often operated in a more fuel efficient range of the engine map. Cars with more power, however, do often not need to be operated at higher engine loads, they can easily catch up with other traffic and may thus be operated at average lower throttle positions. In contrast to the effects mentioned, the cars with a higher level of motorisation can often easily be driven at low engine speeds and may thus invite a driver to do so better than a small car would. Another example is the difference in engine characteristics of petrol and diesel engines. Diesel engines have a relatively high torque at low engine speeds and may thus be stimulating the low rev up-shifting more than petrol cars would. Until now it is not possible to extract figures for this kind of effects, because they were never investigated.

Equipment like a GSI (Gear Shifting Indicator) may help drivers that have not been trained the fuel efficient driving style to apply the optimal shifting strategy. Furthermore, as a study indicated [VITO 2003] an on-board computer (actual and average trip fuel consumption) helps to keep a driver aware of his impact on fuel consumption and so it results in an overall larger decease of fuel consumption (-6%) than it would have been the case without the on-board computer (-2%).

Engine and driveline technology will continue to change in the next decades. Changes already expected in the near future (2008-2012) may impact the effect an adapted driving style has on fuel consumption. The main reason is that the typical effect of avoiding low and part load situations of the engine may decrease because of the improvement of the part load efficiency of engines.

Research

Finally, the way the tests have been performed, the size of the sample and the selection of the sample may well influence the level of the effect measured. A major obstacle in determination of the effects of driving style adaptation is the availability of a large representative group of drivers who are unbiased by their awareness of being observed. Juridical aspects namely block the opportunity to monitor someone's behaviour without having the person in question informed in advance and after having received his approval for it.

Table 9.1 Summary and subdivision of influential parameters.

Human behaviour	**Driving conditions/ circumstances**	**Equipment (vehicle)**	**Research**
Driver • training • trainer • experience • motivation • habits • passengers • other road users	*Traffic* • traffic conditions • road type • traffic situation • weather • road condition • speed control • other road users	*Vehicle* • assistance: AMT, CVT • information: on-board computer • advice: GSI • forced: AMT/CVT/hybrid • driveability • power • noise/vibrations • engine type/power train • future technology	*Measurement* • statistics • representativity • analyses • methodology

9.6.2 Communication and training

The following package of ways to promote a fuel efficient driving style was investigated in this study on its cost effectiveness:

Table 9.2 Option to promote a fuel efficient driving style

What	**How**	**Who**
Training	dedicated course	volunteers
Training	as part of regular driving lessons	license B candidates
Media communication	advertisement by mass communication	license B holders

The contents of a voluntary training course, a course integrated in driving lessons and a mass communication programme will be discussed hereafter.

Dedicated training course

Driver training is one of the ways to communicate the fuel efficient driving tips to a driver. If the fuel efficient driving style is taught in a practical training programme with educated instructors, it is possible to correct driving behaviour on the spot. A training programme combining theory and practice is probably to be preferred above communication campaigns (advertisement) when it comes to the level of skill to be reached. The effect of this kind of a training combining theory and practice is investigated in this study. Training courses for fuel efficient driving are already offered by driving schools or Automobile Associations as special driving courses. Often the course is given next to some advanced driving course. The most common form of a course for fuel efficient driving is as follows:

- Practical evaluation of the base situation with the driver applying his / her own driving style
- Theoretical training
- Practical training
- Evaluation of the driving style just learned

The duration of one course is for most driving schools half a day (about 4 hours), but some go up to one working day (8 hours), depending on the exact contents of the training course. For the latter often extra attention is paid to driving skill in general and can thus be regarded as more extended compared to driving courses only aiming at fuel efficient driving. It is assumed that for training a fuel efficient driving style a minimum of half a day will suffice and includes the 4 elements as mentioned above.

Integration into driving lessons

For integration into standard driving lessons, required for obtaining the license papers (EU license B), it is assumed that eco-driving can be taught during regular lessons. As such, training eco-driving is not additional to the training of the normal driving style, but replaces some of the regular training. E.g. for shifting, the special strategy can be taught immediately as ‘the regular’ way of shifting instead of teaching the ‘old’ way and the ‘Eco’ way of shifting separately. Additional lessons would not be required. To teach eco-driving during driving lessons the instructors should be educated with the driving style and they should be educated with some extra pedagogic skills focussed on teaching eco-driving. Integration into driving lessons thus requires the instructor to follow an additional course to obtain the eco-driving skills and extra pedagogic skills. Because instructors are already educated drivers it is assumed that learning the eco-driving style and some pedagogic skill would not require more than a normal course for volunteers which takes about 4 hours to about a day. VVCR in the Netherlands educates driving instructors with HNR (“Het Nieuwe Rijden”, the Dutch name for Eco Driving) in a day.

Mass communication

Mass communication to reach license B holders and even license B candidates may be achieved through:

- TV advertisement campaigns
- Radio advertisement campaigns
- News papers/magazines
- Posters/brochures
- Internet
- Exhibition promotion stands
- Sponsoring of events

In the Netherlands a subsidized programme was conducted over several years. The programme included all of the above elements. Investment costs and CO_2-abatement costs of the campaigns were assessed in [Goudappel 2005]. During 2004 the campaign reached 29% of the license B holders, of which 4,5% said that they had decided to fully apply the driving tips, while 24% said that they apply the tips to a limited extent. For the people fully applying the tips, an achievable CO_2 reduction of 10% was assumed, while the group applying the tips only partly was assumed to achieve a reduction of 2%.

9.6.3 Gear Shifting Indicator

The GSI advises the driver about when to shift up or down by some indicator in the dash board of a car. This instrument only advises on when to shift and by no means affects the driving dynamics induced by the driver directly. The advised shifting moments are very well adapted to the fuel efficiency map of the engine. This may be of a benefit compared to a more general advice on shifting speed as given in awareness campaigns. However, a GSI does not only indicate the optimal shifting moment for the best fuel economy. It also takes into account the drivers demand. If a stronger acceleration is required, to catch up with traffic for example (the gas pedal is fully, or almost fully pressed), the GSI will not advise to shift up at a low engine speed, because in that case too little power would be available for the required action, which could lead to a dangerous situation. Instead, to avoid the risk of a dangerous advice, the GSI will indicate to shift up at a higher, possibly less fuel efficient, engine speed.

The application of a GSI is characterized by the involvement of an in-car instrument that advises on how to act. On the one hand the GSI will have a learning effect for uneducated drivers, mainly in the situations when little or no accelerations are required. In these situations a GSI advises to shift up at low engine speeds, often much lower than an inexperienced driver would do. On the other hand the driver can neglect this advise and it is therefore dependant upon his willingness if and how much he obeys the advise.

9.7 The effect of Eco-driving training and GSI on CO_2-emission and fuel consumption

9.7.1 Ecodriving

The effect of fuel efficient driving on fuel consumption was investigated in several studies. Different approaches can be distinguished between the studies. Most studies investigated the effect of the education of drivers *just after*:

- a practical and theoretical training
- communication in writing
- communication in speech.

The effects obtained from these studies have to be regarded as the *achievable* effects (although not in all investigations feed-back was given to correct errors e.g. caused by misconception, something which would be given in the case of a training course). Very few studies, however, have investigated the *achieved* effects. In other words, what is the effect of the training over a certain period of time after the training, without the driver knowing his driving is monitored. The latter to obtain an effect that is not biased by the driver knowing he is monitored.

[TNO 2005] investigated the effects of Eco Driving as applied correctly under real world Dutch urban and rural traffic conditions of Euro 3 and Euro 4 petrol and diesel passenger cars. The effects are in the order of -6 to-10%. The effects for petrol and diesel cars are almost of the same absolute level. The results can be interpreted as *achievable* effects under real world traffic conditions, because only the correctly applied style was used.

[TNO 2002] investigated the interpretation of three driving tips related to Eco driving. The communication was in writing. There was a large spread in interpretation of the tip to press the throttle quickly and vigorously. In some cases it even lead to an increase of fuel consumption. Excluding the results of the person misinterpreting tip 2, effects were found of -5 to -25%. The effects should be interpreted as *achievable*.

[TNO 2000] investigated 4 different driving styles; defensive (reference), egg (restricted use of the throttle), sportive and economic-driving. For urban driving an effect of -7% of Eco driving compared to the reference driving style was found (combined for petrol and diesel) and -11% for rural driving (also for both fuels combined). Comparing Eco Driving to sportive driving resulted in much larger effects. The effects can be interpreted as achievable effects under real world Dutch traffic conditions. Also these results should be regarded as *achievable*.

[VITO 2003] investigated the effects just after giving drivers of a company fleet a training and just after communication by a brochure. Furthermore, the long term effects with and without an on-board computer were investigated. The cars were all regular Euro 3 diesel cars. Effects found just after the training were in the order of -10 to -20%. The effects were determined from fuel consumption and trip registration from the company fuel card. Effects found after communication by a brochure were clearly less and in the order of -2 to -3%. Longer term effects (of about half a year) were found to be -2% without on-board computer and -6% with on-board computer. It is not known to what extent drivers were informed about being monitored, but the latter figures give an indication of *achieved* effects.

MTC and SNRA [AVL-MTC 2003] found differences between trained, trained motivated and non trained drivers. The motivated drivers drove with a significantly lower fuel consumption than the other drivers. Furthermore, a difference in effect was found between an average size petrol car and a large size petrol car. For the large car an effect of -8% was found, while for the smaller car no effect was found.

[ETH 2003] investigated the effect of adapted shifting according Eco driving on future technology drivelines by means of computer simulation on; a variable valve control concept, a downsize concept, a mild hybrid concept and some more. ETH used the same driving cycle for the reference as well as for the investigated situation. For a regular petrol and a diesel car, simulation of adapted gear shifting over an urban driving cycle results in an effect of -21% for the petrol car and a remarkable lower effect for the diesel car of -6%. The variable valve control concept showed an effect of Eco driving of about -4%, the downsize concept +0.5%, the mild hybrid -18%. A 6 speed gear box results in a higher fuel consumption than a 5 speed gear box with regular driving as well as with Eco driving.

Furthermore, some field studies were carried out; ‘Eco Drive (Switzerland)’ found an effect of -17% just after training by a driving simulator; In Germany 354 drivers achieved an average effect of -8% just after instruction; In the Netherlands (SenterNovem) driving instructors achieved -13%.

[Goudappel Coffeng 2005] evaluated the effectiveness of Dutch subsidy projects promoting dedicated driving courses, in-car instruments and training during the general license B driving course. The study used an effectiveness of 35% for the training course, meaning that 35 out of 100 drivers actually apply the tips after training. Furthermore, the study used 10% for the efficiency improvement (CO_2 reduction). Finally, the study used 90% for the durability of the effects over one year, but concludes that overall results are very sensitive to durability. This results in an overall CO_2 emission reduction of 3.2%.

Several studies have shown achievable effects in the order of 5 to 25%. Most studies show effects somewhat lower or somewhat higher than 10%. The effects are probably scattered by the large amount of circumstances that may affect the results. Summarizing, an average *achievable* effect of about 10% seems reasonable. The studies that took effectiveness and durability of the training into account reported an overall *achieved* effect of about 2 to 3.5% about a year after training.

Looking at the application of future fuel efficient technology (hybrid, downsizing, alternative valve trains, Direct Injection, etc.), it is not very clear how much it affects the potential of driving style adaptation. Generally, it is assumed that optimized concepts have less potential to reduce fuel consumption by adaptation of driving style, because these concepts would have improved partial load efficiencies compared to the current applied technologies and as a result the difference between normal and optimized driving style would be reduced. The potential reduction can therefore be expected to decrease, but as it is not clear how much the potential reduces and how much of the concepts will be marketed, the relative *(achieved)* effects could be applied directly to the future passenger car CO_2 emission. This will lead to a decrease of the *absolute* effect dependent on the decrease of the base CO_2 emission of the concept.

Calculation model

The total annually avoided CO_2 emission of a measure can be calculated as follows:

$$CO_2 \text{ avoided [g]} = \text{reach [\# of people]} \times \text{annual mileage [km/person]} \times \text{effectiveness [\%]} \times \text{durability [\%]} \times CO_2 \text{ emission [g/km]} \times \text{achievable effect [\%]} \times \text{technology effect [\%]}$$

- Reach is the number of people reached by the measure;
- Effectiveness is the percentage of the exposed people really adapting their driving style;
- Durability is the longevity of the effect (i.e. how much of the effect is maintained in the longer term);
- Achievable effect is the reduction that can be obtained by an average driver under average traffic conditions in an average car;
- Technology effect is the change in reduction potential due to changes in technology applied.

In this calculation the achieved effect is determined by:

$$\text{Achieved effect [\%]} = \text{achievable effect [\%]} \times \text{effectiveness [\%]} \times \text{durability [\%]}$$

With an achievable effect of 10% for an average driver, under average driving conditions and using an average car, a net effectiveness of 35% and a durability of 90% [Goudappel Coffeng 2005] the achieved effect amounts 3.2%. This value is rounded to 3%. With net effectiveness we mean that in the case of a voluntary course 100% of the trainees may be assumed to be initially motivated to apply what they are taught, but after an initial period only 35% of these trainees will still purposely maintain and correctly apply eco-driving.

For the effect of technology the decrease of the *absolute* CO_2 emission is made dependent on the decrease of the base CO_2 emission of the concept, by using the same percentage for the future concept with its lower base CO_2 emission.

Table 9.3 Effects of an Eco Driving course on CO_2 emissions in g/km per trainee, just after the training (short term), one year after the training (long term) and with the application of future fuel efficient power train technology.

Eco Driving course	Achievable effect short term* (2005) 191g/km***	Achieved effect long term** (2005) 191g/km	Achieved effect long term** (2008) 167g/km***	Future technology (2012) 143g/km***
[%]	-10%	-3%	-3%	-3%
[g/km]	-19.1	-5.7	-5.0	-4.3

*) directly after a training course.

**) one year after training. The decrease compared to the short term effect is mostly due to effectiveness of the training (amount of people adapting) and for a small share due to durability. It is assumed that the durability does not decrease further after this year.

***) TA value of 160 g/km (2005), 140 g/km (2008) resp. 120 g/km (2012) multiplied by 1.195 to arrive at real-world CO_2-emission.

9.7.2 The effect of a Gear Shifting Indicator on CO_2 emission and fuel consumption

The effect of a Gear Shifting Indicator was extensively investigated in one study [TNO 2005]. For the study 28 passenger cars were tested (equally distributed over petrol and diesel and over the M_1 Euro 3 and Euro 4 category, resulting in 7 cars per sample). The cars were tested over the regulated European Driving Cycle (MVEG-B) and the Common Artemis Driving Cycle, which is currently accepted as the best representative driving cycle for European driving. The study was performed in close cooperation with the stakeholders (car industry as represented by ACEA for Europe and JAMA for Japan, the EC and the Dutch Ministry of the Environment). Because, at the time of the study no cars were available with a GSI, with exception of one Honda Civic IMA which was added to the test sample, the adapted gear shifting points had to be generated. The car manufacturers were consulted for this issue; they delivered the special gear shifting points for the cars to be tested. In the case no special shifting points could be delivered, they were generated from the algorithms from the received shifting points.

In general the study showed a significant decrease of CO_2 emission and fuel consumption due to the adapted shifting strategy according a GSI. Over the standardized European Driving Cycle the decrease was -3 to -5%, with generally the largest effect over the Urban part (UDC). Over the CADC urban and rural the effects were larger and in the order of -7 to -11% for petrol and -4 to -6 for diesel. These effects should be regarded as *achievable* effects, because they were obtained by fully changing from the regular shifting strategy to shifting according a GSI. At this moment a study is initiated into the level of acceptance and the extent of real world application of a GSI, so no real figures are available. For other in-car devices, like an econometer, cruise control, on-board combined trip - fuel consumption computer, the study [Goudappel Coffeng 2005] found an effectiveness level in the order of 25 to 36%, the level depending on familiarity with the Dutch HNR programme. The largest effectiveness level was found for the people familiar with HNR. If application and use of a GSI would be taken separately from Eco Driving, the Achievable and Achieved effects would again be;

Achieved effect [%] = Achievable effect [%] x Effectiveness[%] x Durability[%]

The achievable effect is estimated to be 6% for an average driver, under average driving conditions and using an average car (average of petrol and diesel). For the average effectiveness a value of 30% is assumed, meaning that 30% of the drivers actually follow the instructions of the GSI. Durability is estimated at 75% based on [Goudappel Coffeng 2005]. Combining these values the achieved effect amounts 1.35%. This value is rounded to 1.5%.

Table 9.4 Effect of GSI on tail pipe CO$_2$ emissions.

GSI	Achievable effect* (2005) 191g/km***	Achieved effect** (2005) 191g/km	Achieved effect ** (2008) 167g/km***	Future technology (2012) 143g/km***
[%]	-6%	-1.5%	-1.5%	-1.5%
[g/km]	11.5	2.9	2.5	2.1

*) If all drivers follow indications of GSI all the time.
**) Assuming that in practice not all drivers follow GSI indications all the time (30%).
***) TA value of 160 g/km (2005), 140 g/km (2008) resp. 120 g/km (2012) multiplied by 1.195 to arrive at real-world CO$_2$-emission.

9.7.3 Combined effect of Eco driving and a GSI

Table 9.5 Effects of the combination of an Eco Driving course and the use of GSI on CO$_2$ emissions in g/km per trainee, just after the training (short term), one year after the training (long term) and with the application of future fuel efficient power train technology.

Eco Driving course	Achievable effect short term* (2005) 191g/km***	Achieved effect long term** (2005) 191g/km	Achieved effect long term** (2008) 167g/km***	Future technology (2012) 143g/km***
[%]	-10%	-4.5%	-4.5%	-4.5%
[g/km]	-19.1	-8.6	-7.5	-6.4

*) directly after a training course.
**) one year after training. The decrease compared to the short term effect is mostly due to effectiveness of the training (amount of people adapting) and for a small share due to durability. It is assumed that the durability does not decrease further after this year.
***) TA value of 160 g/km (2005), 140 g/km (2008) resp. 120 g/km (2012) multiplied by 1.195 to arrive at real-world CO$_2$-emission.

As the shifting strategy proposed by the GSI is essentially the same as the shifting strategy stated in the ecodriving instructions, the effects of GSI and ecodriving on the achievable effect can not be added. Instead GSI should be seen as a tool that may help drivers to adequately apply ecodriving or to maintain applying ecodriving to some extent. As such it is believed to increase the *achieved* effect of ecodriving, meaning that applying a GSI would reduce the efficiency drop of *achievable* to *achieved effect* of ecodriving. For the purpose of this study it is assumed that the *achieved* effect is increased from 3% for ecodriving to 4.5% for the combination of ecodriving and GSI.

9.8 Costs

9.8.1 Costs of Eco driving training

Ecodriving as part of the license B training

If ecodriving lessons are included in the training of new drivers then the costs are limited. In principle the training time can be considered the same as for learning the ‘old’ driving style. It therefore does not involve extra lessons. Existing driving instructors do need to be trained to be able to teach ecodriving.

For a back-of-the-envelope calculation to attribute the costs of the training of the instructor to the new drivers receiving ecodriving training the following assumptions are made:

- an ecodriving training for driving instructors costs between 150 and 200 Euro;
- a trainer works 200 days a year, is able to fill 75% of a 40 hours working week with giving training;
- after his ecodriving training the instructors remains in this profession for 15 years on average;
- new drivers need on average 35 – 40 lessons of 1 hour to pass their exam and receive the license B.

Using these assumptions the costs of training can be divided over around 500 new licenses, so that these costs are well below 1 Euro per new driver. Even at significantly higher training costs the costs per new driver can be considered negligible.

Dedicated ecodriving lessons

Dedicated lesson, usually given to existing drivers, can consist of different combinations of theoretical and practical training. In general a half day (4 hour) group session should suffice to be able to adequately apply the ecodriving instructions. Costs of training as found in literature are:

Netherlands driving schools:	€ 50 – 165 (higher costs incl. training on the road)
ADAC	€ 48
Fahr und Spar	€ 51
VITO	€ 98
[IEA 2005]	€ 150 – 250
ACEA CARS21	€ 100 – 160

For the purpose of this study it is assumed that the costs are between 50 and 100 Euro (excl. VAT).

9.8.2 Costs of government campaigns

The Dutch Eco Driving campaign ‘HNR’ (Het Nieuwe Rijden) has provided information about the costs of a national mass communication campaign, the target group of such a programme being mainly the license B holders [Goudappel 2005]. A monitoring survey has revealed that during 2004 the campaign has reached 29% of the license B holders, i.e. 2.9 million of the driver population of 9.9 million in the Netherlands. Of the people that were reached by the campaign 4.5% (130.000 drivers) said that they had decided during that year to fully apply the driving tips, while 24% said that they apply the tips to a limited extent. The costs of the campaign were 3.2 M€ in 2004. Attributing the campaign costs only to those drivers that during 2004 decided to fully apply the ecodriving instructions, the campaign costs per affected driver are thus around €25.

The above obviously is only a rough assessment of the order of magnitude of the costs of an effective campaign.

9.8.3 GSI

Various sources provide indication of the costs of GSI devices. If they are integrated in new vehicles then the additional retail price is € 25 – 35 according to [IEA 2005]. Under CARS 21 ACEA has submitted a retail price estimate of € 20. Auxiliary options like GSI are usually sold with a significant margin, so that the factor of 1.44 between retail price and manufacturer costs (see Annex A) is not expected to be an overestimate. Using this factor the manufacturer costs of GSI are assumed to be around €15.

9.9 CO_2-abatement costs of eco-driving

The tables and graphs below present an analysis of the CO_2-abatement costs of eco-driving (possibly supported by the use of a GSI) as a function of the investment costs per driver, the net effect on fuel consumption, the duration of the effect and the fuel price. All calculations are made for the average new vehicle in 2008, which is assumed to emit 140 gCO_2/km on the Type Approval test.

CO_2-abatement costs are calculated using investment and fuel costs exclusive of taxes (four different levels of fuel costs: 0.21 / 0.30 / 0.41 / 0.60 €/litre). The investments may include the costs of lessons, the manufacturer costs of GSI (if applied) and the costs of government campaigns to promote fuel efficient driving. The interest rate used is 4%. The average annual mileage is assumed to be 16,000 km. Fuel cost savings and lifetime CO_2-emission savings are based on real-world fuel consumption derived from TA values by multiplication with a factor of 1.195 (see section 2.3 and Annex B). Lifetime CO_2-emission savings furthermore include the avoided WTT CO_2-emissions, by multiplying the real-world TTW CO_2-emission with a factor of 1.184. This factor is the average of the WTW/TTW factors for petrol and diesel as derived from [Concawe 2006] (see also section 2.4), weighted with the expected sales distribution of petrol and diesel in 2012 (see Table 3.13). Real-world driving and WTW-aspects are included to make the abatement cost calculation comparable to the assessments for e.g. biofuels (chapter 7).

For GSI manufacturer costs of €15 per vehicle are assumed. In the calculations assuming a duration of the effect of eco-driving combined with GSI that is longer than the lifetime of the vehicle (12 years on average), the attributed costs of GSI are multiplied by the duration divided the vehicle lifetime. Furthermore in the calculation of CO_2-abatement costs investment costs are calculated as 1.16 times the manufacturer costs (see section 2.1 and Annex A).

In Figure 9.2 the effects of the assumed reduction percentage, the investment costs (possibly including costs of lessons, GSI and public campaigns), and fuel price are explored. All parameters are found to have a significant effect on the estimated CO_2-abatement costs.

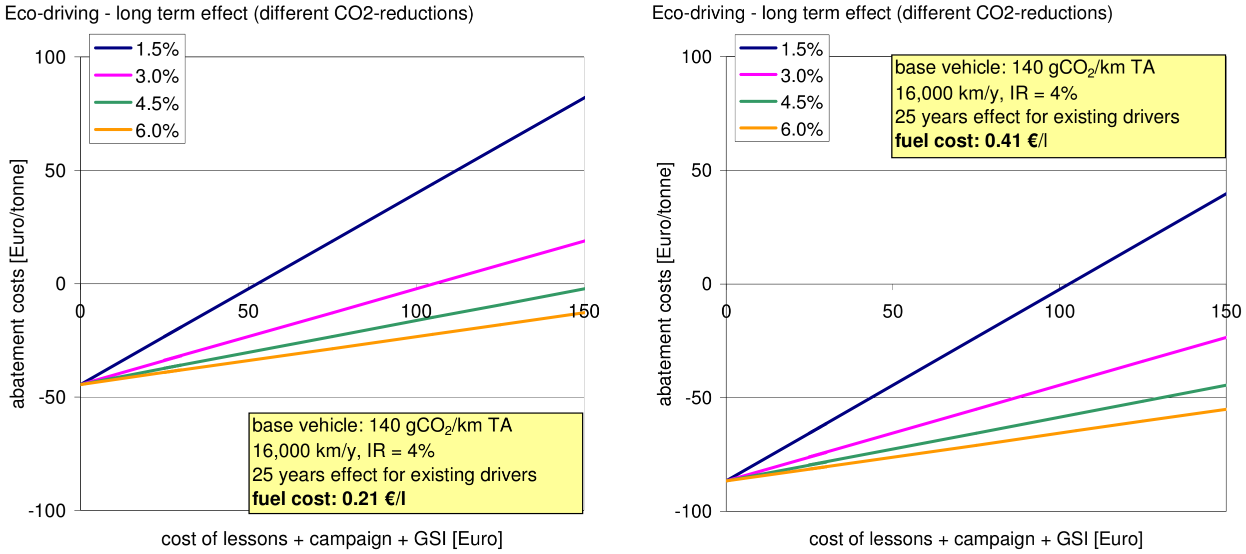

Figure 9.2 CO_2-abatement costs of ecodriving as a function of reduction percentage and investment costs for two different values of fuel price.

Table 9.6 lists the CO_2-abatement costs of ecodriving and GSI for various situations (ecodriving with and without lessons and applied by new drivers and existing drivers, and combination with and without GSI) for different levels of the fuel cost. The assessment is based on the costs and effect levels as summarized in sections 9.7 and 9.8. CO_2-abatement costs are calculated for the following scenarios:

- eco-driving included in lessons for new drivers, resulting in 3% fuel consumption reduction at zero additional costs with an assumed duration of the effect of 40 years;
- application of GSI in new vehicle, resulting in 1.5% fuel consumption reduction over an assumed lifetime of the vehicle of 13 years;
- existing drivers effectively applying eco-driving based on driving style tips communicated in government campaign (i.e. without training), assuming average campaign costs of € 25 per affected driver, resulting in 3% fuel consumption reduction with an assumed duration of the effect of 25 years;
- existing drivers following eco-driving lessons costing € 50 or € 100, resulting in 3% fuel consumption reduction with an assumed duration of the effect of 25 years;
- existing drivers being encouraged by government campaigns to follow eco-driving lessons costing € 50 or € 100, resulting in 3% fuel consumption reduction with an assumed duration of the effect of 25 years;
- existing drivers of cars equipped with GSI being encouraged by government campaigns to follow eco-driving lessons costing € 50 or € 100, resulting in 4.5% fuel consumption reduction with an assumed duration of the effect of 25 years;

It is clear from this assessment that, under the assumption of a long lasting duration of the effect, ecodriving, the use of GSI, and the combination of the two are cost effective for all levels of the fuel cost. Given the high share of tax in the retail price of fuels, GSI and ecodriving are even more cost effective to the consumer.

Table 9.6 CO$_2$-abatement costs of ecodriving and GSI for various situations (ecodriving with and without lessons and applied by new drivers and existing drivers, and combination with and without GSI) for different levels of the fuel cost.

				new drivers	existing drivers / with GSI / without training	existing drivers / response to campaign / wothout training	existing drivers / with training	existing drivers / response to campaign / with training	existing drivers / with training / with GSI	existing drivers / with training	existing drivers / response to campaign / with training	existing drivers / with training / with GSI
cost of eco-driving lessons			[€]	0	0	0	50	50	50	100	100	100
cost of pubic campain costs			[€]	0	0	25	0	25	0	0	25	0
manufacturer cost of GSI			*[€]*	*0*	*15*	*0*	*0*	*0*	*30*	*0*	*0*	*30*
retail price excl. tax of GSI			[€]	0	17.4	0	0	0	34.8	0	0	34.8
total cost			[€]	0.0	17.4	25.0	50.0	75.0	84.8	100.0	125.0	134.8
fuel saving				3.0%	1.5%	3.0%	3.0%	3.0%	4.5%	3.0%	3.0%	4.5%
duration of effect			[years]	40	13	25	25	25	25	25	25	25
CO$_2$-abatement costs	fuel cost =	0.21 €/l	[€/tonne]	-35	-26	-34	-23	-13	-21	-2	8	-7
	fuel cost =	0.30 €/l	[€/tonne]	-50	-50	-53	-42	-32	-40	-21	-11	-26
	fuel cost =	0.41 €/l	[€/tonne]	-69	-78	-76	-66	-55	-63	-45	-34	-49
	fuel cost =	0.60 €/l	[€/tonne]	-100	-128	-116	-106	-95	-103	-85	-74	-89

9.9.1 Comparison with data supplied by ACEA under CARS21

The Figure 9.3 below shows the results of a reproduction of the assessment by ACEA for CARS21, based on an assumed effect of ecodriving of 10% and a duration (durability) of the effect of 2 years. To be consistent with the ACEA calculation the assessment assumes:

- an average vehicle with 130 gCO$_2$/km TA (multiplied by 1.195 to arrive at RW CO$_2$-emissions);
- an interest rate of 5% (although the difference with 4% is negligible);
- a fuel cost of 0.30 €/l (for comparison also a line based on 0.60 €/l is added).

The red markers indicate the costs and CO$_2$-abatement costs of ecodriving with and without GSI as assessed by ACEA. As can be seen from the graph the ACEA results are exactly reproduced by the method for assessing CO$_2$-abatement costs as used in this study, when using the same input data. Obviously, the main difference between the ACEA data and the calculations presented above is the assumed duration of the effect in combination with the short-term vs. long-term level of the effect. Most available literature seems to indicate a limited but long lasting effect. Based on the assumptions made by ACEA eco-driving can be considered a relatively expensive measure (same level of CO$_2$-abatement costs of technical measures at the vehicle level), while under the assumptions made in this study eco-driving has negative abatement costs.

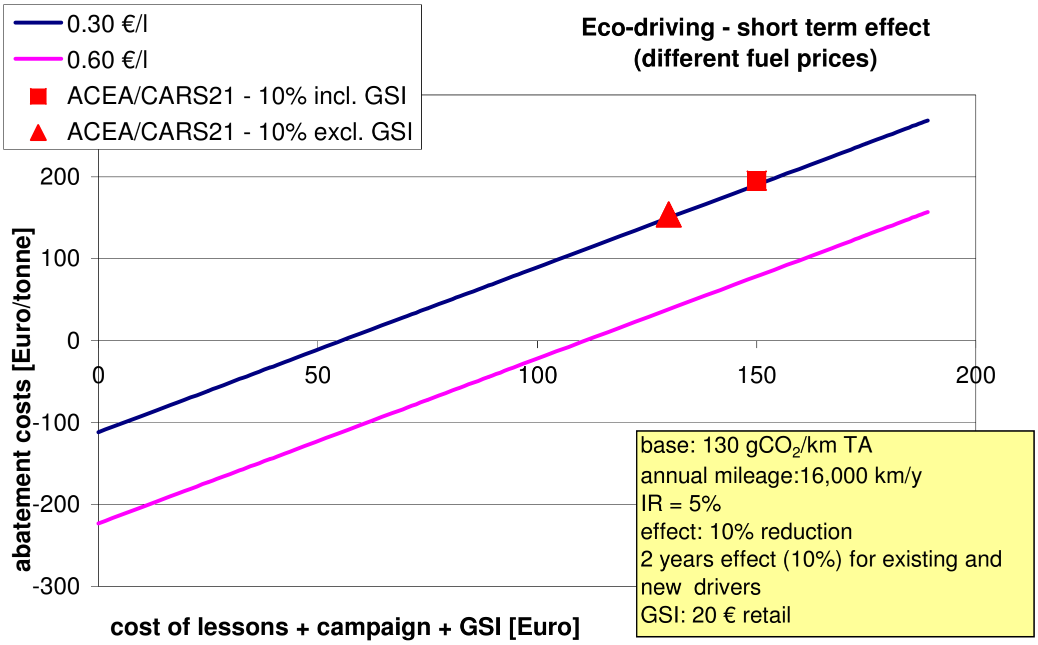

Figure 9.3 Reproduction of the assessment by ACEA for CARS21, based on an assumed effect of ecodriving of 10% and a duration (durability) of the effect of 2 years.

9.10 Total reduction potential

As eco-driving impacts vehicles of all ages in the fleet it is not necessary to use the fleet spreadsheet as described in section 2.5 for assessing the total reduction potential of eco-driving. Instead, calculations are based on the fleet averaged CO$_2$-emission values from the TREMOVE 2.42 baseline. Policies to promote the application of eco-driving are assumed to be implemented from 2008 onwards. For 4 different (constructed) scenarios the total share of drivers is defined that applies eco-driving in response to these policies. Combining the share of drivers (equal to the share of the fleet) with the reduction percentages for the various forms of eco-driving as presented in Table 9.3 to Table 9.5 gives the average CO$_2$-emission reduction percentage achieved at fleet level. The overall Well-to-Wheel GHG reduction is calculated by multiplying the average real-world CO$_2$-emission factors (in g/km) from the TREMOVE 2.42 baseline with the annual mileage, the total number of vehicles in the fleet, the average CO$_2$-emission reduction percentage and the average WTW/TTW correction factor (see section 2.4). Similar estimates have also been made for the situation in which eco-driving is applied to the fleet that results under scenarios from chapter 3 in which a 2012 target between 135 and 120 g/km is reached for the sales average TA CO$_2$-emissions of new passenger cars. Results based on the TREMOVE 2.42 baseline are presented in Table 9.7 and Figure 9.4.

The 4 scenarios compared in Table 9.7 and Figure 9.4 are:
1. eco-driving included in lessons for new drivers
2. GSI on new vehicles
3. existing drivers applying eco-driving after lesions, without GSI
4. existing drivers applying eco-driving after lesions, with GSI

For scenario 1, eco-driving included in lessons for new drivers, the following assumptions are made:
- The annual number of new driving licenses is about 2.5% of total population with driving license;
- The annual increase of the share of the fleet for which eco-driving is applied increase with the same percentage as the share of new driving licenses on the total population with driving license;

- 100% of new drivers will adopt eco-driving and will maintain a fuel-efficient driving style for 40 years on average.

For scenario 2, GSI on new vehicles, the following assumptions are made:

- The annual new vehicle sales amounts about 8% of the total fleet;
- Starting 2009 all new vehicles are equipped with GSI;
- 50% of new vehicle owners will use the GSI with which their vehicle is equipped.
    - This results in a 4% increase p.a. of the share of the fleet for which GSI is used.

For scenario 3, existing drivers applying eco-driving after lesions (without GSI), the following assumptions are made:

- Starting 2009 all new car buyers will be offered or will receive eco-driving training (e.g. offered by vehicle manufacturers);
    - 50% of these new cars buyers will follow the coarse and will initially adopt eco-driving;
    - This results in a 4% increase p.a. of the share of the fleet for which eco-driving is applied. The overall share is assumed to level off at 30% in 2019;
- In addition it is assumed that 1.5% of the existing drivers voluntarily follows eco-driving training and that 100% of these will initially adopt eco-driving;
    - This results in a 1.5% increase p.a. of share of fleet for which eco-driving is applied. The overall share of drivers voluntarily adopting eco-driving in this way is assumed to level off at 20% in 2018
- For all drivers that initially adopt eco-driving after following a course only 35% is assumed to maintain an energy-efficient driving style for more than one year (consistent with assumptions made in 9.7.1), resulting in a net reduction of CO_2-emissions by 3%.

For scenario 4, existing drivers applying eco-driving after lesions (with the help of GSI), the same assumptions are made as for scenario 3, but with the additional assumption that GSI is used by all drivers adopting the eco-driving style.

The impacts of scenarios 1 and 2 can be added to effect of scenarios 3 or 4. Scenarios 1 to 4 should be considered as rather optimistic scenarios with respect to the effectiveness of policies promoting the application of fuel-efficient driving. The results presented in Table 9.7 and Figure 9.4 therefore are upper limits for the overall GHG emission reduction that can be obtained by eco-driving for different implementation pathways. The overall reduction results for the situation in which eco-driving is applied to the fleet that results under a scenario from chapter 3 in which a 2012 target between 135 and 120 g/km is reached for the sales average TA CO_2-emissions of new passenger cars differ less than 10% from the results based on the TREMOVE baseline.

Table 9.7 Annual well-to-wheel GHG-emission reduction (in Mtonnes CO_2-eq. p.a.) for EU-15 resulting from eco-driving applied to passenger cars based on 4 different scenarios for implementing eco-driving.

	WTW GHG emission reduction [Mtonnes/y]	
	2012	**2020**
new drivers	1.8	5.5
GSI on new vehicles	1.5	4.4
existing drivers w/o GSI	4.0	9.1
existing drivers with GSI	6.0	13.7

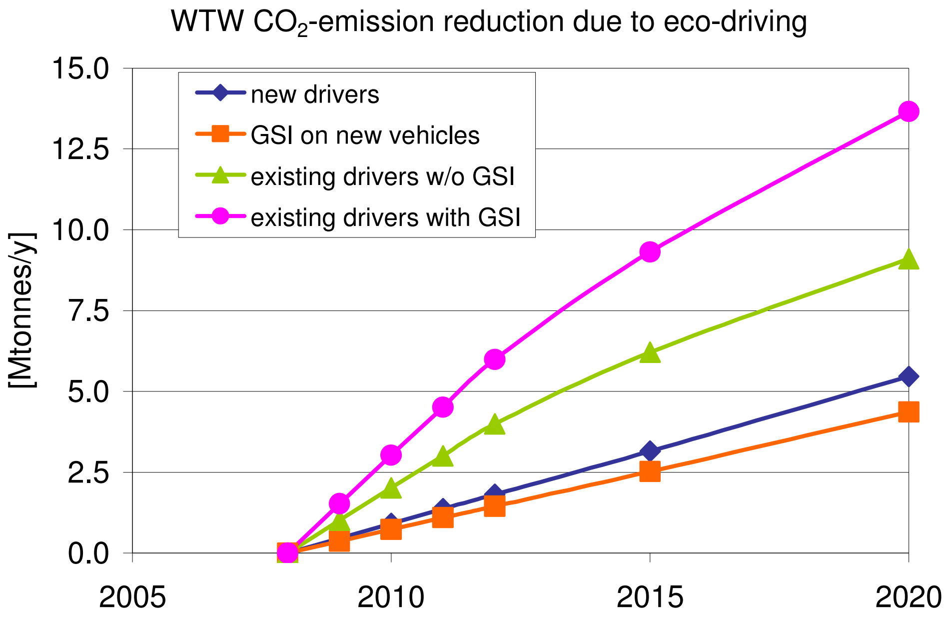

Figure 9.4 Annual Well-to-Wheel GHG-emission reduction (in Mtonnes CO$_2$-eq. p.a.) for EU-15 resulting from eco-driving applied to passenger cars based on 4 different scenarios for implementing eco-driving.

9.11 Policy options to promote fuel efficient driving

The following are some of the scenarios which can be envisaged under which new and existing drivers are encouraged to apply some form of eco-driving:

- application of GSI in new vehicles, either standard or as an optional accessory;
- incorporation of eco-driving in the training of new drivers;
- government campaigns to explain eco-driving and to promote the application, resulting in either:
  - existing drivers applying eco-driving based on instructions communicated in the campaign, or;
  - existing drivers being encouraged to voluntarily follow eco-driving lessons
- government subsidy on eco-driving lessons for existing drivers;
- car manufacturers offering eco-driving lessons (for free or for a reduced price) to buyers of new vehicles;
- companies offering eco-driving lessons (for free or for a reduced price) to employees driving a (leased) company car.

The application of GSI in new vehicles can be promoted by means of legislation or a voluntary agreement between EC and car manufacturers. A subsidy on the additional costs of GSI hardly seems appropriate given the robust CO$_2$-abatement costs of this technology (provided that drivers follow the instructions of the GSI to a sufficient extent).

Incorporation of eco-driving in the training of new drivers is already applied in several countries and is absolutely cost effective.

To make existing drivers change their driving behaviour government campaigns appear an essential ingredient for increasing awareness. The number of drivers that will apply eco-driving correctly in response to driving style tips communicated in public campaigns is expected to be limited. Better effects are expected if government campaigns encourage existing drivers to follow eco-driving lessons. A subsidy on the cost of these lessons could be helpful and gives the opportunity to market more intensive training programmes yielding a higher long term effect on fuel consumption and a higher share of drivers correctly applying eco-driving after training.

Manufacturers offering eco-driving lessons to buyers of new cars are an effective means for reaching a large number of existing drivers in a short period of time. This option could be part of a wider agreement between EC and car manufacturers to reduce CO_2-emissions from passenger cars. Quantifying the effect of eco-driving, however, is difficult so that exchanging a certain level of CO_2-reduction to be reached through technical measures for (efforts to promote) eco-driving may not yield robust results.

The option of companies offering eco-driving lessons to employees driving a (leased) company car reaches a smaller share of the driver population, but does reach a share that drives more kilometres per year than the average driver. Effects may be monitored by means of the fuel card that is used in combination with many leased vehicles. The measure is cost-effective to companies providing company cars to their employees and therefore does not require any form of financial stimulation.

Monitoring

As mentioned above a problem with eco-driving is the lack of monitorability. Important uncertainties in the assessment of the effectiveness of any policy on eco-driving are:

- the number of people that effectively change their driving behaviour after having received instructions or lessons;
- the duration with which affected drivers maintain an energy efficient driving style;
- the accuracy with which eco-driving is applied.

The effectiveness of campaigns with regard to behaviour of drivers can to some extent be monitored by means of surveys and questionnaires (see e.g. the monitoring for the Dutch eco-driving programme [Goudappel 2005]). The net effect on fuel consumption or CO_2-emissions, however, can not be measured or quantified with sufficient accuracy.

9.12 Output supplied to TREMOVE and Task B

9.12.1 Costs and effects

The net costs and average effect of eco-driving depends on the number of people that adopt ecodriving under various conditions (as result of lessons for driver's license, voluntary training, the use of GSI, etc.). Output data for TREMOVE can thus only be generated under certain scenario assumptions regarding the shares of drivers that apply various levels of eco-driving. These shares depend on the effectiveness of policies promoting eco-driving and can not be predicted. Some guidelines could be given to construct scenarios of the penetration of eco-driving using the following guiding inputs:

- The number of new drivers licenses obtained per year in the EU-25 gives provides the maximum potential for eco-driving encouraged by incorporating eco-driving in lessons for new drivers;
- If eco-driving lessons are offered by manufacturers to buyers of new cars, then the share of new cars in the fleet gives an upper limit of the number of drivers that can be reached annually through this measure;
- If eco-driving lessons are offered by companies to employers driving company cars, then the total share of company cars in the fleet gives an upper limit to the total number of that can be reached through this measure.

The effectiveness and reach of government campaigns is impossible to predict.

9.12.2 Scenarios on level of application

In order to be able to construct scenarios for the market share and resulting net costs and effects of eco-driving, a spreadsheet has developed in which assumptions on the share of drivers that is reached through various measures can be quantified and translated into input to TREMOVE. The format for this spreadsheet is given in Annex K. The data included in the table are example data constructed under the following scenario assumptions:

- the number of new drivers receiving drivers licenses is 2.5% of the driver population. It is assumed that starting 2008 all will be taught eco-driving and that the majority of new drivers will adopt this driving style;
- the number of new cars sold per year is about 8% of the total fleet. It is assumed that from 2008 onwards all new cars are equipped with GSI. Car buyers will be offered eco-driving training by the dealers. 50% of these buyers will follow the training and adopt the driving style assisted by the GSI in the vehicle. Of the remaining half again 50% will use the GSI in their vehicle;
- In response to government campaigns 1.5% of the existing drivers will voluntarily follow eco-driving training and adopt the driving style.

Definitive scenarios will be constructed by TML and DG-ENTR / DG-ENV at a later stage. TREMOVE will be used to calculate estimates of the total reduction potential (in Mtonnes/y) cost effectiveness of eco-driving taking account of the impacts of changes in costs on consumers purchasing behaviour, transport volumes and modal split.

9.13 Conclusions

- Assessment of the CO_2-abatement costs of eco-driving is extremely sensitive to the methodology that is used and to variations in the values of the input parameters The initial effect of eco-driving is reasonably well measured and documented. The long term effect on the other hand is less well known, but is expected to be significantly smaller. As both the level of effect and the duration strongly affect the outcome of the CO_2-abatement cost calculation the assessment presented here has significant uncertainty margins;

- The effective use of a gear shift indicators (GSI) in itself only captures part of the total reduction potential of eco-driving. On the other hand GSI can be an effective tool to assist drivers in maintaining a correct and effective fuel efficient driving style. In this way the use of GSI in combination with eco-driving is expected to increase the long-term effectiveness of eco-driving;

- In this study it is assumed that the long term effect of applying eco-driving is a fuel consumption reduction of 3%. With the aid of GSI this can be improved to 4.5%. The effect of only using GSI is 1.5%. The duration of the effect of eco-driving is assumed to be 40 years for new drivers to whom eco-driving has been taught during the regular driver training for their drivers licence. For existing drivers, e.g. following a dedicate course on eco-driving, an average duration of the effect of 25 years is assumed. The costs of lessons are set at €100 (no costs for new drivers). The additional manufacturer costs of GSI are €15 (€22 additional retail price);

- Under the assumptions made in this analysis with regard to costs of lessons, GSI and government campaigns the application of eco-driving is a very cost effective means of reducing CO_2-emissions of passenger cars for oil prices ranging from 25 €/bbl upwards;

- Incorporation of eco-driving in an EU-policy aimed at reducing CO_2-emissions from passenger cars is hindered by the limited monitorability of the effects of eco-driving;

- Large amounts of drivers can be influenced to apply eco-driving by means of:
  - incorporating eco-driving in the lessons for new drivers;
  - car manufacturers offering eco-driving lessons (for free or for a reduced price) to buyers of new vehicles;

  - companies offering eco-driving lessons (for free or for a reduced price) to employees driving a (leased) company.

  Other existing drivers can be targeted through government campaigns.

- The total GHG reduction potential of fuel-efficient driving depends strongly on the way the measure is implemented or promoted and on the assumed effectiveness of such promotion measures. Indicative calculations for EU-15 show the following results:
- If eco-driving is included in the lessons for new drivers, then a total reduction of 1.8 Mtonne/y could be achieved in 2012, increasing to 5.5 Mtonne/y in 2020;
- The total effect of mounting GSI systems on new vehicles is estimated at 1.5 Mtonne/y in 2012 and 4.4 Mtonne/y in 2020;
- For a combination of measures promoting the application of eco-driving by existing drivers the overall reduction potential is estimated at 4.0 Mtonne/y in 2012 growing to 9.1 Mtonne/y in 2020. If GSI is used to assist these drivers in maintaining a fuel-efficient driving style these values increase to 6.0 Mtonne/y in 2012 and 13.7 Mtonne/y in 2020.

  A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

9.14 Literature

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10 Review of CO_2 based taxation schemes for passenger cars

10.1 Goal of Task 1.3

The goal of this task was to identify and characterise the role that taxation can play in reducing CO_2 emissions from passenger cars. The focus of the work was the use of taxes to encourage the purchase and use of low emission vehicles, i.e. taxes on registration, annual circulation and fiscal incentives for the purchase of more fuel efficient vehicles, e.g. the early introduction of emission limit standards, as required by the terms of reference.

The task did not, therefore, explore the role of fuel taxes (including differentiating taxes by carbon content), road user charging or the taxation of the private benefit for cars supplied by employers in reducing CO_2 emissions. The omission of these instruments from the study does not suggest that the authors believe that they do not have the potential to impact on behaviour regarding fuel use – on the contrary we recognise that they do – just that they were not within the scope of the original terms of reference. Additionally, fuel taxes do not have the potential to fragment the market to the same extent as differential vehicle taxes.

10.2 Approach

- Review the literature on the use and level of vehicle taxes applied by Member States in order to characterise the taxes applied.
- Review any literature that has assessed the effectiveness of differentiated taxes for reducing CO_2 emissions.
- Collect recent information from Member States by means of a questionnaire.
- Outline possible developments in this area.
- Explore issues around ‘cost’ concepts, and develop estimates of costs and benefits. Draw on information in IA for possible scenarios.

10.3 Technical description

The main purpose of vehicle taxation is to influence the decision of the consumer when considering the purchase of a new vehicle and, more indirectly, to influence a manufacturer’s decision over vehicle engine specifications. While the measure does not directly impact on an individual vehicle’s CO_2 emissions, it attempts to incentivise an increase in the average fuel efficiency of the car fleet. By setting differing taxation bands for vehicles, manufacturers structure vehicle and engine characteristics to fit into the banding categories so that the consumer will be liable for the minimal tax band relative to the vehicle type. The influence over the consumer is to promote the purchase of a vehicle which minimises their tax burden.

The structure of vehicle taxation within Member States is based on Registration Taxes (RT), Circulation Taxes (CT), or a combination of the two; by no means all Member States have both RT and CT, while some Member States apply neither. RT is a one off charge at vehicle registration, usually at the vehicle’s initial purchase, while CT is a reoccurring charge throughout the vehicle lifecycle, generally an annual or bi-annual charge. These taxes are differentiated by a number of different factors such as retail price, engine capacity, power or vehicle weight measures and fuel type. Some Member States also offer either an incentive or a reduction in the charge dependant on meeting other factors such as safety or environmental standards.

In July 2005, the Commission published a proposal for a Directive on passenger car taxes (COM(2005)261)). The Impact Assessment accompanying this proposal noted that relatively few

Member States explicitly linked their vehicle taxation with environmental objectives and, at that time, only two (the UK and Cyprus) either based or adjusted taxation according to CO_2 emissions. The proposal sought to increase the harmonization of CT and RT across Member States by using three measures:

1. A phase out of RT over a five to ten year time frame.
2. A refund of RT and CT for consumers penalised by the movement of vehicles between Member States.
3. Restructuring the tax base of RT and CT to be totally or partially CO_2 based.

The main environmental rationale for the proposal is to introduce the 'polluter pays' principle in the area of passenger cars and to implement the third strand of the Community Strategy on Passenger Car CO_2 Emissions COM(95)689 on fiscal instruments.

As noted, above, the UK CT is linked to CO_2 emissions. The recent UK budget has amended the tax rates to increase the differential between the least and most polluting cars, as well as introducing an additional band for the most polluting vehicles (see Table 10.1, for the revised tax rates).

Table 10.1 UK circulation tax banding and tax rates introduced in the 2006 budget

Band	CO_2 emissions grams per kilometre (g/km)	Diesel car		Petrol car		Alternatively fuelled car	
A	Up to 100	£0	€ 0	£0	€ 0	£0	€ 0
B	101 to 120	£50	€ 74	£40	€ 59	£30	€ 44
C	121 to 150	£110	€ 162	£100	€ 147	£90	€ 132
D	151 to 165	£135	€ 198	£125	€ 184	£115	€ 169
E	166 to 185	£160	€ 235	£150	€ 221	£140	€ 206
F	186 to 225	£195	€ 287	£190	€ 279	£180	€ 265
G	226 and over	£215	€ 316	£210	€ 309	£200	€ 294

Note: Euro figures based on an exchange rate of 1.47.
Source: Adapted from [DVLA 2006]

From the survey of Member States undertaken for this project, it is now clear that many Member States have recently, or are considering, amending their vehicle taxation systems to take account of CO_2 emissions. Nine of the Member States that responded (Austria, Belgium, France, Germany, Ireland, Luxembourg, the Netherlands, Portugal and Sweden) are at various stages (from early scoping studies to firm proposals close to introduction) of considering adjusting either their RT or CT to take account of CO_2 emissions (see Annex L). In addition, Malta is considering the alteration of its current CT and RT, which are based on bands linked to engine size, to reflect CO_2 emissions. In general, reform of RT involves the provision of a reduction for more efficient vehicles, whilst the CT reform relates to the introduction of a graduated banding system.

10.4 Assessment of effectiveness for CO_2 emission reduction

A number of studies report that non technical influences such as the use of taxation can contribute to reductions in average CO_2 emissions of vehicles, such as DLR's review of the car manufacturers' voluntary agreement [DLR 2004]. [ADAC 2005] also reports that in Denmark, the introduction of a green motor tax based on fuel reach (kilometres per litre (km/l)) and the labelling Directive 1999/94/EC increased diesel fuel's share of the market from 4.7% in 1998 to 19.3% in 2002. Average fuel reach of the vehicle fleet also increased by 4.1 km/l for diesel and 0.6 km/l for petrol. Fiscal incentives also appear to have an influence, as a scheme adopted for a single year (2002) in the

Netherlands alongside vehicle labelling also produced significant results. The application of the incentive was for the two most energy efficient categories of vehicle (i.e. those labelled A and B) and amounted to a rebate of €1000 for A-labelled cars and €500 for B-labelled cars. Compared to 2001, the market share of the A-labelled cars increased from 0.3% to 3.2%, while that of B-labelled cars rose from 9.5% to 16.1%. The loss of the incentive resulted in a drop in market share for these vehicles in 2003 but their share still remained higher than the pre-incentive year. An evaluation study [VROM 2003] suggested that the existence of the subsidy had had significant benefits in terms of stimulating the market for lower emission vehicles. The ex ante expectation of the effectiveness of the subsidy was that the number of A-labelled cars sold to private buyers would increase by 100% and the B-labelled cars by 33%. No effect on the sale of company cars was expected. In the event the purchase of A-labelled vehicles grew by private purchasers by 967% in the course of its year of operation, and the purchase of B-labelled vehicles by 41%.

Direct assessment of tax restructuring for CO_2 emissions by the COWI report [COWI 2002a] found that it was possible to reduce average CO_2 emissions of new passenger cars by 5% on average across the EU-15. It is important to note, however, that this conclusion is valid within the boundary conditions of the study, which assumes that there will be no reduction in the average size of new vehicles purchased and that the proportion of diesel vehicles remains the same. The level of CO_2 reduction was not found to depend on the tax used, i.e. CT or RT, however, it necessitated a structure directly related to and differentiated by CO_2 emissions. It is worth noting, however, that the study also assumed revenue neutrality, i.e. that the changes to the taxation systems should not result in any net gain in revenue. This clearly imposes implicit limits on the rate of taxes that might be applied. If tax revenues were allowed to increase, then clearly tax levels could be higher, thus potentially further reducing CO_2 emissions.

The aim of the COWI study was an attempt to bridge the 20g gap between the car industry target of 140grams of CO_2 per km (gCO_2/km) to the Commission target of 120gCO_2/km through fiscal measures. While it is clear that reductions are achievable through the restructuring of the tax regime in Member States, the achievement of this goal was not possible within the boundary conditions where there was no reduction in the size of vehicles sold and no change to the proportion of diesel vehicles in the fleet. Fiscal neutrality was however achieved, which should enhance the political acceptability of the changes. Reference is made to the potential for synergistic effects of combining taxation policy with the other initiatives developing out of COM(95)689 such as the labelling Directive 1999/94, which could further enhance reductions achieved by prompting consumer choice towards more efficient vehicles. It can be argued that these boundary conditions do not represent a good reflection on the reality of the car market, as it is likely that the incentives created by changing the taxation system will have an impact on vehicle down sizing; less tax would be payable on a smaller vehicle, and a shift to diesel; greater fuel efficiency and lower CO_2 emissions would reduce the tax payable. Simply controlling these parameters in the market regardless of tax changes is also unlikely to reflect reality where consumers make purchasing decisions based on imperfect knowledge. The sensitivity analysis for the COWI study revealed that an increase in the proportion of the diesel fleet would result in a greater reduction in CO_2 emissions and similarly with a relaxation on vehicle downsizing. Sensitivity analysis carried out on the budget neutrality condition revealed relatively little change in the impact on CO_2 emissions for either tax when the definition of the neutrality was altered.

On a country specific level, the report found the greatest potential for fiscal measures in Denmark and the Netherlands where reductions of 8.5% and 7% respectively were possible. In Belgium, Germany and the UK reductions ranged from 4.5% to 5%; for Italy, Sweden and Finland this was between 4% and 4.5%, while Portugal only achieved a reduction of 3.3%. COWI suggests that countries with a relatively high RT such as Denmark offer a great potential for CO_2 emissions reductions through a switch to a CO_2 emission based tax. In the UK, they also suggest that simply enhancing the current differentiation by increasing the progression of the existing system for Vehicle Excise Duty could produce a reduction of 4.8%.

COWI clearly demonstrates the potential of fiscal measures to reduce the average CO_2 of new passenger cars, however in concluding, it cautions that this will not necessarily result in a decline in emissions from car passenger transport, necessitating the use of other complementary measures.

The COWI report, in common with the TREMOVE model, assumes that the car buyer has perfect information on which to base his/her purchasing decision, whereas arguably their understanding of future running costs of a vehicle is rather limited. The TIS report, on the other hand, assumed a certain degree of myopia on the part of the car purchaser. In reality, there is significant evidence to suggest new car purchasers apply a very high discount rate, i.e. show myopia, to possible future savings on fuel, for example. Certainly other factors such as size, performance, safety, luxury features, etc are clearly very important and may well override such considerations. Also, some years ago, work by Eriksson (1993) presented evidence that both new car purchasers and manufacturers only take account of fuel costs in the first three years of a vehicle's life, or effectively around 40% of the full fuel costs, in making purchasing decisions. He also reviewed a number of earlier studies, which supported this general conclusion, and evidence from the household sector shows a similar level of myopia in buying energy-efficient appliances. In some cases consumers will only consider investing in appliances or other energy-saving measures with payback periods of a year or two - which is a very high discount rate indeed in economic terms. This may in fact be quite rational behaviour for car buyers, as new cars are typically only retained by their initial purchasers for a few years, and the second hand price may not reflect future fuel cost savings at all closely. Obviously, however, this raises questions as to how effectively fuel or vehicle price signals can influence new car purchasing patterns, particularly when they have only an indirect effect on the initial car purchase decision.

A recent country level study into the CO_2 graduated CT system by the UK government [Lehman 2003] revealed that the introduction of the system made very little difference on the respondents' vehicle choice, as other factors such as fuel efficiency, comfort and safety were considered more important. While CO_2 emissions are linked to fuel efficiency, the study reported that respondents did not make this link when choosing their new vehicle. The evidence suggested that a greater impact would be achieved if the price differential between the bands was significantly increased, although there remained a hard core of 28% who felt that even with a differential of £300 (€444) that the CT would not influence their vehicle choice.

An example of the potential that can be achieved by differentiating vehicle taxes according to CO_2 emissions can be found in the example of the reform of the UK company car tax system. The Inland Revenue, the government department responsible for the tax, found that around 40 per cent of drivers thought that they might choose a future car with a lower CO_2 emission than their current model, as a result of the tax reform [IR 2004]. A positive impact was also found concerning fleet managers' attitudes towards vehicle emissions. Over half of the employers surveyed were actively encouraging a switch to lower emissions cars; while 59 per cent had changed their policies towards emissions and 36 per cent had changed their policy towards car list prices (IR, 2004). Coupled with the findings of an earlier study [Lex 2001], this suggests that company car tax reform has had an impact on the environmental policy of fleets in the intervening period. Average CO_2 emissions from new company cars have also fallen in the UK from around 199gCO_2/km in 1999 to 182gCO_2/km in 2002. This reduction has been estimated to have saved between 0.15 and 0.2 million tonnes of carbon in 2003 [IR 2004). Further analysis by the authors of this report also indicated that company cars in the UK are now more CO_2-efficient on average than those bought by private buyers, which is a radical reversal of past trends [Fergusson and Skinner 2004].

In a further study, the COWI model has also been used to test the implications of restructuring CT and RT into CO_2 graduated taxes in Sweden [COWI, 2002b]. In the latter case, the RT was imposed as a completely new tax with both a fixed element based on the car price and a CO_2 graduation imposing either an increase or decrease (non negative) on the fixed element around a reference level. The CT simply imposed an additional graduated CO_2 element to the existing weight based tax as either an increase or decrease (non negative) around a reference level. CO_2 savings from the car fleet were projected to be around 5% annually for RT and 2% annually for CT over a twenty year time horizon[38]. In the shorter term (five years) however, savings were limited to just over 1% and 0.5% respectively.

10.5 Assessment of efficiency

As part of the study, COWI (2002b) specifically examined the implications of the changes to the tax structure on wider socio-economic factors. The study does not purport to be a comprehensive quantification of these impacts, but it does attempt to develop an 'order of magnitude' assessment of the two tax systems in a cost benefit analysis. Over the twenty-year time horizon, the cumulated net benefits (defined as the sum of the annual net benefit over 20 years) of the RT are negative (-1,096 million Swedish Krona (SEK) (€-118 million)), whilst for CT they are positive (1,767 million SEK (€190 million))[39]. The main explanatory factors for this are the reduction in the car market size and vehicle downsizing, quantified as a welfare loss. The change to CT does not impact on the market size, while the imposition of the totally new RT has a much greater effect on both features of the market. Interpretation of these results should be made with caution as the simplifications and assumptions underlying the calculations clearly have a significant bearing on the result and would be disputed by some. Additional analysis was also carried out solely on the CO_2 differentiated part of the tax, with the result that both taxes produce a net benefit to society.

10.6 Assessment of consistency - Overview of impacts and trade offs

As the main purpose of vehicle taxation based on CO_2 emissions is to influence consumer choice towards a more efficient vehicle, it does not have a direct effect on the actual environmental performance of the vehicle itself. In the longer term, indirect effects on consumer and manufacturer behaviour have been shown to impact on CO_2 emissions. For example, TIS (2002) derived elasticity values for RT and CT of -0.144 and -0.121 respectively in relation to car ownership, indicating the modest negative effect of taxation on the decision to own a car, with RT having the greater influence of the two taxes. They also indicated that manufacturers are influenced by tax regimes in different Member States with respect of the design of vehicle engines to fit within the various tax bands.

In terms of wider economic and social implications of taxation, the findings of COWI suggest that CO_2 emissions benefits can be gained within the constraints of fiscal neutrality; overall tax burden therefore, need not increase. Structural adjustments to the car market towards more efficient vehicles, are however likely to occur over time. The result will be a trade off between savings to the consumer in terms of fuel consumption and losses to Government revenue from reduced fuel tax income, providing that greater fuel efficiency does not encourage greater levels of trip making. COWI (2002b) examined in greater detail the change in welfare brought about taxation restructuring in Sweden. The focus was on the difference between rural and urban families and the change in employment for the car manufacturing and related industries. The two key impacts assessed were vehicle downsizing and a reduction in the fleet size; both were considered as a welfare loss. It was found that rural families were likely to suffer a greater welfare loss because of their tendency to prefer larger and less fuel

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[38] CT was applied only to new cars

[39] The value placed on the CO2 reductions were 1.50 SEK (€0.16) per unit.

efficient cars. The same implications were found for families with children as opposed to those without. Welfare loss is defined in terms of car purchasers being forced to buy other cars than those they would have preferred in the absence of tax. As there are a number of influences on these wider social and economic implications, it is the aggregate impact that becomes important. This will be more fully dealt with in Task 1.1.

10.7 (Enhanced) Policy measures

Two studies commissioned to review the options for vehicle taxation in the EU ([TIS 2002] and [COWI 2002]), numerically modelled how the structure of taxation currently affects the car market and the likely environmental effects of restructuring. Largely based on this analysis, one Commission communication and one Commission proposal for a directive have been produced outlining the proposals for harmonizing the tax system (COM(2002)431 and COM(2005)264). COM(2005)264 is a Proposal for a Directive on passenger car taxes and is an attempt to advance the process of harmonization through legislation justified under the subsidiarity principle. Three key measures have been proposed; the gradual phase out of RT over a five to ten year time frame, establishing a refund system for RT and CT for consumers who have been penalised by movement of vehicles between countries and restructuring the tax base to partially or wholly reflect CO_2 emissions. It suggests that by the 1st December 2008 at least 25% of total tax revenue from RT and CT is related to the CO_2 element of the tax and by 31st December 2012 this is at least 50%.

The TIS study, which did not explicitly deal with tax restructuring to reflect CO_2 emissions, identified other possible environmental implications under a fiscally neutral scenario of RT removal:

- increasing car demand and associated fuel consumption;
- which could be partially offset by switching some of the taxation to fuel tax, encouraging the purchase of more fuel efficient vehicles; and
- a reduction in average car age and the associated purchase of new more fuel efficient vehicles.

TIS (2002) indicated that it would be difficult to assess the net environmental effect of tax harmonization; however there would be an expected environmental deterioration in countries with high RT such as Denmark and Finland.

As indicated in Section 10.3, responses to the questionnaire survey indicated that several Member States are actively considering adjusting their vehicle taxation systems. Three of these countries are worth highlighting as their proposals develop taxation policy a stage further. The Netherlands is proposing to link the RT tax bands to the vehicle labelling system (see Task 1.4), so that vehicles which fall into the most energy efficient classes A and B receive a tax reduction of €1000 and €500 respectively, whilst those in the least efficient bands D to G face an increase in tax of €500. Directorate-General for Environmental Protection, the Netherlands (2001) also carried out a modelling exercise on the impact of three different tax related scenarios which has been used to inform the proposed RT changes, these are detailed in Table 10.2 below

Table 10.2 Directorate-General for Environmental Protection, the Netherlands tax scenarios for the Netherlands

<table>
<tr><th>Measure</th><th>Proposal</th></tr>
<tr><td>Integrating a CO$_2$ differentiation element in the registration tax</td><td>Tax change = differentiation rate * (CO$_2$ emission – reference CO$_2$ emission)</td></tr>
<tr><td>Changing circulation tax from vehicle weight to fuel consumption</td><td>Change the direct relationship with CT from that of vehicle weight in kilograms to fuel consumption in litres per 100 kilometres</td></tr>
<tr><td>Introducing EEV purchase subsidies for passenger cars with a green fuel economy label</td><td>Three scenarios:
<table>
<tr><th></th><th>Low level</th><th>High level</th><th>Currently considered</th></tr>
<tr><td>A label</td><td>700</td><td>1000</td><td>1000</td></tr>
<tr><td>B label</td><td>400</td><td>700</td><td>500</td></tr>
<tr><td>C label</td><td>225</td><td>400</td><td>0</td></tr>
</table>
</td></tr>
</table>

Source: [COWI 2001]

A recently adopted system in France seeks to differentiate the RT paid by business cars solely by CO$_2$ emissions and is again linked to the label. As such seven categories of charges graduated by the label category are defined (Table 10.3 below).

Table 10.3 The charging categories for the French RT on business cars

Label Category	Charge per gram of CO$_2$ per kilometre
A vehicles	€2
B vehicles	€4
C vehicles	€5
D vehicles	€10
E vehicles	€15
F vehicles	€17
G vehicles	€19

In Sweden, a three phase CT has been proposed that is composed of:

- a fiscal component (€40 per vehicle);
- plus an incremental CO$_2$ component based on €1.3 per gram above the 100gCO$_2$/km threshold;
- plus for diesel vehicles, an environment and fuel factor that takes into account the higher NOx and particulate emissions of diesel vehicles. This is derived by multiplying the sum of the fiscal and CO$_2$ components by 3.5.

By not adopting a banded system, the incremental rise in costs will really reflect the vehicles CO$_2$ emissions.

10.8 Possible taxation scenarios and implications for TREMOVE and Task B

Reviewing the above information, there were theoretically a number of possible taxation scenarios that could be modelled, e.g. by applying particular national taxation schemes, or variations thereof, to the entire EU market. Four potential scenario options are summarised as follows:

1. Registration Tax based on the proposal from the Netherlands (detailed above), linking the RT to the labelling system to provide a greater incentive for the purchase of category A and B vehicles. The use of scenarios suggested by the Directorate-General for Environmental Protection, the

Netherlands (2001) study could be the basis for this work. Although it should be noted that COM(2005)264 does not favour the use of RT.

2. Registration tax based on the French system for cars purchased by companies in which the tax is based on a car's CO_2 emissions, multiplied by an increasing factor dependent on a car's band, as indicated by the label.
3. Circulation tax based on the current UK system (detailed in 10.3 above), providing some differentiation through banding CO_2 emissions. A different approach might be to enhance the UK approach by having a greater price differential between bands, as suggested by COWI (2002).
4. Circulation tax based on the Swedish proposal (detailed above), providing incremental differentiation for each gram of CO_2 emitted above the 100g/km threshold.

Alternatively, a scenario could model changes to both the circulation and registration taxes, based on one, or a combination of the options above.

The modelling of such taxation scenarios with the TREMOVE model could be undertaken, providing a previous simulation of the effects of the scenarios for each TREMOVE category is undertaken: TREMOVE can model registration and circulation taxes, but the options for doing this are limited and effectively rule out, at least for the purposes of modelling, some of the options set out above. TREMOVE does not have CO_2 for each car; rather each of its 16 categories of car has a CO_2 figure associated with it, which could be used as the basis of a tax that approximates CO_2 emissions. However, the model only contains three sizes of car (small, medium and large) [40], which could be used as bands, although countries that have introduced differentiated taxation on the basis of bands generally have seven bands. Additionally, the size category into which a car is classified in TREMOVE is based on engine capacity (measured in cc's) not on CO_2 emissions, which although they are correlated adds a further complication to using the TREMOVE categories to model differentiated CO_2 taxes. Further, currently TREMOVE does not distinguish between cars that are bought privately or through companies (i.e. company cars), hence restricting the possibility of model taxes on the latter and not the former. Finally, it is not possible to model the effect of differentiating registration and/or circulation taxes exogenously, and feed the outputs of this, i.e. revised numbers of cars per category, and revised associated CO_2 emissions for each category, as the former are endogenous in the model.

Hence, the added value of modelling the scenarios above with TREMOVE is limited for the following reasons:

1. All of the systems are based on a tax that relates directly to a car's CO_2 emissions, while TREMOVE can only model average CO_2 emissions associated with a car's size as indicated by its engine capacity and technology.
2. For three of the systems, a car is categorised as belonging to one of seven bands that correspond to a given range of CO_2 emissions. The tax payable increases as the emissions increase. The bands used in these systems are narrower than those that can be modelled in TREMOVE.
3. The French system focuses only on company cars – a distinction that cannot be made within TREMOVE.

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[40] Within each size band, cars are also sub-divided on the basis of technology, i.e. 'small cars' are further sub-divided into small cars with conventional petrol engines, small hybrid petrol cars, small cars with conventional diesel engines, and hybrid diesel engines and small CNG-powered cars. These five categories exist for each size of car, making a total of 15; the 16th band is for medium/large retrofitted LPG cars. However, such a categorisation is not helpful with respect to further differentiation by CO_2 emissions.

For (1) and (2), TREMOVE requires a previous assessment of the impact of the taxation scenario, using a detailed vehicle database, and applying hypothesis on the price elasticity consistent with TREMOVE. The resulting effect in average car price and CO2 emissions by vehicle category would then be translated to TREMOVE.

10.9 Conclusions and Recommendations

As a policy instrument, taxation can be used to complement other measures in order to encourage the wider take up of more fuel efficient vehicles in the market through the use of a strong fiscal signal. Although this influence is not as direct as the measures that produce physical changes to the vehicle, the combination of both should create a situation that can ultimately drive the structure of the market. Taxation and fiscal incentives have the potential to strongly influence the motor vehicle market and new vehicle CO_2 emissions if they are structured and differentiated in the most appropriate way. Of the potential taxation measures that can impact on fuel use, only those measures aimed at directly encouraging the purchase and use of more fuel efficient vehicles were considered in this study; fuel taxes, road user charging and the taxation of the private benefit for cars supplied by employers were all excluded. According to [COWI, 2002a], restructuring tax systems so they are based on CO_2 emissions has the potential to produce, on average, a 5% reduction across the EU-15 in emissions from new vehicles. Within the boundary conditions of the study, which included no downsizing of vehicles, no changes in the proportion of diesel cars and revenue neutrality, taxation mechanisms alone however, would be unable to totally ‘bridge’ the 20g gap between the manufacturers target of 140gCO_2/km for 2008/09 and the EU target of 120gCO_2/km by 2012 without a change in the proportion of diesel vehicles in the fleet and some reduction in the size of vehicles sold. In addition, it is worth noting that the principle of revenue neutrality imposes implicit limits on the tax rates that could be applied; if this condition were relaxed then tax rates could be higher, which could result in further CO_2 reductions. There are some doubts, as to whether the findings of [TIS, 2002] regarding the ‘myopia’ of car buyers in relation to the life-time costs of vehicles, can be universally applied, but in cases where they are applicable, RT might have the potential to provide a stronger signal to the consumer than CT. As such the removal of RT, as suggested by the current proposed Directive on harmonising the taxation system across Member States, can be considered a missed opportunity for a very direct instrument for CO_2 differentiation. To reach a similar effect through CT will probably require a much stronger level of CO_2-differentiation, possibly combined with fuel tax measures, and should be combined with effective communication measures to educate consumers at the point of purchase on the effect of the vehicle's CO_2-emissions on annual operating costs.

The achievement of the proposed harmonisation in the tax system across Europe is likely to prove politically difficult and the retention of decisions over vehicle taxation structure is likely to remain with individual Member States. This should not adversely effect these potential reductions, as COWI based their assessment on individual countries, but it will necessitate individual concerted action by Member States, over which the European Commission is likely to have a limited influence without the agreement over the Directive proposed in COM(2005)264. The evidence from the Member State questionnaires indicates that a realignment of vehicle taxes to reflect CO_2 and other emissions is currently being considered in a number of countries. A package of measures, which includes the use of fiscal instruments, is likely to be the most effective way to influence vehicle CO_2 emissions.

As noted in Section 10.3 many Member States have, or are planning to, amend their vehicle taxation systems to reflect CO_2 emissions in some way. However, in most cases such developments are still at the proposal stage, or, if not, only recently introduced, so there has been little experience to enable an evaluation as to whether these policies have been effective. For example, of the possible taxation scenarios initially considered for modelling in TREMOVE (see Section 10.8), the French system was only voted on in Parliament in November 2005 and the Swedish proposal was even less well advanced. Of the four scenarios proposed in Section 10.8, however, there is evidence from the Netherlands and the UK of the potential benefits of differentiating vehicle taxes according to CO_2 emissions (see Section 10.4). In the UK, the company car tax reforms appear to have been effective to the extent that company cars in the UK are now more CO_2-efficient on average than those bought by private buyers, which is a radical reversal of previous trends. Conversely, the evaluation of the CT reforms in the UK, suggests that differentiating this tax by CO_2 emissions has had little impact on car buyer behaviour. The research suggested that this was due to the relatively low level of differentiation. The UK government appears to have taken this message on board, as it has recently increased the differentiation between the CT tax bands. The most striking example of the potential of differentiating taxes on the basis of their CO_2 emissions comes from the Netherlands, where a one-year incentive in favour of the purchase of the less CO_2 emitting vehicles (i.e. those of Band A and B) led to a doubling of the numbers of these vehicles purchased. When the incentive was withdrawn after one year, this proportion declined significantly. The Netherlands will introduce this system on a permanent basis in the course of 2006. These examples, coupled with the fact that many other Member states are planning to introduce similar differentiated taxes, suggests that there can be an environmental benefit in such differentiation and that increasingly Member State governments believe that this is the case.

10.10 Literature

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[COWI 2002a] *Fiscal measures to reduce CO_2 emissions from new passenger cars.*

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[VROM 2003] *Evaluatie studie Energiepremie.* Notitie van de staatssecretaris van VROM aan de Tweede Kamer, gedateerd 20 oktober 2003

[Member States 2005]
Responses to the questionnaire circulated for the purposes of this project.

11 Review of options for improved energy or CO_2 labelling

11.1 Goal of Task 1.4

The goal of this task is to identify and characterise the role that fuel efficiency and/or CO_2 labelling can play in reducing CO_2 emissions from passenger cars. It will draw heavily on the experience with the labelling Directive 1999/94. In addition, a consideration of the role of vehicle marketing is made in reference to the relationship between the content of current vehicle advertising and manufacturers' CO_2 emission commitments.

11.2 Approach

- Review the literature on role of fuel efficiency/CO_2 labelling in reducing CO_2 emissions from passenger cars, and in particular any literature that has assessed the effectiveness of such labelling for reducing CO_2 emissions.
- Review the literature on the content of vehicle marketing and the environment.
- Collect recent information from Member States by means of a questionnaire.
- Outline possible developments in this area (based on feedback from Commission and Member State experts), and review current state of play.
- Produce estimates of possible costs and scale of benefits from such measures.

11.3 Technical description

The objective of labelling cars with information on fuel efficiency and CO_2 emissions is to provide potential buyers with information on these in the hope that this will influence their purchasing decision. Hence, the measure does not directly impact on a car's CO_2 emissions, as measured in the course of the type approval's test cycle, rather it aims to increase the average fuel-efficiency of the car fleet and thus reduce transport's total CO_2 emissions. In addition, the measure is intended to stimulate the market for more fuel-efficient/lower emission cars through increasing awareness.

In the 1990s, a number of Member States developed fuel efficiency/CO_2 labels for cars. In 1999, Directive 1999/94/EC was adopted to require all EU Member States to display a fuel efficiency/CO_2 label on new cars, and set out certain requirements in order to ensure the consistency of the label and its contents. Directive 1999/94 requires that the label is attached to, or displayed near, the car in a clearly visible manner at the point of sale. It must include the official fuel consumption (in litres per 100 kilometres) and the official specific emissions of CO_2 (in grams per kilometre) for that particular mode, as measured in accordance with the harmonised methods and standards set out in Directive 80/1268 and its amendments. The label should also include a reference to the fact that a free fuel economy guide is available, state that CO_2 is the main gas responsible for global warming and inform the consumer that driving behaviour and other non-technical factors also influence fuel economy and CO_2 emissions. In addition, the Directive requires the production and provision of a fuel economy guide, showroom information posters and references to fuel consumption and CO_2 emissions to be made in the relevant promotional literature.

A review of EU-15 Member States' experience with implementing the Directive revealed that all 14 Member States of the EU-15 that responded (i.e. all except Luxembourg) had implemented the Directive, including the introduction of the label, and that six had gone beyond the requirements of the Directive. In these cases, the countries have introduced energy rating systems with colour-coded classes (usually seven) along the lines of the household appliance energy label. In other words, the new car fleet is sub-divided into colour-coded vehicle classes and the label indicates the fuel efficiency and CO_2 emissions class into which the particular vehicle falls. In the case of Spain and the

UK the energy rating label is voluntary, while in Belgium, Denmark, Portugal and the Netherlands it is mandatory [ADAC 2005].

Additionally, the Dutch and Spanish schemes are relative in that the lower and upper ranges of the categories are not fixed. Such measures are based on the CO$_2$ emissions of the vehicle *relative* to some function of the vehicle, e.g. size or weight, to provide the basis for classes, whereas an *absolute* measure provides an energy efficiency category defined by CO$_2$, fuel reach or fuel consumption across all categories of vehicle. In the Netherlands, the relative energy efficiency of a vehicle is defined as the percentage by which its CO$_2$ emissions vary from a reference CO$_2$ emission value, which is defined as:

0.25*(average CO$_2$ emission value of all new passenger cars) + 0.75* (average CO$_2$ emission value of all new passenger car of the same size),

*where vehicle size is given by a vehicle's pan area, i.e. its length * width.*

In Spain, the relative fuel efficiency index shows the relative fuel consumption of the car in question compared to the average fuel consumption of all passenger cars of the same size (again measured by pan area) and fuel type. The average fuel consumption is calculated statistically, as follows:

$$a \text{ x } \mathrm{e}^{(b \text{ x } S)}$$

where a, b are constants (and vary for petrol and diesel cars), e is Euler's constant (2.7183) and S is the pan area.

The relative classes in the Netherlands and Spain are given in Table 11.1 [ADAC 2005].

Table 11.1 Relative energy rating classes in the Netherlands and Spain

	Relative energy efficiency index (%)	
Class	Netherlands	Spain
A	index < -20%	index < -25%
B	-20%<= index < -10%	-25%<= index < -15%
C	-10%<= index < 0%	-15%<= index < -5%
D	0%<= index < 10%	-5%<= index < 5%
E	10%<= index < 20%	5%<= index < 15%
F	20%<= index < 30%	15%<= index < 25%
G	30%<= index	25%<= index

Source: [ADAC 2005]

ADAC (2005) summarises the main arguments for and against the use of both relative and absolute measures. It concludes that a system using an absolute measure best serves the requirements of the fuel efficiency label for the following reasons:

- An absolute measure provides the simplest method for use across the EU and is easy to understand by consumers.
- It does not require the potentially arbitrary identification of a function against which to measure CO$_2$ emissions, which, as for relative targets, is likely to be contentious.
- It provides greater direct encouragement to buy vehicles with lower CO$_2$ emissions, providing the incentive to down size across the fleet.
- It provides the most direct link with fiscal measures linked to CO$_2$ emissions and avoids giving mixed messages in doing so.

There are arguments for a relative measure, e.g.:

- It enables easy comparison between different cars in the same class, rather than across the fleet as a whole. This is useful, as most consumers will have already selected the type of vehicle they want to purchase before entering the showroom, making a comparison across the entire fleet less useful. A relative measure enables a consumer to identify better the most fuel-efficient 'large' vehicle, for example.
- It also creates potential incentives for manufacturers to scale up borderline cases to obtain a more fuel efficient label from the class above

However, the main argument against a relative measure is that it would be potentially confusing for consumers in regard to cases where a small car with low absolute fuel consumption is labelled in a worse category than a bigger car that has low fuel consumption in its class but higher consumption overall.

From the survey of Member States undertaken for this project (see Annex M), France also reported that it is planning to go beyond the requirements of the Directive by implementing a mandatory label, which will look like the household appliance energy label and contain seven absolute CO_2 emission classes.

11.4 Assessment of effectiveness for CO_2 emission reduction

ADAC reported [ADAC 2005] that five Member States had undertaken an assessment of the effectiveness of the label in terms of reducing CO_2 emissions. While the studies revealed that CO_2 emissions have declined since the label was introduced, it was not possible to separate out the effect of the label from the broader impact of the reductions in emissions resulting from the parallel voluntary agreement. Surveys of the effectiveness of the Directive's provisions in relation to informing and influencing customers have been undertaken in eight Member States. These revealed that fuel economy and environmental impact are not generally an important factor taken into account by potential purchasers of new cars, but that awareness of climate change and CO_2 emissions is growing slowly. After having reviewed other information and reports, ADAC concludes that it is impossible to separate any shift in consumer behaviour resulting from increased awareness from the technical improvements in vehicles and associated fiscal instruments. (A good example of the potentially positive role that might be played by fiscal incentives relates to the introduction for one year only of such an incentive in the Netherlands; see Task 1.3., Chapter 10) It then agrees with the [DLR 2004] study that technical developments are the main source of the CO_2 reductions from new passenger cars that have been seen between 1995 and 2003.

ADAC acknowledges that the information on the label will never be the only information on which consumers base their purchase decision. However, it notes that the label has a role in raising awareness, but that, at the moment, its impact is not significant, as dealers show little interest in the information that it contains due to the fact that few customers ask about it. For their part, customers are not aware of the information, so do not ask for it.

As indicated above, a number of factors have a role to play in the consumer purchasing decision. Among these is the role that manufacturers' marketing campaigns have in promoting specific attributes of car ownership. A recent study by Bund[41] in Germany indicates that, while manufacturers

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[41] Friends of the Earth Germany

have made commitments to reduce passenger car CO_2 emissions, there is no recognition of this in the cars that they advertise the most [Bund, 2006]. On the contrary, it was found that manufacturers are focusing their advertising efforts on their least fuel-efficient cars, i.e. those with higher CO_2 emissions. The findings were based on an analysis of car advertisements in two daily newspapers over a ten year period in order to investigate the trend in car marketing. Interestingly, the research also suggests that issues such as fuel economy and protection of the environment were more prevalent in the advertisements of 1995 than they are today.

The role of vehicle advertising and the images and lifestyle that they sell is also a consideration in the United States. This is particularly the case for the Sports Utility Vehicle (SUV) which is often marketed on its ability to provide control, security and mastery over the environment whilst very few ever actually leave their owners' largely urban surroundings [Anderson, 1998]. It appears that these vehicles are often the focus of manufacturers advertising efforts, largely due to the higher profit margins afforded by such vehicles. A study of car adverts in national newspapers by Friends of the Earth UK, for example, found that over half (57.6%) of adverts were for cars in the two most polluting categories (>166g CO_2km), and over a third (35.8%) were for the highest band (>185gCO_2km) [FOE, 2005]. Effectively, the information provided as part of Directive 1999/94/EC appears to be currently functioning in the shadow of, and at odds with, the large marketing budgets of the car manufacturers. In 2002, for example, automotive advertising accounted for 13% of the total UK advertising expenditure, while the figures for Germany and the EU as a whole were 12% and 5.6% respectively [EACA, 2004].

11.5 Assessment of efficiency

ADAC identified that the costs relating to the introduction of the label (and posters) are generally borne by manufacturers/importers and/or dealerships, whereas the cost of the guide is usually covered by industry or public authorities. Most Member State reports did not indicate what the costs of the label were; instead they tended to focus on the cost of the guide, which was often the responsibility of the lead ministry. Two reports did, however, include an assessment of the costs associated with the label that were made prior to its introduction:

- €400,000 of material costs associated with the label and the poster, plus €2 million of personnel costs (NL).
- €36,000 per manufacturer (UK).

Any costs incurred by the manufacturers, importers and dealerships are likely to be passed on to the consumer.

11.6 Assessment of consistency - Overview of impacts and trade offs

As mentioned above, the objective of labelling is to influence a customer to purchase a car that emits less CO_2 than another car. Hence, it does not directly impact on the actual environmental performance of the car. There may be longer, indirect impacts on car purchasing behaviour as a result of an increased awareness about the impact of car use on CO_2 emissions and climate change, as well as potential synergies to be gained by linking the label categories to, for example, vehicle taxation. Similarly, the use of a label does not have that many broader economic and social implications beyond the cost of the label. The exception to this could be the fuel, and therefore cost, savings to a particular customer of utilising a more fuel-efficient car. However, it is the aggregate impact that matters for the sake of this analysis and this will also be picked up in Task 1.1.

11.7 (Enhanced) Policy measures

In its review of the effectiveness of Directive 1999/94, ADAC recommended that the label should be further harmonised within the EU, with the introduction of colour-coded energy efficiency classes based on a system of absolute comparison (i.e. not correcting for the size of the car in any way). Additionally, it argues that these should be relatively uncontroversial, as similar labels are in place for household electronic and electrical goods. However, the report acknowledges that the definition of the energy efficiency classes would be controversial, as Member States currently base these on different criteria, e.g. such as directly linked to annual car taxation. This would imply a harmonisation of the criteria on which the classes were based, which would be politically difficult if it were linked to a fiscal measure.

According to its questionnaire response for this project, the Netherlands is to use the fuel efficiency/CO$_2$ emissions rating class of the car, as indicated on the label required by Directive 1999/94, as the basis for differentiating its registration taxes (BPM). New passenger cars with either an A- or a B-rating will receive a tax reduction – of €1,000 and €500, respectively – while the tax for new passenger cars rated D to G will increase by up to €500. This is similar to a system introduced in 2002 whereby there was a tax rebate for A- and B-rated cars of the same amount, which led to a significant increase in the purchase of such vehicles ([VROM 2003], reported in [ADAC 2005]).

In the United States (US), vehicle fuel economy labels have been displayed on new vehicles since the 1970s and, as such, consumer awareness of them is high. Changes to the current label are proposed, alongside amendments to the test cycles over which the fuel economy is measured (US EPA, 2006). The proposals are to improve the incorporation of real life cycle emissions through additional tests reflecting aggressive driving, the effect of air conditioning and cold start conditions. These would then be reflected in the values reported on the label. Currently the US system already requires fuel economy values in miles per gallon to be reported for city and highway driving conditions, both in terms of a single figure and range. It also provides an indication of annual fuel costs and a relative comparison of fuel economy ranges for the average vehicle in the class. The proposed new system would not only incorporate the changes in fuel economy for the test cycle but also improve the appearance of the label to highlight the fuel cost and comparative information and clarify the variability of mileage in real world conditions. The new label would also make reference to the Fuel Economy Guide (available at dealerships and online) and the government website on fuel economy[42]. The website provides a range of information for consumers allowing detailed comparison of individual vehicles along with pages on fuel saving strategies, alternatively-fuelled vehicles and a fuel cost calculator (it is also proposed to incorporate the new test cycle parameters into this feature to demonstrate the impact that these elements have on overall fuel use).

The work undertaken in other tasks of this project, particularly Task 1.5 on fuel-efficient driving (see Chapter 9) and Task 1.7 on inter alia lubricants (Chapter 5), suggest a number of further possibilities for sharing information on measures to improve the fuel-efficiency of passenger cars, e.g. the database on lubricants (see Section 5.4.5.1). Following the example of the US, all such information could be stored on a website, whose address could be added to the label and all other literature covered by Directive 1999/94. The website could cover, for example:

- The CO$_2$ emissions category of different vehicles, as classified by the respective Member State systems, or by a harmonised label, if one is introduced.
- Information on fuel efficient driving, including information on eco-driving techniques and contacts for eco-driving courses in each Member State.

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[42] www.fueleconomy.gov

- Information on other ways of saving fuel, e.g.:
    - The importance of maintaining tyres at the correct pressure;
    - The most fuel-efficient lubricant for each car;
    - The most fuel-efficient tyre for each car; and
    - The wider benefits of improved maintenance.

The website could act as the central focus for the public dissemination of the Community's passenger car CO_2 strategy as a 'Consumer Guide to Cleaner Vehicles' and could provide links to other relevant sites from industry and Member States to maximise the site's potential. Clearly the website would have to be accessible in each Member State language and tailored to reflect national and, possibly, even regional or local considerations. Hence, thought would have to be given as to whether the site should be developed and maintained centrally or by individual Member States using similar data and to similar specifications.

In terms of the ability to adapt the current marketing strategies of car manufacturers, a working paper presented to the working party on the integrated approach as part of the Cars21 process suggested the adoption by the manufacturers associations of a 'code of good practice regarding car marketing and advertising aimed at the promotion of sustainable consumption patterns' [IA WP, 2005]. In France, a self-regulatory code has been adopted for car advertising in respect of safety. It suggests that car advertising should not promote speed, or that it should not present power and braking capacity as a means of going faster rather as features that can contribute to safety [BVP]. A similar code could be used as a steer to influencing manufacturers marketing strategies to promote more environmentally sensitive cars. Currently, the European Association of Communication Agencies (EACA) is undertaking an initiative to develop guidelines for advertising agencies on their approach to car advertising. The guidelines are likely to cover issues such as not portraying excess speed or braking in commercials, encouraging the portrayal of care for the environment and not showing SUVs in inappropriate environmental locations. This proposal has been submitted for consideration at the International Chamber of Commerce and if adopted would form the minimum standards by which self-regulating bodies such as the Advertising Standards Authority in the UK or BVP in France would expect their industry to behave [EACA, 2006].

11.8 Output supplied to TREMOVE and Task B

The impact of labelling cannot be modelled by TREMOVE. So far TREMOVE assumes that consumers are perfectly informed about car characteristics and that consumer choices are mainly driven by costs. This issue will be thoroughly discussed during the forthcoming workshop on car purchase behaviour and environmental impact of company car taxation (20-21 June 2006).

11.9 Conclusions and Recommendations

Labelling has a role to play in increasing awareness. However, evidence to date suggests that awareness of the impact of cars on climate change is only growing at a slow rate. There is a rationale, therefore, in improving the label, e.g. along the lines suggested by ADAC. Several Member States are already developing their respective labels along these lines, but the current approach is leading to diverse and disparate responses. The Commission should consider the harmonization of the approach to labelling based on the experience from those Member States who have gone beyond the requirements of the current Directive. It also appears that manufacturers' marketing strategies are often at odds with, and overshadowing, the message that the label is projecting. As the respective budgets for car advertising versus the label are currently heavily skewed towards the message portrayed by the former, it is arguable that more attention needs to be given to influencing the manufacturer's message.

However, the assessment of the label introduced under Directive 1999/94 suggests that it has not yet contributed significantly to actual emission reductions, and so should be used as part of a package of measures, which could include, for example, fiscal instruments, as is the case in the Netherlands, for example. The focus on a package of measures reflects the acceptance that labelling on its own is unlikely to have a major impact, but might have a stronger synergistic effect if linked, for example, to tax bands or incentives, as some Member States are now seeking to do. In addition, the further dissemination of vehicle energy efficiency information to the public could be accomplished through an EU-based, or coordinated, 'Consumer Guide to Cleaner Vehicles' website. This could include *inter alia* information on the CO_2 emissions and energy efficiency of different vehicles, as well as additional information on how to reduce emissions and improve energy efficiency while driving. For example, it could include information on eco-driving, including links to courses, information regarding tyres, e.g. the importance of properly inflating them, as well as information on the products that can improve energy efficiency, e.g. which lubricants and tyres, for example, are better in this respect.

In addition to this, at a minimum, the consideration of a code of conduct for advertising on environment and sustainability grounds should be considered. This could take the form of something similar along the lines of the voluntary French code for safety or the EACA initiative, or it could be more prescriptive. Given that there is already legislation concerning how information regarding the CO_2 emissions and fuel efficiency of passenger cars is communicated to the public, i.e. Directive 1999/94, the option of expanding the scope of this Directive should be considered. Currently this Directive focuses on the provision of information at the point of sale to which potential buyers are only exposed at the end of their decision making process. Consequently, to ensure that potential car buyers are more aware of the impact of the climate impact of their purchasing decision, consideration should be given to ensuring that information on CO_2 emissions and fuel efficiency is given wherever and whenever cars are promoted. In other words, thought should be given to expanding the scope of Directive 1999/94 to cover car advertising in all media, i.e. including TV and radio, as well as newspapers and magazines.

11.10 Literature

[ADAC 2005] *Study on the effectiveness of Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO_2 emissions in respect of the marketing of new passenger cars*, A report to DG Environment, March 2005.

[Anderson 1998] *Road to Ruin Sports Utility Vehicles and the Greening of Environmental Destruction*. Available online: http://www.fair.org/index.php?page=1432, September 1998.

[Bund 2006] *Die Werbung deutscher Automobilhersteller*. Available online: http://www.bund.net/lab/reddot2/aktuell_pressemitteilungen_5304.htm, April 2006.

[BVP] *Self-regulatory code for car advertising*. Available online: http://www.bvp.org/fre/.

[DRL 2004] *Preparation of the 2003 review of the commitment of car manufacturers to reduce CO_2 emissions from M_1 vehicles,* A report to DG Environment, December 2004.

[EACA, 2004] *NAC Lobbying Seminar*. Presentation in Brussels, September 2004.

[EACA, 2006] Personal communication, May 2004.

[FOE, 2005] *Government and Industry must do more on greener cars*. Press Release available online: http://foe.co.uk/resource/press_releases, November 2005.

[IA WP 2005] Working Paper for the Working Party on the Integrated Approach: Promoting Sustainable Marketing and Advertising. Working Paper presented as part of the Cars21 process, 2005.

[VROM 2003] *Evaluatie studie Energiepremie (Evaluation study Energy Subsidy)*, Notitie van de staatssecretaris van VROM aan de Tweede Kamer, Dutch Ministry of VROM, October 20, 2003.

[US EPA 2006] *Fuel economy labelling of motor vehicles: Revisions to improve calculation of fuel economy estimates; proposed rule*. Environmental Protection Agency Federal Register Wednesday February 1, 2006.

[Member States 2005] Responses to the questionnaire circulated for the purposes of this project

12 Review of public procurement proposals

12.1 Goal of Task 1.8

The goal of this project is to assess likely contribution of public procurement activities to future passenger car demand over the study period, and to give (primarily qualitative) indications of the CO$_2$ and broader greenhouse gas emissions implications, and costs, of these developments.

12.2 Approach

- Review the literature on role of public procurement in reducing CO$_2$ emissions from passenger cars, in particular any documentation supporting the Commission's public procurement proposal.
- Collect recent information from Member States by means of a questionnaire.
- Outline possible developments in this area (based on feedback from Commission and Member State experts), and review current state of play.
- Produce estimates of possible costs and scale of benefits from such measures.
- Results of all of the above will then need to be assessed for their implications for future qualitative and quantitative modelling as inputs to Task B, if appropriate.

12.3 Technical description

The principle behind the use of public procurement is that through the large collective buying power of the public sector it could be possible to establish a market which is able to absorb the initially higher costs of new technologies. Manufacturers can then scale up production in this market segment and obtain sufficient economies of scale to reduce the overall costs of more fuel efficient vehicles. The benefits of this are then passed on to all consumers, thereby making the more fuel efficient vehicles more competitive in terms of cost compared to conventional vehicles; the result is that there is increased take-up of new, more fuel efficient vehicles.

The European Commission recently published a proposal for a Directive COM (2005) 634 on the promotion of clean road transport vehicles. The proposal sets a quota that 25% of the public fleet of Heavy Duty Vehicles (HDVs) weighing over 3.5 tonnes should meet the "Enhanced environmentally friendly vehicle" (EEV) standard defined in Directive 2005/55/EC (summarised in Table 12.1).

Table 12.1 EEV emission limit values from Directive 2005/55/EC

Category	Mass of carbon monoxide (CO) g/kWh	Mass of hydrocarbons (HC) g/kWh	Mass of Methane (CH4) (1) g/kWh	Mass of nitrogen oxides (NOx) g/kWh	Mass of particulates (PT) g/kWh	Smoke m^{-1}
ESC and ELR tests (all vehicles)	1.5	0.25	-	2.0	0.02	0.15
ETC tests (diesel and gas vehicles only	3.0	0.4	0.65	2.0	0.02	-

Source: Directive 2005/55/EC

Clearly EEV standards relate to local air quality pollutants and ozone precursors and are applicable only to HDVs weighing over 3.5 tonnes. The proposed Directive therefore will not impact on the passenger car (M_1) or light commercial vehicle (N_1) markets directly and as such cannot be used to inform this work. The Impact Assessment (IA) [SEC (2005) 1588] that accompanied the proposal, however, did carry out an assessment of the publicly owned fleet across the European Union (EU) on the basis of all vehicle types (including M_1 and N_1 categories). The IA suggests that public procurement accounts for less than 1% of the total annual passenger car market and that "in the light vehicle sector: "public procurements do not represent a sufficient share [to stimulate the market]". The potential to develop scale economies in the light duty vehicle (LDV) segment (M_1 and N_1 vehicles) is likely to be limited by this small market share. This clearly has implications for the effectiveness of a public procurement strategy for these vehicles. Having said that, public procurement could have a role to play in market development, i.e. ensuring a market for new post-demonstration technologies to help them to become fully commercial, which is otherwise often a 'gap area' in market transformation policy packages. A further reason for promoting Commission and Member State involvement is that individual local authorities are often poor at communicating and coordinating, and tend to develop their own specific policies and priorities for vehicle procurement, resulting in a highly diverse and disaggregated range of demands for vehicle and technology types which is much less effective in developing the market than it could be. However, some experience suggests that where procurement is coordinated at national level a much stronger market signal can be given, along with more concerted support on after-sales maintenance, operational guidelines, etc.

The assessment in the IA of the market for public procurement is provided in Table 12.2 below and summarises estimates of the total fleet and annual levels of procurement.

Table 12.2 Total fleet and yearly procurement characteristics for the public sector

	Total Fleet		Yearly Procurement	
	Passenger Cars	Light Duty Vehicles	Passenger Cars	Light Duty Vehicles
Conventional DIESEL	73,654	368,436	22,615	88,226
Conventional PETROL	282,929	84,918	85,715	20,189
Natural Gas – CNG	553	951	167	245
LPG	3,732	4,154	1,144	1,070
BIOFUEL	n.a.	n.a.	0	0
HYDROGEN	n.a.	n.a.	0	0
ELECTRIC	954	1,044	287	269
HYBRID	243	n.a.	73	0
TOTAL	362,065	459,503	110,000	110,000

Source: SEC (2005) 1588

The IA also models the impact of the application of the 25% quota of clean vehicles to all categories including M_1s and N_1s (see Table 12.3). From the IA results, it is clear that a large increase in terms of volume is expected for the CNG and LPG vehicles. It is also anticipated that the shares of electric and hybrid vehicles will increase, particularly for passenger cars.

Table 12.3 Comparison of the current annual procurement levels with the 25% policy option

	Current Yearly Procurement		Procurement with 25% clean or more fuel efficient vehicles	
	Passenger Cars	Light Duty Vehicles	Passenger Cars	Light Duty Vehicles
Conventional DIESEL	22,615	88,226	17,041	67,047
Conventional PETROL	85,715	20,189	65,459	15,453
Natural Gas – CNG	167	245	2,508	2,797
LPG	1,144	1,070	21,637	24,202
BIOFUEL	0	0	0	0
HYDROGEN	0	0	0	0
ELECTRIC	287	269	2,969	501
HYBRID	73	0	385	0
TOTAL	110,000	110,000	110,000	110,000

12.4 Assessment of effectiveness of CO_2 emission reduction

The cost-benefit assessment indicates that the measure would produce a net benefit of €30 million for passenger cars and €36 million for N_1s compared to the 'no policy' option, over the timescale of the study. These benefits appear to be largely derived from a change in vehicle technology (from conventionally fuelled to LPG, CNG, electric and hybrid) and some improvement in overall fuel efficiency. These results are based on the assumptions that the external costs of GHG emissions are valued at €0.02 per kilogram and that the voluntary agreement will result in a 15% reduction in vehicle energy consumption to 2010, with a further 6% reduction from 2010 to 2015.

12.5 Assessment of efficiency

Within the IA, an estimate of the cost effectiveness for each vehicle category was undertaken and reveals that total environmental and energy benefits for passenger cars over the period 2006 to 2030 are €252 million, while the additional purchase costs are €257 million, producing a net cost of €5 million and an Internal Rate of Return (IRR) of 3.7%. For light commercial vehicles, these figures equate to benefits of €339 million, costs of €85 million, a net benefit of €253 million and an IRR of 37.6%.

12.6 Assessment of consistency – Overview of the impacts and trade offs

Public procurement itself has no direct effect on the environmental performance of a vehicle. By implementing the policy however, it is possible to create a market for specific vehicles that comply with certain environmental criteria. For example, the current proposal COM(2005)634 uses local air quality pollutant standards similar to the EURO V standards for HDVs. In this proposal, CO_2 benefits are secondary as the EEV measures relate to local air quality limit values and will occur as a consequence of improved vehicle fuel efficiency. In principle, however, the performance measure for procurement could be based on CO_2 emission levels, perhaps through the use of the banding system in the label.

Wider economic impacts of a public procurement policy relate to the extent of influence the measure has on the market. Public authorities are initially likely to have a higher expenditure on vehicles as the higher cost of the technology is passed on by manufacturers. This essentially means that there will be less public money to spend on other sectors. In the longer term, these higher costs should be partially offset by reduced running costs for the vehicles and a gradual reduction in vehicle costs as the market matures. Savings are also likely to be made in other sectors, for example as a result of less damage from pollutants and the attainment of air quality standards. For manufacturers, the ability to attain economies of scale in particular markets should reduce the costs of the technology and increase the level of investment for the technology allowing the potential expansion in the fleet range offered (SEC(2005)1588). Private consumers should not experience an increase in costs if the market for the alternative vehicle develops properly. There could even be a reduction in lifetime costs due to fuel efficiency improvements and an increase in choice for consumers, as manufacturers expand vehicle ranges. However, there may be issues regarding a reduction in other services from the public sector, as a result of the increased spending on vehicle procurement. Alternatively, this increase in vehicle spend may result in an overall increase in public sector spending that would have to be borne by the taxpayer.

Other social and environmental impacts identified in the IA are the reduction in illness and healthcare demand and a reduction in damage to agriculture and the corrosion of buildings. It also suggests that there will be increased demand for qualified engineers and workers along with the changes to the level of activity in the fuel supply sector. A final wider benefit is also likely to be the improvement to the security of energy supply, with the potential to diversify away from oil-derived fuel technologies.

12.7 (Enhanced) Policy measures

Identifying current action at the Member State level for procurement of M_1 and N_1 vehicles was undertaken as part of the questionnaire that was distributed to Member States as part of this study. From the results of this, several Member States had local policies, while others had national or central government requirements for public procurement. In addition, Sweden has also adopted a central government target (Regeringskensliet, 2005). Central government targets are summarised in Table 12.4, while the full responses to the questionnaire are given in Annex N.

Table 12.4 Summary of public procurement targets for M_1/ N_1 vehicles for selected Member States

Country	Procurement Target	Detail
Belgium	50% new purchase or lease since 2004	CO$_2$ emissions must be less than 145g/km for diesel and 160g/km for petrol cars
France	20% mandatory purchase of alternative technologies since 1997 and all new vehicles CO$_2$ emissions less than 140g/km	Central Authorities - 20% applies to (LPG, NGV or electric)
Netherlands	Purchase of 10,000 vehicles	Central government policy - Meet EURO IV and be in label categories A, B or C (Category D is allowed for government ministers)
United Kingdom	10% of fleet cars by 2006	Central government – alternatively-fuelled vehicles (being reviewed likely to be replaced by technologically-neutral target)
Sweden	25% of cars by 2007	All government authorities – green cars[43]

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[43] In Sweden the ‘green cars’ term prior to 2006 was based on local definitions. Since 2006 and the changes to taxation and advent of the congestion charge scheme in Stockholm an attempt has been made to develop a generic term. The intention is that this will unify the use of the term for fiscal measures such as taxation reform and congestion charging as well as that used for public procurement. The 2006 definition relates to the carbon emissions of the vehicle (<120gCO$_2$km); local air quality emissions (must meet 2005 Environment Class

The approach adopted by different Member States varies considerably, with a mixture of either technologically-neutral targets or technology driven targets forming the basis for the requirements. The Netherlands has linked its procurement to the energy efficiency label, while France and Belgium have adopted specific CO_2 emission ceilings for vehicles. The United Kingdom's target was initially technologically-driven; however this is currently under review and may be replaced by a technologically-neutral approach.

12.8 Possible public procurement scenarios and implications for TREMOVE and Task B

Public fleets are not separately modelled in TREMOVE. As a consequence the policy option of public procurement cannot be modelled.

12.9 Conclusions and Recommendations

Public procurement provides the opportunity to stimulate the market in alternative cleaner or more fuel efficient vehicle technologies and fuels by creating economies of scale for manufacturers and thereby reducing the costs of production. Based on the results of the IA carried out for the recent Commission proposal COM(2005)634, a 25% quota for public procurement of more fuel efficient vehicles could result in substantial savings in terms of CO_2 for both M_1 and N_1 vehicles. The cost-benefit analysis carried out for this work reports a net cost of €5 million for passenger cars and a net benefit of €253 million for N_1s and IRRs of 3.7% and 37.6% respectively. The IA does however point out that the overall market share for LDVs is small and that the implementation of the "Directive [if it had included light duty vehicles] is unlikely to achieve economies of scale" (SEC(2005)1588). The omission of light duty vehicles from the proposal is consistent with this conclusion, given that the development of these scale economies is the main driver of the policy. However, a number of Member States already have existing environmental vehicle public procurement policies at various tiers of government based on environmental or technologically driven criteria.

Given that the Commission's current public procurement proposal does not propose action on either M_1 or N_1 vehicles, and focuses on environmentally enhanced vehicles (EEVs), which do not have a criterion relating to CO_2 emissions, it is of limited relevance to the current work on light duty vehicles. However, if the proposed public procurement Directive does come into force and a CO_2-criterion is included in the EEV definition, then it might provide a model for a future public procurement proposal on N_1 vehicles.

12.10 Literature

[COM(2005)634]	Proposal for a Directive of the European Parliament and of the Council on the promotion of clean road transport vehicles COM(2005)634 final.
[Directive 2005/55/EC]	Directive 2005/55/EC of the European Parliament and of the Council on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles

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standards); and energy efficiency (for example electric vehicles with up to 6 passengers must use below 37kWh).

[SEC(2005)1588]	Annex to the Proposal for a Directive of the European Parliament and of the Council on the promotion of clean road transport vehicles impact assessment. SEC (2005) 1588.
[Regeringskensliet 2005]	Environmentally friendly cars and fuels; Accessed online (16/01/06): http://www.sweden.gov.se/sb/d/5745/a/52366;jsessionid=arxva7HlA7vc.
[Member States 2005]	Responses to the questionnaire circulated for the purposes of this project

13 Scenario development

Scenarios for further assessment in TREMOVE and Task B will be constructed by DG-ENV / DG-ENTR in cooperation with TML. Scenarios in this context are consistent packages of technical and non-technical measures aimed to achieve the overall target of 120 gCO_2/km, or possibly even a further reduction. For comparing scenarios the target of 120 g/km will be translated into an overall CO_2-reduction target in Mtonnes/year on the basis of a reference scenario in which the 120 g/km target is reached solely by technical measures at the vehicle level.

As a starting point for building scenarios the options will be evaluated and ranked in terms of CO_2-abatement costs (expressed in €/tonne CO_2 costs to society) and potential impact (contribution to reaching the overall CO_2-target). Complementary options will be combined to create robustness. These include technical and market-oriented measures. Measures and targets will be differentiated towards the various responsible stakeholders:

- Car industry: efficient vehicles;
- Fuel industry: alternative fuels;
- Consumers: purchasing & driving behaviour;
- Public authorities: taxation policies, information campaigns on ecodriving, public procurement.

In the selection and combination of measures account will be taken of the issue of measurability / monitorability / accountability (see e.g. section 1.6.3.5). Targets should be defined in such a way that the success of one stakeholder does not substantially reduce the required effort by other stakeholders.

14 Conclusions and recommendations

14.1 Conclusions from the assessment of the various options

14.1.1 Technical options to reduce fuel consumption at the vehicle level

Using the methodology as developed in [IEEP 2004] an assessment has been made of the costs for reaching various possible targets for the sales averaged type approval CO_2-emissions of newly sold vehicles in 2012, reaching from maintaining the 140 g/km level of 2008 to 120 g/km. For this assessment a new review has been made of available data from literature on costs and CO_2-reduction potential of a wide range of technical options that can be applied to passenger cars. Also data have been collected from industry associations by means of a questionnaire and meetings. Based on these data and expert judgement by the consultants a new data set has been drawn up for CO_2-reduction measures to be applied to passenger cars. Based on these data the assessment of costs and CO_2-abatement costs has provided the following results:

- The costs of reaching an average CO_2-emission of new vehicles of 140 g/km in 2008 will involve additional manufacturer costs of €832 per vehicle compared to the 2002 baseline. This translates into an additional retail price of €1200 per vehicle. The CO_2-abatement costs for reaching the 2008/9 target of 140 g/km compared to the 2002 baseline value of 166 g/km are 72 €/tonne at an oil price of 25 €/bbl, 20 €/tonne at an oil price of 50 €/bbl, and even go down to -30 €/tonne at an oil price of 74 €/bbl.

- The overall costs as well as the distribution of CO_2-reductions and costs over the different segments of passenger cars depend strongly on the policy measure that is used to implement the target.

- For most target-measure combinations the manufacturer costs for reaching a 2012 target of 120 g/km are around €1700 per vehicle compared to average costs of the 2008/9 baseline vehicle emitting 140 g/km. This translates into an additional retail price of €2450 per vehicle.

- The results of the new assess costs are significantly higher than the value calculated in [IEEP 2004]. The reasons for this significant difference are the following:
    - The translation from retail price data obtained from literature to manufacturer costs has been done with a different factor (1.44 instead of 2.0), resulting in higher input on the manufacturer costs;
    - The effects of autonomous weight increase have been modelled with a different formula resulting in a higher amount of additional CO_2-emissions to be compensated;
    - Cost and CO_2-reduction data for individual options have been newly estimated taking into account new literature data, information from industry and evolved expert judgement;
    - The resulting overall CO_2-reduction of packages of measures that target engine and powertrain efficiency has been assessed more conservatively;
    - In the present study investment costs in the formula for assessing CO_2-abatement costs are assumed to equal retail price minus tax, fuel cost savings are calculated on the basis of real-world fuel consumption, while lifetime CO_2-savings are based on real-world TTW CO_2-emission plus the WTT emissions coming from the fuel chain. In [IEEP 2004] investment costs were assumed equal to additional manufacturer costs, while the other variables were estimated on the basis of TA values instead of real-world and WTW values.

2012 target [g/km]	CO_2-abatement costs [€/tonne] at various levels of fuel costs			
	0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
135	169	146	117	68
130	190	166	138	88
125	212	188	160	110
120	235	212	183	134

- The abatement costs of reducing CO_2-emissions with technical measures applied to passenger cars depends on the reduction target and the oil price / fuel costs. For an oil price of 25 €/bbl the cost-effectiveness ranges from 166 to 233 €/tonne for 2012 target values between 135 and 120 g/km. For an oil price of 50 €/bbl the cost-effectiveness ranges from 114 to 181 €/tonne for 2012 target values between 135 and 120 g/km. CO_2-abatement costs in this assessment are based on real-world fuel consumption and CO_2-emissions and include the Well-to-Tank greenhouse gas emissions.
- In general it can be concluded that, regardless of the type of policy measure that is chosen, reaching a new vehicle sales average TA CO_2-emission of 120 g/km requires the introduction of hybrid vehicles in the segments of small, medium ad large petrol cars and of large diesel cars. For small diesel cars the necessity for hybridisation depends on the policy measure, while for medium size diesel cars hybridisation is necessary for none of the policy measures.
- If a 2012 target is to be reached through a legislative approach this can be implemented through a large number of combinations of the definition of the target and the measure under which it is applied. Targets can be either uniform, expressed as a percentage reduction compared to a reference situation or can be differentiated according to a parameter that quantifies the utility of the vehicle. Each of these targets can be applied to all cars or to average sales of each manufacturer (“company bubbles”), either without or with the option of emission credit trading among manufacturers.
- The feasibility of different target-measure combinations has not been assessed in detail in this study. Based on results from [IEEP 2004] and from the a brief review of the detailed results for individual manufacturers as provided by the cost assessment model car-based targets expressed as a uniform or percentage reduction target do not seem practical. The first target definition leads to huge costs for large cars and the second is difficult to define as car models come and go. A utility-based target per car, however, could be feasible and could be related to already developed or improved labelling schemes. Manufacturer-based targets without trading seem generally feasible, but the practical feasibility of including trading should be further analysed with respect to e.g. transparency of the market and the costs of setting up and maintaining a trading system in comparison to the benefits of trading for cost optimisation of reaching the 2012 target. In the present assessment the effect of trading on the overall costs and the division of CO_2-emission reductions over the various segments is found to be rather limited. In the assessment trading does significantly influence the division of costs over the various segments, but that is mainly due to the fact that the model automatically adds costs or revenues of trading to the size of the CO_2-deficit or surplus in each of the segments. Manufacturers, however, may choose to pass through the costs or benefits of trading in a different way. A more detailed assessment of the pros and cons of different target-measure combinations will be undertaken by the European Commission at a later stage.
- For different target-measure combinations the division of CO_2-emission reductions and costs over the individual manufacturers can be very different. This was already analysed in detail in [IEEP 2004].

- A first assessment of the overall GHG reduction potential associated with reducing the TA CO_2-emissions of new M_1-vehicles from 140 g/km in 2008/9 to 120 g/km in 2012 shows that for EU-15 a total reduction of 14.4 Mtonne/y would be achieved in 2012 growing to 54 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

- A sensitivity analysis shows that variations on the assumptions underlying the construction of cost curves may lead to variations of 10 to 20% in the estimated costs at the vehicle level for reaching 120 g/km in 2012. Similarly the alternative scenarios for the assumption on autonomous weight increase lead to a variation of plus or minus 20% in the costs for reaching the 120 g/km target. Combination of these two aspects yields a significant bandwidth for the costs of reducing CO_2-emissions from 140 g/km in 2008/9 to 120 g/km or another target in 2012. Due to a leveraging, that is intrinsic to the formula for calculating CO_2-abatement costs, variations on the vehicle costs of this relative order of magnitude lead to even higher variations in the CO_2-abatement costs, especially in the case of high fuel prices. Interpretation and comparison of CO_2-abatement costs resulting from calculations as presented in this study should be carried out with great care. This is especially the case for comparison of CO_2-abatement cost data from different sources (concerning the same subject or in the context of comparing abatement costs between sectors), where underlying assumptions and methodologies are often not compatible or not clearly documented.

14.1.2 Options for application of fuel efficient air conditioning systems

- The EC has proposed several measures to reduce greenhouse gas emissions from passenger cars in the next decade. The EC aims at reducing greenhouse gas emissions from aircos by a ban on the high GWP R134a as a refrigerant for all mobile air conditioner systems as from 2011. As a result of this legislation, the auto industry is challenged to develop new systems which use low GWP refrigerants as an alternative to R134a. Parallel to these developments, the industry investigates possibilities to improve existing systems, as such legislation is not proposed for other parts of the world and as for the EU still some time has to be bridged before switching to alternatives. It is expected that CO2-based systems (R744) will be the dominant alternative and that in response to existing policy these systems will gradually enter the market after 2008, reaching near 100% of new sales by 2014 or 2015.

- Both the existing R134a systems and the future R744 systems have room for improvement with respect to energy efficiency and the resulting indirect CO_2-emissions associated with use of these aircos. In response to a possible EU policy promoting energy efficiency of MACs it is expected that improved systems will come to the market which have significantly lower energy consumption. The additional manufacturer costs for improved systems are estimated at €40 for R134a systems and €60 for R744 systems. Besides that further improvement of the average efficiency of R134a systems is expected to be achieved by an increased share of systems variable displacement compressors.

- CO_2-abatement costs of a policy promoting the introduction of more efficient MACs are assessed by estimating the total annual indirect CO_2-emissions, investment and fuel costs for a baseline scenario (describing the response to existing policy) and a constructed policy scenario sketching a possible response to a not yet defined EU policy aimed at the efficiency of MACs.

- At low oil prices (25 to 35 €/bbl) the abatement costs of reducing CO_2-emissions by means of energy efficient MACs vary between 40 and 90 €/tonne. At 50 €/bbl the CO_2-abatement costs vary between 15 and 40 €/tonne, becoming even negative for an oil price of 74 €/bbl. Compared to other technical options fuel efficient MACs therefore are a relatively cost-effective measure to reduce CO_2-emissions from passenger cars.

- For the moment there are no means for including the indirect fuel consumption of MACs in the type approval test. In [TNO 2004] a simplified test procedure has been developed to this end, but this procedure was found not to yield sufficiently reproducible and accurate results. More accurate ad-hoc test procedures exist which are applied in vehicle development and testing with regard to airco performance and interior comfort, but these require very expensive test facilities and elaborate tests that are beyond the scope of the European type approval test. The procedure developed in [TNO 2004] could be used to monitor overall progress in the average indirect CO_2-emissions of MACs when applied in a monitoring programme to a number of vehicles that is large enough to yield statistically significant average results. The sample size required to yield statistically significant results, however, could not be determined on the basis of the limited amount of vehicles and systems tested in [TNO 2004], and requires further experimental study.
- The impossibility to include MACs in the TA test procedure for the moment seems to exclude legislative measures aimed at promoting airco efficiency. The existing procedure can be used as a monitoring tool accompanying a voluntary agreement with the automotive industry on airco efficiency.
- A first assessment of the overall reduction potential associated with promotion of the use of fuel-efficient air conditioner systems shows that for EU-15 a total GHG reduction of 1.0 Mtonne/y could be achieved in 2012 growing to 2.7 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

14.1.3 Options to reduce vehicle and engine resistance factors

- Low rolling resistance tyres and tyre pressure monitoring systems showed an important CO_2 reduction potential which was approximated at 3% and 2.5% respectively.
- The CO_2-abatement costs of low rolling resistance tyres remains relatively high compared to other solutions and were estimated to be 140 €/tonne CO_2 reduced for low oil prices and 15 €/tonne for high oil prices in the case of LRRT. For TPMS CO_2-abatement costs were found negative in most cases.
- Important issues that are presented regarding these technologies are the absence of the necessary standardisation and legislative framework that will support their introduction in the market and possible inconsistencies in relation to the vehicle type approval test. As for the last the potential of these technologies has either zero impact on the vehicle type approval test (TPMS) or can be incorporated without necessarily reaching the market (LRRT).
- Low viscosity lubricants present similar characteristics with LRRT and TPMS. Their CO_2 reduction potential was found at 2.5% and their CO_2-abatement costs were estimated at approximately 180 €/tonne for low oil prices and 50 €/tonne for higher oil prices. Certain problems were revealed in the case of LVL regarding standardisation and vehicle warrantee issues when applying LVL.
- Various measures are proposed for supporting and accelerating the introduction of the aforementioned technologies in the market. Amongst them are the application of labelling schemes, creation of consumer support tools such as product databases, adoption of relevant standards for each technology and purchase incentive programs. All of these should be combined with a necessary update of the relevant legislative framework.
- The assessment for TPMS assumes that the user of the vehicle appropriately responds to the signals provided by the TPMS. This may certainly be expected when the TPMS is bought as an accessory, but as soon as TPMS becomes a standard auxiliary it seems likely that not all users will

inflate their tyres when the TPMS reports underpressure. This poses a problem in terms of monitorability for policies aiming to promote the application of TPMS.

- Assuming a constructed scenario quantifying the effectiveness of policy measures promoting the application of low rolling resistance tyres, the total reduction potential associated with the increased use of low rolling resistance tyres is estimated for EU-15 at 2.4 Mtonne/y in 2012 growing to 5.3 Mtonne/y in 2020. Similarly for tyre pressure monitoring systems the overall potential is estimated at 2.0 resp. 9.6 Mtonne/y for 2012 and 202. The application of low-viscosity lubricants is estimated to result in an overall GHG reduction at EU-15 level of 2.0 Mtonne/y in 2012 increasing to 9.6 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

14.1.4 Natural gas vehicles

- The additional manufacturer costs of medium sized natural gas vehicles (NGVs) compared to equivalent petrol vehicles is estimated at around €1750 per vehicle. Compared to equivalent petrol vehicles the direct (exhaust or Tank-to-Wheel (TTW)) CO_2-emissions of NGVs are about 22% lower;
- Emissions of methane (CH_4) only marginally reduced the greenhouse gas reduction potential of NGVs. Including CH_4 and other greenhouse gases (mainly N_2O) in the comparison between petrol, diesel and natural gas does not significantly influence the outcome of the assessment;
- The abatement costs of reducing CO_2-emissions from passenger cars by means of natural gas depend strongly on the price of oil and the costs of natural gas at the filling station, as well as on the origin of the natural gas. Longer transport distances incur relatively high Well-to-Tank (WTT) emissions that counteract the TTW benefits to some extent. For this study it is assumed that most of the additional natural gas consumed between 2008 and 2012 by NGVs will be imported from outside Europe with an average transport distance of 4000 km. Using the WTW-assessment made in [Concawe 2006] for this fuel chain the net WTW CO_2-emission reduction compared to petrol vehicles is about 17% for this case;
- Including the benefits of NGVs (and possibly also other alternative fuels, specifically biofuels) in a monitoring scheme accompanying legislative or other policy measures aimed at reaching a defined CO_2-emissions reduction would thus preferably include a methodology for dealing with the WTT greenhouse gases for all fuels;
- Even at a petrol price of 0.60 €/l (oil price = 74 €/bbl) NGVs are not a cost effective solution for reducing CO_2-emissions given the level of additional manufacturer costs as estimated in this study. CO_2-abatement costs range from around 350 €/tonne at an oil price of 25 €/bbl to 190 €/tonne at 74 €/bbl;
- Compared to technical measures that can be applied to conventional vehicles, NGVs are a less cost effective option for reaching a 2012 target of e.g. 120 g/km, are partly due to the high additional manufacturer costs and partly due to the higher fuel price excluding taxes per unit energy for natural gas. As a result of the latter NGVs have higher fuel costs (excl. taxes) than baseline petrol vehicles to which the natural gas technology is applied, while more efficient petrol vehicles have a net fuel cost reduction compared to the same baseline;
- As natural gas can also be applied to petrol vehicles to which technical measures are applied in order to reach an overall 2012 goal between 140 and 120 g/km, NGVs may play a role in extending the potential for CO_2-reduction beyond 120 g/km. NGVs can be an alternative for the expensive technologies that need to be applied for reaching targets beyond 120 g/km. For the levels CO_2-reduction as foreseen for the 2008 – 2012 timeframe NGVs can only become an

interesting alternative if the costs could be reduced significantly below the level estimated in this chapter. When these costs are assumed to be € 1250 instead of € 1750 then NGVs still only become cost effective in the case of high oil prices and 2012 targets below 130 g/km.

- Assuming a linear increase of the additional share of NGVs in new vehicle sales from 0% in 2007 to 10% in 2012 and a constant share of 10% after 2012, the total GHG reduction potential for EU-15 is estimated at 2.1 – 2.4 Mtonnes/y in 2012 growing to 6.4 – 7.3 Mtonne/y in 2020. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

14.1.5 Options to promote application of biofuels

- Currently the biofuels most commonly available as transport fuels are biodiesel and bioethanol (with the latter often converted to bio-ETBE to be used as an additive in petrol). The main feedstocks are crops grown for oil (such as rape, soya and sunflower) for biodiesel, and crops high in sugar or starch (including sugar beet and cane, various grain crops, etc) for ethanol. In future, ‘second generation’ processes should be able to produce a range of synthetic fuels from a wider range of biomass sources, including bio-wastes, woody crops and grasses, but these are unlikely to contribute significantly up to 2012.
- Biofuels offer CO_2 reduction benefits relative to mineral fuels because their carbon was absorbed from the atmosphere as the source plants grew, rather than being released from underground storage as with fossil fuels. However few if any biofuels are truly ‘carbon neutral’; those grown in Europe typically offer around a 50% greenhouse gas reduction, although the benefits of ethanol imported from Brazil are typically much greater (around 80% reduction).
- Current biofuels are produced at a cost premium relative to conventional fuels, but this is reduced significantly if oil prices remain high. For the cheaper biofuel options (particularly Brazilian ethanol) the cost of CO_2 avoided falls to around zero on the assumption of a high oil price (€50/bbl), but more expensive European sources continue to have a cost premium, although this varies substantially according to both the cost and greenhouse gas reduction of the biofuel in question, and the anticipated price of oil.
- The current biofuels policy framework sets indicative targets for biofuel percentages to the year 2010; it is proposed to model the greenhouse gas benefits of a linear extrapolation of the agreed trend for the years 2011 and 2012.
- The additional replacement of 1% of fossil fuel use (in energy terms) by the use of biofuels over and above the effects of the Biofuels Directive is estimated to result in an overall GHG emission reduction for EU-15 of 3.1 to 4.0 Mtonne/y. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

14.1.6 Possibilities to include N_1 vehicles into the Commitments

- Cost and CO_2-reduction potentials of options to reduce CO_2-emissions form N_1-vehicles have been based on the results of Task 1.1 on passenger cars. For each fuel data from the M_1 categories small, medium and large have been used for the N_1 categories Class I, II and III. Based on the input provided by ACEA the following modifications are applied:
    - The CO_2-reduction potential of engine down-sizing for N_1-vehicles is assumed to be smaller than for M_1-vehicles;

  - The costs of start-stop systems with regenerative braking, mild hybrid and full hybrid powertrains for Class III N$_1$-vehicles are assumed to be a factor of 1.3 higher than for large M$_1$-vehicles. This factor is somewhat smaller than the one assumed by ACEA;
  - Some options such as strong downsizing and dual clutch transmission are considered not applicable to N$_1$-vehicles. For strong downsizing (in combination with (twin) turbo) this is due to the relatively high engine loads, that would cause problem with durability of the turbo, and the high torque requirements at low rpm that may not be fulfilled by this system;

- For each of the classes a business-as-usual package (BAU) has been defined of CO$_2$-reducing options that are assumed to be applied in the period 2002 – 2012 even in the absence of policy aimed at the CO$_2$-emissions of N$_1$-vehicles, as well as four packages with increasing levels of CO$_2$-reduction and technical complexity that may be applied by manufacturers in response to policy. For each of these packages the overall costs and CO$_2$-emission reductions have been assessed;

- The CO$_2$-abatement costs are found to depend strongly on the desired level of CO$_2$-reduction and on fuel costs. Small levels of CO$_2$-reduction compared to the BAU baseline (up to 15 g/km) are found to yield cost benefits for almost all levels of fuel costs;

				average	abatement costs [€/tonne]			
					0.21 €/l	0.30 €/l	0.41 €/l	0.60 €/l
	2002 baseline CO2-emission		[g/km]	200.9				
	2012 baseline CO2-emission		[g/km]	189.7				
least costs - 2012	15 g/km reduction	ΔCO2	[g/km]	15.0	6	-16	-44	-91
		CO2	[g/km]	175				
		Δcosts	[€]	352				
	30 g/km reduction	ΔCO2	[g/km]	30.0	63	41	14	-34
		CO2	[g/km]	160				
		Δcosts	[€]	1394				
	45 g/km reduction	ΔCO2	[g/km]	45.0	131	108	81	34
		CO2	[g/km]	145				
		Δcosts	[€]	3315				
	60 g/km reduction	ΔCO2	[g/km]	60.0	206	184	156	109
		CO2	[g/km]	130				
		Δcosts	[€]	6239				

- Achieving an average 60 g/km TA CO$_2$-emission reduction in N$_1$-vehicles has about equal CO$_2$-abatement costs as reducing the average TA CO$_2$-emission from M$_1$-vehicles with 20 g/km form 140 to 120 g/km. Given the non-linear dependence of CO$_2$-abatement costs on the reduction target, an average 20 g/km TA CO$_2$-emission reduction in N$_1$-vehicles can thus be reached at significantly lower costs per ton than the same reduction in M$_1$-vehicles;

- CO$_2$-emission reduction in N$_1$-vehicles therefore is an interesting option to consider in the context of the Integrated Approach. Obviously this advantage of N$_1$-vehicles compared to M$_1$-vehicles is largely due to the fact that M$_1$-vehicles are subject to CO2-reducing policy until 2008, while such a policy does not exist for N$_1$-vehicles.

- A first assessment of the overall GHG reduction potential associated with reducing the TA CO$_2$-emissions of new N$_1$-vehicles compared to the business-as-usual baseline has been made for EU-15. For a 2012 reduction target of 15 g/km the overall GHG reduction potential grows from 1.2 Mtonne/y in 2012 to 2.2 Mtonne/y in 2020. These values increase with higher reduction targets reaching 4.9 Mtonne/y in 2012 and 16.5 Mtonne/y in 2020 for a reduction target of 60 g/km. A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

14.1.7 Options for promoting fuel efficient driving

- Assessment of the CO_2-abatement costs of eco-driving is extremely sensitive to the methodology that is used and to variations in the values of the input parameters. The initial effect of eco-driving is reasonably well measured and documented. The long term effect on the other hand is less well known, but is expected to be significantly smaller. As both the level of effect and the duration strongly affect the outcome of the CO_2-abatement cost calculation the assessment presented here has significant uncertainty margins;
- The effective use of a gear shift indicators (GSI) in itself only captures part of the total reduction potential of eco-driving. On the other hand GSI can be an effective tool to assist drivers in maintaining a correct and effective fuel efficient driving style. In this way the use of GSI in combination with eco-driving is expected to increase the long-term effectiveness of eco-driving;
- In this study it is assumed that the long term effect of applying eco-driving is a fuel consumption reduction of 3%. With the aid of GSI this can be improved to 4.5%. The effect of only using GSI is 1.5%. The duration of the effect of eco-driving is assumed to be 40 years for new drivers to whom has been taught during the regular driver training for their drivers licence. For existing drivers, e.g. following a dedicate course on eco-driving, an average duration of the effect of 25 years is assumed. The costs of lessons are set at €100 (no costs for new drivers). The additional manufacturer costs of GSI are €15 (€22 additional retail price);
- Under the assumptions made in this analysis with regard to costs of lessons, GSI and government campaigns the application of eco-driving is a very cost effective means of reducing CO_2-emissions of passenger cars for oil prices ranging from 25 €/bbl upwards;
- Incorporation of eco-driving in an EU-policy aimed at reducing CO_2-emissions from passenger cars is hindered by the limited monitorability of the effects of ecodriving;
- Large amounts of drivers can be influenced to apply eco-driving by means of:
    - incorporating eco-driving in the lessons for new drivers;
    - car manufacturers offering eco-driving lessons (for free or for a reduced price) to buyers of new vehicles;
    - companies offering eco-driving lessons (for free or for a reduced price) to employees driving a (leased) company.

  Other existing drivers can be targeted through government campaigns.
- The total GHG reduction potential of fuel-efficient driving depends strongly on the way the measure is implemented or promoted and on the assumed effectiveness of such promotion measures. Indicative calculations for EU-15 show the following results:
- If eco-driving is included in the lessons for new drivers, then a total reduction of 1.8 Mtonne/y could be achieved in 2012, increasing to 5.5 Mtonne/y in 2020;
- The total effect of mounting GSI systems on new vehicles is estimated at 1.5 Mtonne/y in 2012 and 4.4 Mtonne/y in 2020;
- For a combination of measures promoting the application of eco-driving by existing drivers the overall reduction potential is estimated at 4.0 Mtonne/y in 2012 growing to 9.1 Mtonne/y in 2020. If GSI is used to assist these drivers in maintaining a fuel-efficient driving style these values increase to 6.0 Mtonne/y in 2012 and 13.7 Mtonne/y in 2020.

  A more in-depth assessment of overall reduction potential, including possible effects of cost changes in consumer purchasing behaviour with respect to car size and fuel type, transport volume and model split, will be made outside this project using TREMOVE.

14.1.8 CO_2 based taxation schemes for passenger cars

- As a policy instrument, taxation can be used to complement other measures in order to encourage the wider take up of more fuel efficient vehicles in the market through the use of a strong fiscal signal. Although this influence is not as direct as the measures that produce physical changes to the vehicle, the combination of both should create a situation that can ultimately drive the structure of the market. Taxation and fiscal incentives have the potential to strongly influence the motor vehicle market and new vehicle CO_2 emissions if they are structured and differentiated in the most appropriate way. According to [COWI 2002a][44], restructuring tax systems so they are based on CO_2 emissions has the potential to produce, on average, a 5% reduction across the EU-15 in emissions from new vehicles. Taxation mechanisms alone however, would be unable to totally 'bridge' the 20g gap between the manufacturers target of 140gCO_2/km for 2008/09 and the EU target of 120gCO_2/km by 2012 without a change in the proportion of diesel vehicles in the fleet and some reduction in the size of vehicles sold. The 'myopia' of car buyers in relation to the life-time costs of vehicles suggests that RT has the potential to provide a stronger signal to the consumer than CT. COWI's work also suggests that RT has the potential to reduce emissions more than CT even when the consumer 'myopia' in terms of life-time vehicle costs is not considered. TIS' work suggests that the removal of RT, as suggested by the current proposed Directive on harmonising the taxation system across Member States, can be considered a missed opportunity for a very direct instrument for CO_2 differentiation. To reach a similar effect through CT will probably require a much stronger level of CO_2-differentiation, possibly combined with fuel tax measures, and should be combined with effective communication measures to educate consumers at the point of purchase on the effect of the vehicle's CO_2-emissions on annual operating costs.
- The achievement of the proposed harmonisation in the tax system across Europe is likely to prove politically difficult and the retention of decisions over vehicle taxation structure is likely to remain with individual Member States. This should not adversely effect these potential reductions, as COWI based their assessment on individual countries, but it will necessitate individual concerted action by Member States, over which the European Commission is likely to have a limited influence without the agreement over the Directive proposed in COM(2005)264. The evidence from the Member State questionnaires indicates that a realignment of vehicle taxes to reflect CO_2 and other emissions is currently being considered in a number of countries. A package of measures, which includes the use of fiscal instruments, is likely to be the most effective way to influence vehicle CO_2 emissions.
- Many Member States have, or are planning to, amend their vehicle taxation systems to reflect CO_2 emissions in some way. However, in most cases such developments are still at the proposal stage, or, if not, only recently introduced, so there has been little experience to enable an evaluation as to whether these policies have been effective. For example, of the possible taxation scenarios initially considered for modelling in TREMOVE, the French system was only voted on in Parliament in November 2005 and the Swedish proposal was even less well advanced. Of the four scenarios proposed, however, there is evidence from the Netherlands and the UK of the potential benefits of differentiating vehicle taxes according to CO_2 emissions. In the UK, the company car tax reforms appear to have been effective to the extent that company cars in the UK are now more CO_2-efficient on average than those bought by private buyers, which is a radical reversal of previous trends. Conversely, the evaluation of the CT reforms in the UK, suggests that differentiating this tax by CO_2 emissions has had little impact on car buyer behaviour. The research suggested that this was due to the relatively low level of differentiation. The UK

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[44] See section 10 for literature reference.

government appears to have taken this message on board, as it has recently increased the differentiation between the CT tax bands. The most striking example of the potential of differentiating taxes on the basis of their CO_2 emissions comes from the Netherlands, where a one-year incentive in favour of the purchase of the less CO_2 emitting vehicles (i.e. those of Band A and B) led to a doubling of the numbers of these vehicles purchased. When the incentive was withdrawn after one year, this proportion declined significantly. The Netherlands will introduce this system on a permanent basis in the course of 2006. These examples, coupled with the fact that many other Member states are planning to introduce similar differentiated taxes, suggests that there can be an environmental benefit in such differentiation and that increasingly Member State governments believe that this is the case.

14.1.9 Options for improved energy or CO_2-labelling

- Labelling has a role to play in increasing awareness. However, evidence to date suggests that awareness of the impact of cars on climate change is only growing at a slow rate. There is a rationale, therefore, in improving the label, e.g. along the lines suggested by ADAC. Several Member States are already developing their respective labels along these lines, but the current approach is leading to diverse and disparate responses. The Commission should consider the harmonization of the approach to labelling based on the experience from those Member States who have gone beyond the requirements of the current Directive. It also appears that manufacturers' marketing strategies are often at odds with, and overshadowing, the message that the label is projecting. As the respective budgets for car advertising versus the label are currently heavily skewed towards the message portrayed by the former, it is arguable that more attention needs to be given to influencing the manufacturer's message.
- However, the assessment of the label introduced under Directive 1999/94 suggests that labels are unlikely to contribute actual emission reductions on their own. However, the information on the label has a role in raising consumer awareness of fuel efficiency and CO_2 emissions, a role that could be reinforced, and potentially contribute to reducing emissions, if it were linked to fiscal instruments, as is the case in the Netherlands, for example. In addition, the further dissemination of vehicle energy efficiency information to the public could be accomplished through an EU-based, or coordinated, 'Consumer Guide to Cleaner Vehicles' website. This could include *inter alia* information on the CO_2 emissions and energy efficiency of different vehicles, as well as additional information on how to reduce emissions and improve energy efficiency while driving. For example, it could include information on eco-driving, including links to courses, information regarding tyres, e.g. the importance of properly inflating them, as well as information on the products that can improve energy efficiency, e.g. which lubricants and tyres, for example, are better in this respect.
- In addition to this, at a minimum, the consideration of a code of conduct for advertising on environment and sustainability grounds should be considered. This could take the form of something similar along the lines of the voluntary French code for safety or the EACA initiative, or it could be more prescriptive. Given that there is already legislation concerning how information regarding the CO_2 emissions and fuel efficiency of passenger cars is communicated to the public, i.e. Directive 1999/94, the option of expanding the scope of this Directive should be considered. Currently this Directive focuses on the provision of information at the point of sale to which potential buyers are only exposed at the end of their decision making process. Consequently, to ensure that potential car buyers are more aware of the impact of the climate impact of their purchasing decision, consideration should be given to ensuring that information on CO_2 emissions and fuel efficiency is given wherever and whenever cars are promoted. In other words, thought should be given to expanding the scope of Directive 1999/94 to cover car advertising in all media, i.e. including TV and radio, as well as newspapers and magazines.

14.1.10 Public procurement proposals

- Public procurement provides the opportunity to stimulate the market in alternative more fuel efficient vehicle technologies and alternative fuels by creating economies of scale for manufacturers and thereby reducing the costs of production. Based on the results of the IA carried out for the recent Commission proposal COM(2005)634, a 25% quota for public procurement of more fuel efficient vehicles could result in substantial savings in terms of CO_2 for both M_1 and N_1 vehicles. The cost-benefit analysis carried out for this work reports a net cost of €5 million for passenger cars and a net benefit of €253 million for N_1s and IRRs of 3.7% and 37.6% respectively. The IA does however point out that the overall market share for LDVs is small and that the implementation of the "Directive (if it had included light duty vehicles) is unlikely to achieve economies of scale" (SEC(2005)1588). The omission of light duty vehicles from the proposal is consistent with this conclusion, given that the development of these scale economies is the main driver of the policy. However, a number of Member States already have existing environmental vehicle public procurement policies at various tiers of government based on environmental or technologically driven criteria.
- The Commission's current public procurement proposal focuses on environmentally enhanced vehicles (EEVs), for which a definition only exists in relation to heavy duty vehicles. Additionally there is no EEV criterion for CO_2 emissions. Hence, the proposal is of limited relevance to the current work on light duty vehicles. However, if the proposed public procurement Directive does come into force, and a CO_2-criterion is included in the EEV definition, then it might provide a model for a future public procurement proposal on N_1 vehicles.

14.2 Overall conclusions with regard to a future European Commission policy on the CO_2-emissions of light duty vehicles

For those options for which a quantitative analysis has been made in this report the following overall conclusions can be drawn:

- The abatement costs for reducing CO_2-emissions in M_1-vehicles through technical measures that improve fuel efficiency on the type approval test are a benchmark for the other measures studied in this report. The abatement costs for reaching a new vehicle sales average of 120 g/km in 2012 range from 233 €/tonne at an oil price of 25 €/bbl to 132 €/tonne at an oil price of 74 €/bbl. The results for M_1-vehicles are sensitive to the assumptions made on the autonomous weight increase and to various assumptions made in relation to uncertainties in the cost assessment. Costs have been estimated based on data that are valid for large scale production of the applied technologies, but further assessment may be carried out to gain more insight in possible cost reductions as a function of time and production volume;
- Fuel efficient air conditioning systems reduce the real-world CO_2-emissions of passenger cars more cost effectively that technical measures to improve powertrain efficiency. However, inclusion of the energy use of air conditioning systems into the Type Approval test is not possible at this stage. This is due to the fact that a testing procedure that is consistent with the general approach of type approval testing does not yield sufficiently accurate results, while available more accurate procedures are considered too complex and costly for this purpose. The available TA-type test procedure for MACs can, however, be used in monitoring schemes e.g. accompanying a voluntary agreement with the industry to reduce indirect CO_2-emissions from airco systems;
- Retrofitting of low rolling resistance tyres has positive costs per avoided tonne CO_2-eq., but these abatement costs are somewhat lower than for efficiency improvement of conventional, new cars.
- Tyre pressure monitoring systems can be a very cost effective means of achieving a few percent reduction of the CO_2-emissions of the European passenger car fleet, with negative CO_2-abatement costs for oil prices above 30 €/bbl;

- Low-viscosity lubricants used in existing vehicles have higher CO_2-abatement costs than retrofitting of low rolling resistance tyres;

- Natural gas is a relatively expensive option for reducing CO_2-emissions from passenger cars. Abatement costs are generally higher than for efficiency improvement of conventional cars. If cost reductions would be possible beyond the cost value used for the assessment in this report, then conversion to natural gas could compete with the expensive technologies that need to be applied to passenger cars for reaching 2012 targets of 125 or 120 g/km in scenarios with a high oil price;

- For biofuels the CO_2-abatement costs depend highly on the assumed values for fuel costs and WTW CO_2-emission reduction. Brazilian ethanol is cost-effective for most oil price values. The CO_2-abatement costs of 1st generation European biofuels are in the same range as that of technical measures that can be applied to improve the fuel efficiency of passenger cars. Measures to increase the share of biofuels beyond the existing 5.75% target of the EU Biofuels Directive need to be critically reviewed. Additional policy aiming at increased use of biofuels should include a system to monitor the Well-to-Wheel GHG emission reduction of fuels (incl. conventional fuels), as reducing WTW emissions of biofuels may in some cases be more effective than increasing the share of biofuels.

- The abatement costs of reducing CO_2-emissions in light-duty commercial vehicles (N_1) are generally lower than those of technical measures applied to passenger cars. This is not so much due to lower costs for N1-vehicles, but to the fact that for passenger cars CO_2-abatement costs are calculated compared to a baseline that already incorporates policy measures to reduce CO_2-emissions (i.e. only the costs and effects of going beyond the 2008/9 target of the manufacturers' self commitments is assessed), while for N_1-vehicles such policy is not yet in place.

- Fuel efficient driving, based on lessons and with or without the aid of GSI, is a very cost effective means of achieving one or two percent reduction of the CO_2-emissions of the European passenger car fleet. This option, however, has a problem with regard to measurability, monitorability and accountability;

Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars

Annexes to the Final Report

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Annex A Relation between retail price and costs

Introduction

Defining the relationships between manufacturer costs, investment costs to society and retail price is important for a correct assessment of the CO_2-abatement costs of technical measures to promote reduction of CO_2-emissions. This Annex clarifies the assumptions that were made for the purpose of this report. It should be noted here that a generally accepted definition of societal costs does not exist and that different studies and different areas of application are found to use different, generally inconsistent definitions[45].

Data on breakdown of vehicle retail price

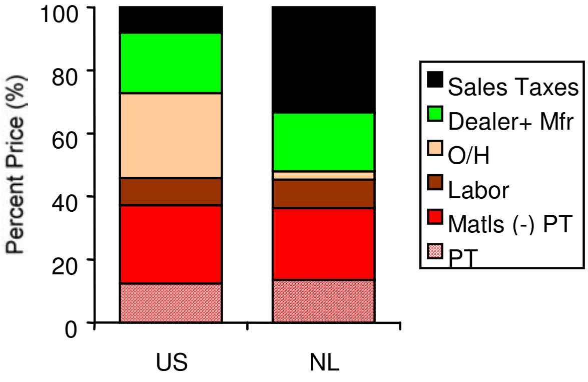
In the public domain limited information is available on the breakdown of retail price into the various elements of tax, profits and costs. Below data from a few sources are presented. Although definitions of e.g. overhead as part of the manufacturer costs may be different in the different sources, the overall picture that emerges seems quite consistent.

Data collected in IEA Annex VII on hybrid vehicles

Report:
"IEA Implementing Agreement for Hybrid and Electric Vehicle Technologies and Programmes", Annex VII, Hybrid Vehicles, *Overview Report 2000*, July 2000[46]

In chapter 8 of this report some information is presented on the breakdown of the retail price of conventional vehicles in the US and the Netherlands. Data for the US originate from CSMI Automotive and were made available by US-DoE. Data for the Netherlands originate from NedCar and were made available by TNO.

Figure 1. Vehicle Cost/Price Structure
Sources: US-CSMI; NL-Dijkhuizen



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[45] Personal communication with environmental economist Dr. Sander de Bruyn of CE, Delft, the Netherlands.

[46] Report can be downloaded from: http://www.ieahev.org/publications/annex7_2000.html

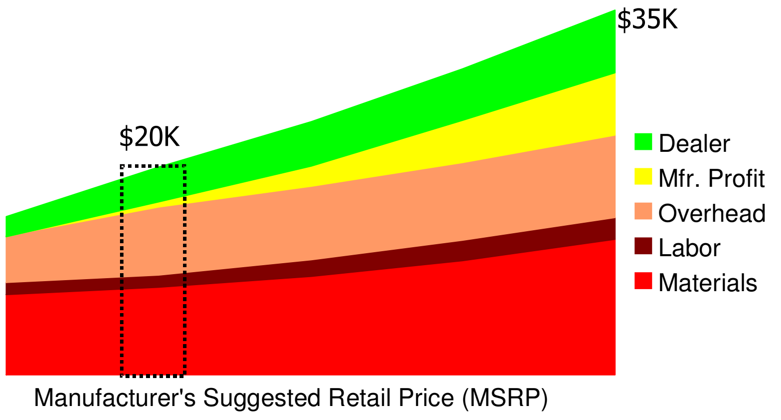

Figure 4. Cost Elements versus Price

Source: CSMI Automotive Systems

Study by Argonne National Laboratory

Article:
"Comparison of indirect cost multipliers for vehicle manufacturing", Anant Vyas, Dan Santini and Roy Cuenca, Centre for Transportation Research, Argonne National Laboratory, April 2000.[47]

In this paper a method by ANL is compared to two other methods for estimating the breakdown of vehicle retail price. The three methods come to roughly the same overall results so that only the data from the ANL method are presented here:

Table 1 Contributors to Manufacturer's Suggested Retail Price in ANL Methodology

Cost Category	**Cost Contributor**	**Relative to Cost of Vehicle Manufacturing**	**Share of MSRP (%)**
Vehicle Manufacturing	Cost of Manufacture	1.00	50.0
Production Overhead	Warranty R&D/Engineering Depreciation and Amortization	0.10 0.13 0.11	5.0 6.5 5.5
Corporate Overhead	Corporate Overhead, Retirement and Health	0.14	7.0
Selling	Distribution, Marketing, Dealer Support, and Dealer Discount	0.47	23.5
Sum of Costs		1.95	97.5
Profit	Profit	0.05	2.5
Total Contribution to MSRP		2.00	100.0

The above data are for the US situation with a MSRP exclusive of taxes.

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[47] Article can be downloaded from:
http://www.transportation.anl.gov/research/technology_analysis/cost_analysis.html

Comparison of data on vehicle retail price

The table below presents a comparison of the data in the above quoted sources. From the ACEA tax guide, combined with vehicle sales numbers in Europe, it can be deduced that the average vehicle tax level in EU15 is 19% of the vehicle retail price. Data from the three sources have been translated to a situation with EU-average tax by assuming the ratios between the various price elements (dealer costs & profits, manufacturing costs, overhead and manufacturer profits) constant and normalizing them to a retail price including 19% tax.

	NedCar data		*CSMI Automotive*		*ANL methodology*		
	original data for Netherlands	translation to EU-average tax	original data for US (MSRP)	translation to EU-average tax	original data for US (MSRP)	translation to EU-average tax	**proposal**
vehicle tax	33.5%	19.0%	0.0%	19.0%	0.0%	19.0%	**19.0%**
dealer profit	19.0%	23.1%	17.5%	14.2%	23.5%	19.0%	**2.0%**
dealer costs							**16.0%**
manufacturer profit			4.5%	3.6%	2.5%	2.0%	**3.0%**
manufacturer overhead	47.5%	57.9%	78.0%	63.2%	24.0%	19.4%	**60.0%**
manufacturing costs					50.0%	40.5%	
	100.0%	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	***100.0%***

The right-hand column presents a proposed average retail price breakdown for further use in Task A.

No data for the dealer profit are available. Obviously a distinction has to be made between profit and margins. From known price discounts obtained by lease companies it is estimated that the dealer margin on vehicles is around 8% of the retail price. The overall profit on sales of new vehicles, however, is expected to be significantly smaller. Here a dealer profit of 2% of the retail price is assumed.

Proposed factors for the relation between various cost definitions and retail price

Average vehicle cost and price

Based on the above proposed average breakdown the average translation factor between manufacturer costs (ex-factory costs) and retail price in Europe is 1 / 0.60 = 1.67. This factor should be used in relation to estimates of the ex-factory costs to manufacturers of manufacturing a complete vehicle.

Investment costs to society can be defined as retail price minus taxes in this case. It can be argued whether profits should or should not be a part of the societal costs. However, profits can to a large share be interpreted as mark-up for entrepreneurial risks (e.g. to cover losses in case of bankruptcy) and can thus be considered as real economical costs to be included in the investment cost calculation. In contrast to what was assumed in [IEEP 2004][48] dealer costs should be included in the investment costs as these are real economic costs of bringing the product to the user. Based on this reasoning and

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[48] *Service contract to carry out economic analysis and business impact assessment of CO_2 emissions reduction measures in the automotive sector*, contract nr. B4-3040/2003/366487/MAR/C2, carried out by IEEP, TNO and CAIR on behalf of DG-ENV, 2004.

the above table the investment costs (for use in the calculation of CO_2-abatement costs) of a complete vehicle are equal to 81% of the retail price and can be calculated from the manufacturer costs using a factor of (2% + 16% +3% + 60%) / 60% = 1.35.

Marginal cost and price increase for new technology

In this study we are dealing with the marginal, i.e. additional costs of applying CO_2-reducing technologies to a baseline vehicle. However, if a car becomes more expensive to build due to CO_2-saving technologies this does not mean that all costs in bringing the car to the consumer (dealer costs) increase with the same percentage. In principle e.g. transport and storage costs may be assumed to remain the same in absolute terms. Only capital costs and e.g. insurance costs during transport and storage and maybe some marketing costs are expected to increase. One can therefore assume that the dealer mark-up on the additional manufacturer costs is a smaller percentage than the average dealer mark-up in the average vehicle price breakdown.

Based on the first table the average dealer mark-up equals 27% of the manufacturer costs (both excl. profits). It is proposed to assume that for additional manufacturer costs related to CO_2-reduction the additional dealer costs are only 10% of the manufacturer costs. Including profit margins[49] this yields a factor of 1.16 between manufacturer costs and the additional retail price excluding taxes, which then also is the new definition to use for the additional investment costs to society. Including a 19% share of tax in the retail price (which is the sum of additional manufacturer costs and profits, additional dealer costs and profits, and tax), the factor between additional manufacturer costs and additional retail price becomes 1.44. This is also presented in the table below.

Relation between marginal manufacturer costs and marginal investment costs to society

add. manufacturer costs		1.00	
manufacturer profit / manuf. costs	0.05		
marginal dealer costs / manuf. costs	0.10		*assumed marginal value for additional technology*
dealer profit / manuf. costs	0.01		
add. retail price excl. tax		1.16	= *factor between retail price excl. tax a and additional manufacturer costs*
tax (19% of retail price)	0.27		
retail price incl. tax		1.44	= *factor between retail price incl. tax and additional manufacturer costs*

For the calculations presented in this report this means the following:

- Literature data on additional retail price should be translated into manufacturer costs using the factor 1.44, unless a different known factor is used by the source[50].
    - Obviously for various sources it is not known what definition they used so this introduces a level of uncertainty. However, as the manufacturer associations and various suppliers and supplier organisations have been asked to provide data on manufacturer costs, this uncertainty has a limited influence on the final cost assessment.
- For the calculation of CO_2-abatement costs the additional manufacturer costs of the option under consideration should be multiplied by a factor of 1.16.

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[49] One might argue that new technologies at their early stage of market introduction are sold without a profit or even with a loss, but the starting point of our assessment is that we analyse whether technologies are cost effective in the situation in which they are technically and economically mature. Whether that can be reached by 2012 for some of the options, is another issue and should be dealt with in the discussion on the time horizon for the policy measures.

[50] Various US sources appear to be using a factor of 1.4.

These factors would be applicable to the price and cost increase of an average vehicle in Europe. In practice the factor will depend on vehicle size and market segments (manufacturers earn more on large luxury vehicles) and may be different for different countries depending on national tax regimes.

Pass through of costs
For vehicles with new technologies which are in an early stage of market introduction obviously different factors may be valid for the pass-through of manufacturer costs to the retail price paid by the consumer. Important to note, however, is that the assessment in Task A does not intend to model the dynamics of market introduction of specific new technologies, but rather tries to asses what the costs of reaching a certain CO_2-emission reduction would be under the assumption that certain technologies are available and can be produced and marketed at sufficient scale in the 2008 – 2012 timeframe. The example of the Toyota Prius shows that the latter is certainly the case for hybrids. How the hurdles of market introduction of new technologies are to be overcome (e.g. by means of tax incentives) is to be discussed in a next phase of the stakeholder consultation in which the policy instruments are discussed that can be used to implement the options to selected on the basis of the assessments carried out in Task A and B.

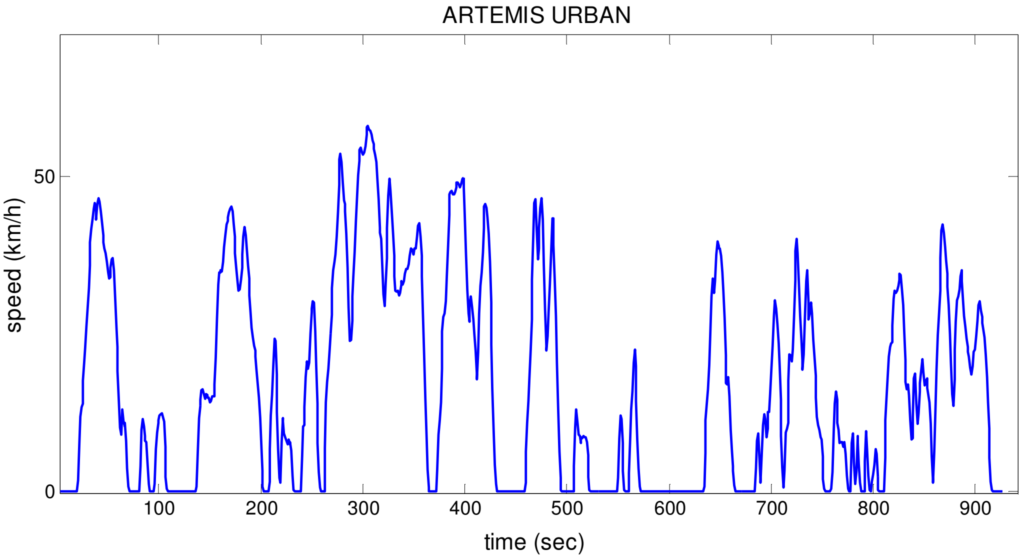
Conclusion

The factors proposed here differ significantly from the factor of 2 that was assumed in [IEEP 2004]. In hindsight that factor has been estimated incorrectly, even in relation to the reasoning applied in that study. Furthermore insights in this issue have evolved as a result of various discussions.

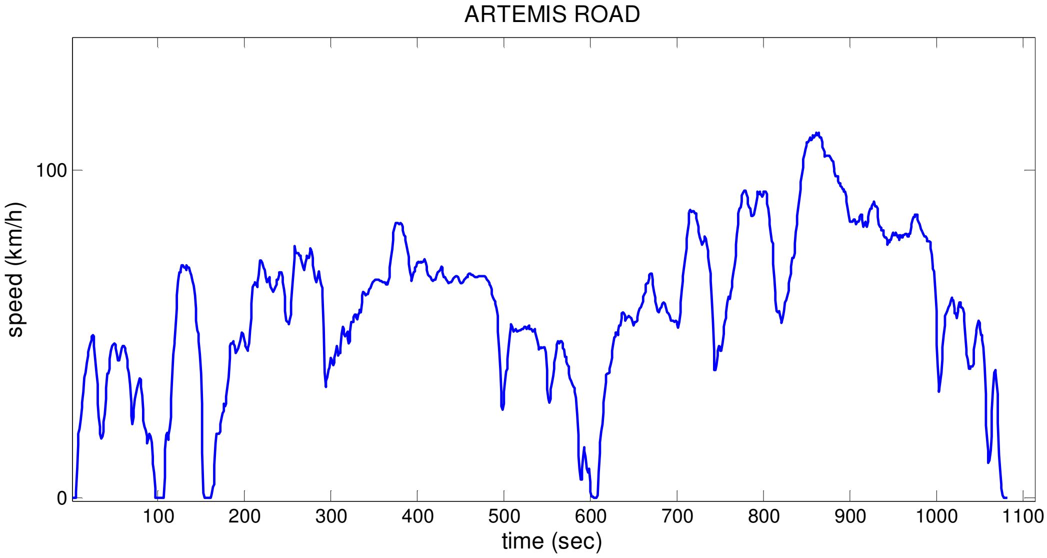
Annex B Real world driving compared to NEDC

In this short analysis, a comparison of the NEDC fuel consumption with that of a 'real world' test cycle is attempted. This comparison is based on data retrieved from the ARTEMIS database.

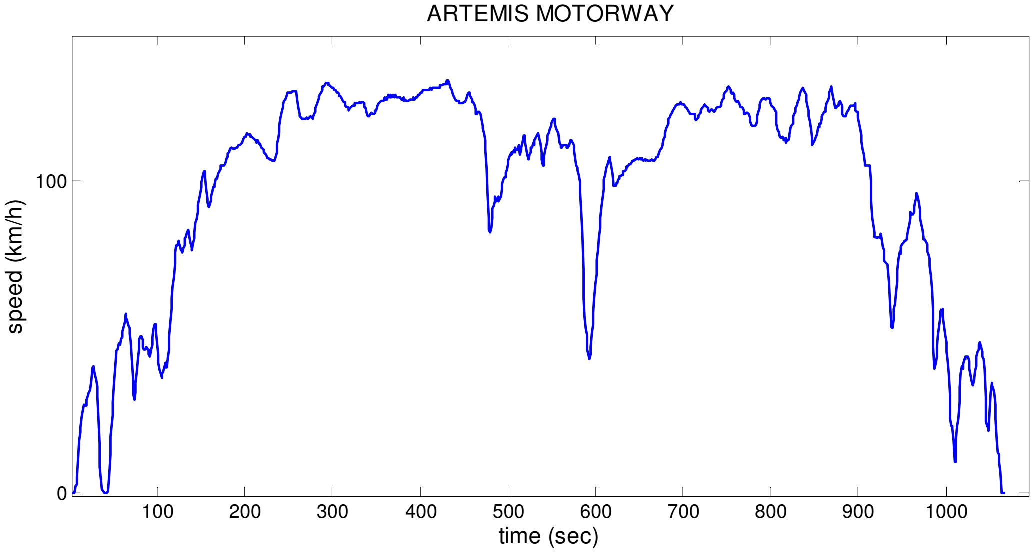
In the framework of the ARTEMIS project a large number of measurements on several different vehicle models was conducted both on legislated and real world cycles (ARTEMIS cycles). The database that was created provides an experimental basis for quantifying the difference between the type-approval driving cycles (NEDC and sub-cycles) and what would be a real world driving profile. The ARTEMIS cycles comprise 3 different parts that attempt to simulate different on road operating conditions, ARTEMIS urban cycle (URBAN) resembling urban driving conditions, a semi-urban cycle (ROAD) simulating the operation of the vehicle in a regular medium speed road, while the extra urban cycle (MOTORWAY) attempts to represent the operation in high speed freeway [ANDRE 2004]. The speed versus time profile of the aforementioned cycles is presented in the Figures below



ARTEMIS urban cycle

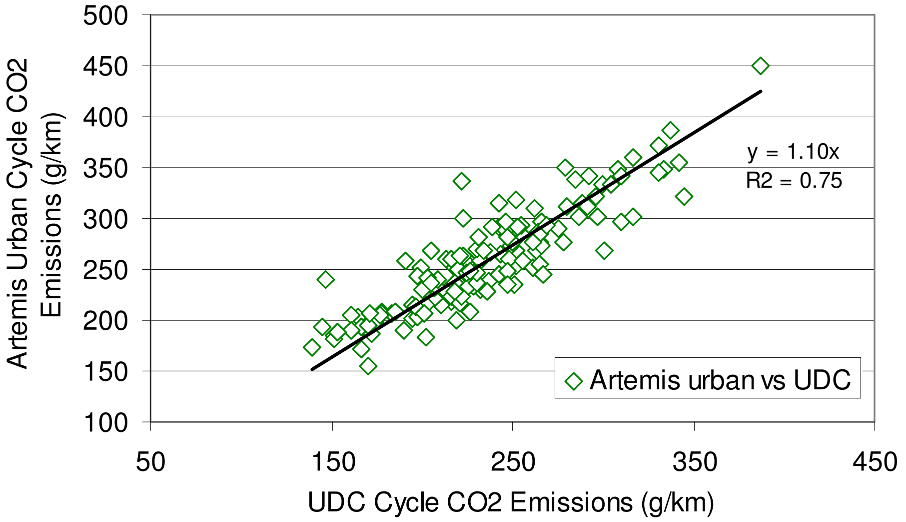


ARTEMIS semi -urban

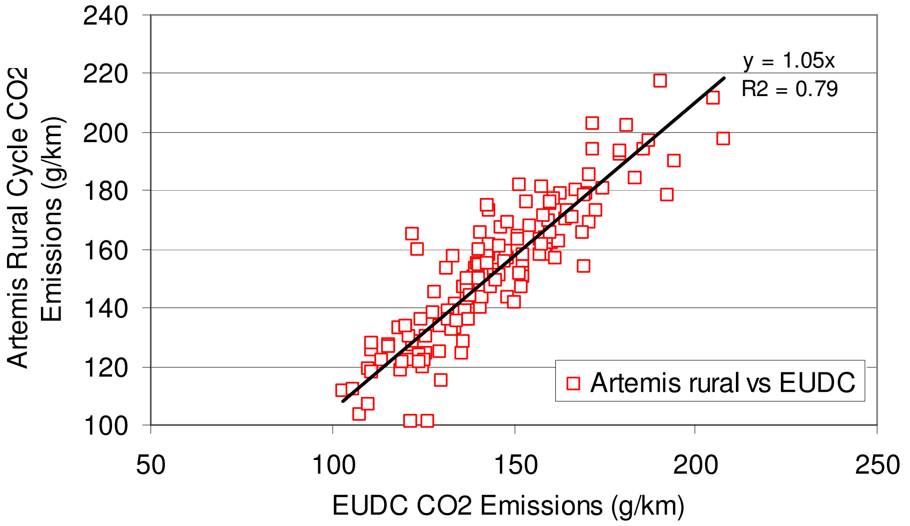


ARTEMIS extra urban cycle

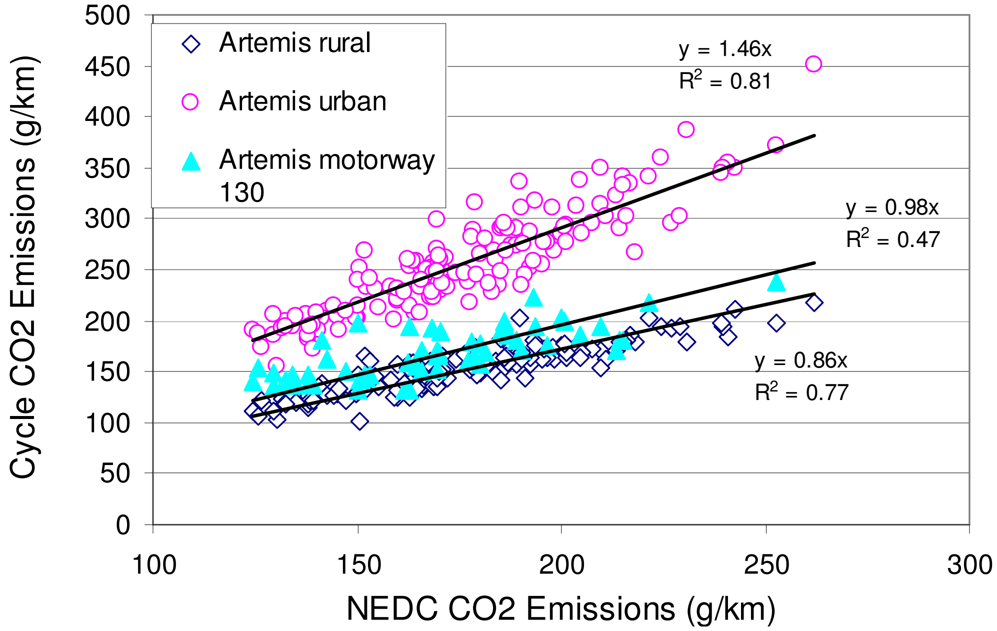
In order to obtain a better view of the difference between a more realistic driving pattern and the legislated driving cycles, the figures below are introduced. In the first two Figures the legislated sub-cycles (UDC and EUDC) are compared against the equivalent ARTEMIS sub cycles (Urban and Rural). The average speed differences between UDC - ARTEMIS Urban and EUDC - ARTEMIS Rural are small and therefore it can be assumed that the relation between the two pairs of cycles represents the relation between a more realistic operating pattern and type approval for the given driving conditions. The type approval test does not contain a highway driving cycle, therefore it is expected that no reliable relation between the NEDC (or its sub-cycles) and the ARTEMIS Motorway test can be produced. Nevertheless, in the third Figure all ARTEMIS cycles CO$_2$ emissions are compared with those of NEDC in order to investigate if a single correlation between the type approval data and a highway driving simulation cycle can be derived. It is important to say that the data presented in the following figures represent both diesel and gasoline vehicles and various emission standards.



UDC cycle emissions compared to the ARTEMIS Urban emissions



EUDC cycle emissions compared to the ARTEMIS Rural emissions



NEDC CO$_2$ emissions relation to the ARTEMIS cycles CO$_2$ emissions

As observed from the above graphs there is an acceptable correlation between NEDC and ARTEMIS sub cycles of similar average speed. In the case of urban driving the differentiation is about 10% whereas for rural conditions the difference between EUDC and ARTEMIS road is approximately 5%. o A commonly accepted percentage of difference between real world and type approval fuel consumption is about 10% [IEA 2005], [De CEUSTER 2005], with real world performance being always less efficient. Another important characteristic of this real world - test cycle shortfall is that it increases as percentage with increasing absolute fuel economy [IEA 2005].

In order to produce a single NEDC-real world factor the adoption of a certain average Urban, Rural, Highway driving composition in vehicle mileage is necessary. Based on data regarding the mileage allocation for Germany and France a weighted average of NEDC-real world CO$_2$ emissions was calculated based on the correlation factors presented above. The mileage distribution an the weighted average , which in both cases is 1,11 (Real world emissions = 1.11 x NEDC emissions), are summarised in the Table below.

Mileage allocation and Real world/NEDC CO_2 emissions ratio

	Urban Mileage	Rural Mileage	Highway Mileage	Real world/NEDC CO_2 emissions ratio (weighted average)
France	40%	50%	10%	1.11
Germany	37.20%	38.40%	24.40%	1.11

As regards real world and type approval CO_2 emissions gap it must be mentioned that even ARTEMIS cycles do not take into account all aspects of real world driving. Therefore even in the ARTEMIS protocol low temperature, differentiations of the vehicle weight, tyre deflation, driver style and other aspects are not taken into account. Therefore this 11% difference calculated here expresses only the difference between the speed vs. time profile of NEDC and more realistic cycles as the ARTEMIS cycles. It is an indicative value that can help to reduce the shortfall that is observed between the actual and the recorded CO_2 emissions and fuel consumption.

Other factors that affect the type approval real world shortfall and that should be considered are:

- Air-conditioning and accessories effect which differentiate throughout the year and geographically. A commonly accepted factor expressing the additional CO_2 emissions that occur from the use of these systems is 3%.
- Occupancy rate and weight increases. The type approval measurement takes under consideration solely the driver. However the average occupancy rate in EU is around 1.7 passengers per vehicle. Furthermore, apart from the extra passenger weight an additional weight increase occurs from accessories: tools, baby seats, chains, luggage etc. At this point an increase factor of 2% was considered based on previous LAT measurements.
- Tyre and road surface effect. Manufacturers are allowed to use different tyres in type approval than those sold with vehicle as mentioned. Additionally most vehicles run on under inflated tyres thus suffer higher rolling resistance. Finally the road quality and the driving conditions vary from those under which the type approval rolling resistance factor is estimated. Therefore based on the data gathered for the project and previous experience an increase factor of 3.5% is adopted to compensate for the rolling resistance differentiations.

As a result the increase factor accounting for real world phenomena to be used is the sum of the 1.11 factor between type approval and more realistic driving and those accounting for the additional phenomena presented above. The overall factor used for the performed analysis was 1.195 (Real world / NEDC emissions = 1.195).

As regards the overall real world and type approval CO_2 emissions gap, it must be mentioned that even ARTEMIS cycles do not take into account all aspects of real world driving. Therefore even in the ARTEMIS protocol low temperature, differentiations of the vehicle weight, tyre deflation, driver style and other aspects are not considered. Therefore this 7% difference presented here expresses only the difference between the speed vs. time profile of NEDC and more realistic cycles such as the ARTEMIS cycles. It is an indicative value that can help to reduce the shortfall that is observed between the actual and the recorded CO_2 emissions and fuel consumption. Concerning various technologies and their potential to reduce fuel consumption and CO_2 emissions it must be reminded that they can have completely different effect on the reported driving cycle and real world performance. The 2005 IEA report on technology for real improvements on the road 'Making Cars More Fuel Efficient' [IEA 2005] deals extensively with the issue of the type approval-real world shortfall.

Literature

[ANDRE 2004]	André, M. 2004. *The ARTEMIS European driving cycles for measuring car pollutant emissions*. Science of the Total Environment 334-335, 73-84
[De CEUSTER 2005]	De Ceuster Griet, Laurent Franckx, Bart Van Herbruggen, Steven Logghe, Bruno Van Zeebroeck, Stijn Tastenhoye, Stef Proost, Jasper Knockaert, Ian Williams, Gordon Deane, Angelo Martino, Davide Fiorello, 2005. *TREMOVE 2.30 Model and Baseline Description FINAL REPORT*, 2005, downloaded from www.tremove.org
[IEA 2005]	*Making cars more fuel efficient: Technology for Real Improvements on the Road,* International Energy Agency and European Conference of Ministers of Transport Joint Report, 2005

Annex C Relation between CO$_2$-emission and weight increase/decrease

	CO2 [g/km]	M [kg]	fc [l/100km]	ΔM [kg]	Δfc [l/100km]	ΔCO2 [g/km]	(ΔCO2/CO2)/(ΔM/M)	
small petrol	149	957	6.3	100	0.15	3.7	0.24	**ΔCO2 = 35*ΔM/M** Formula from IEEP-study [IEEP 2004]
medium petrol	184	1261	7.8	100	0.12	2.8	0.19	
large petrol	238	1500	10.0	100	0.10	2.3	0.15	
small diesel	123	1029	4.7	100	0.13	3.4	0.28	
medium diesel	153	1365	5.9	100	0.10	2.6	0.23	
large diesel	201	1690	7.7	100	0.08	2.1	0.17	
small petrol	149	957	6.3	100	0.23	5.4	**0.35**	**ΔCO2/CO2 = 0.35*ΔM/M** Formula derived from measurements by TNO and LAT on vehicles with additional weight (without adjustment of engine and powertrain to maintain performance).
medium petrol	184	1261	7.8	100	0.22	5.1	**0.35**	
large petrol	238	1500	10.0	100	0.23	5.5	**0.35**	
small diesel	123	1029	4.7	100	0.16	4.2	**0.35**	
medium diesel	153	1365	5.9	100	0.15	3.9	**0.35**	
large diesel	201	1690	7.7	100	0.16	4.2	**0.35**	
small petrol	149	957	6.3	100	**0.4**	9.5	0.61	**100 kg = 0.4 l/100 km for petrol** **100 kg = 0.3 l/100km for diesel** Formula from ACEA based on computer simulations of fuel consumption, assuming adjustment of engine and powertrain to maintain equal performance in response to weight increase or decrease.
medium petrol	184	1261	7.8	100	**0.4**	9.5	0.65	
large petrol	238	1500	10.0	100	**0.4**	9.5	0.60	
small diesel	123	1029	4.7	100	**0.3**	7.8	0.65	
medium diesel	153	1365	5.9	100	**0.3**	7.8	0.70	
large diesel	201	1690	7.7	100	**0.3**	7.8	0.66	
						average	***0.645***	
2003 petrol cars	184	1261	7.8	100	**0.57**	13.5	0.93	Based on **statistics of newly sold vehicles** in 2003. Relative factor is high because heavier vehicles generally have better performance (larger engines) than smaller vehicles and thus lower efficiency.
2003 diesel cars	153	1365	5.9	100	**0.40**	10.4	0.93	
energy at the wheels (average for various typical vehicles)						((ΔE/E)/(ΔM/M))	**0.62 - 0.69**	Effect of weight change on energy E required at the wheels, calculated for small/medium/large vehicles with typical values for mass and resistance factors on NEDC. Assuming that the (scaled) engine map remains roughly the same when the engine is scaled to adapt to the changed power requirement at the wheels, the powertrain efficiency can be assumed constant so that ΔCO2/CO2 ≈ ΔE/E.

Annex D Methodology for cost assessment

Introduction

In [IEEP 2004][51] a spreadsheet model has been developed to assess the costs of meeting a 2012 CO_2-target for passenger cars in Europe (EU-15) by means of different combinations of target definitions and implementation measures. The cost curves developed in section 3.8.1.1 are an important input for this model. This Annex is an excerpt from [IEEP 2004] and describes the principles and structure of the model and the way in which the different target-instrument combinations have been worked out.

The calculation model for overall cost assessment for reaching a 2012 target

In this section the overall methodology and structure of the model is explained. Details on definitions and the practical implementation of various modelling aspects and model assumptions are given in the section 4.3.

Overall structure of the model

The model is based on the following main inputs:

- 2002 sales numbers per manufacturer per market segment – based on Polk Marketing Systems data;
- Estimated sales numbers per manufacturer per segment for 2008 and 2012. These are calculated on the basis of the 2002 data, accounting for overall sales volume changes and a continued shift from petrol to diesel occurring in the periods 2002 – 2008 and 2008 - 2012;
- 2002 average CO_2-emissions per manufacturer per segment – based on Polk Marketing Systems data;
- Cost curves (describing costs as a function of CO_2-emission reduction (g/km)) per segment, with 2002 as base year – as described in Chapter 3 of this report.

The following market segments are discerned:

- petrol, small (p,S)
- petrol, medium (p,M)
- petrol, large (p,L)
- diesel, small (d,S)
- diesel, medium (d,M)
- diesel, large (d,L)

This division has been based on the segments given in the Polk Marketing Systems data, see the table below:

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[51] *Service contract to carry out economic analysis and business impact assessment of CO_2 emissions reduction measures in the automotive sector*, contract nr. B4-3040/2003/366487/MAR/C2, carried out by IEEP, TNO and CAIR on behalf of DG-ENV, 2004.

Market Segments: Small, medium and petrol vehicles

Segment as used/defined by Polk Marketing Systems		Segments for the purpose of our analysis		
Segment	Segment: Name	Small	Medium	Large
1	1 Mini	X		
2	2 Small	X		
3	3 Lower Medium		X	
4	4 Medium		X	
5	5 Upper Medium			X
6	6 Luxury			X
7	7 Sport			X
M	M MPV			X
F	F Off-Road			X
G	G Pick-Up			X
J	J Unspec.			X

The base year for the model is 2002. Before assessing the 2012-situation, first an estimate is made of the CO_2-emissions per manufacturer per segment in 2008. Subsequently for each combination of target definition and implementation measure an assessment is made of the additional costs for going from the 2008-situation to the 2012-situation in which an overall 120g/km goal is to be met. Costs, in this calculation, concern the additional vehicle costs to the manufacturer, related to implementing improved engine and power train technology and reducing mass and resistance factors. Combining the results on technology costs with the established CO_2-reductions, also allows calculation of the net costs to the consumer, accounting for fuel costs savings during the life of the vehicle. As explained in more detail further on, all costs in the model are expressed in Euros retail price.

Calculations have been done for the following 18 (= 3 + 3 + 3*4) options of target-instrument combinations:

- car-based targets:
  - fixed target per car
  - percentage reduction target per car
  - four different versions of utility-based targets per car
- manufacturer-based targets
  - fixed target per manufacturer
  - percentage reduction target per manufacturer
  - four different versions of utility-based targets per manufacturer
- manufacturer based targets with allowing trading of CO_2-credits
  - fixed target per manufacturer including the possibility of emission trading
  - percentage reduction target per manufacturer including the possibility of emission trading
  - four different versions of utility-based targets per manufacturer including the possibility of emission trading

The calculation method for assessing overall costs is dependent on the combination of target definition and policy instrument (implementation of a measure to achieve the target).

For the options with utility-based targets two different utility definitions have been explored as examples. For each utility factor two variants have been assessed, one with a fixed function describing the CO_2-emission limit as a function of vehicle utility and one with a CO_2-emission limit function which is optimised either to reach overall minimum costs or, in the case of emission trading, to minimise the trading volume. An introduction of the meaning of utility-based CO_2-limit functions is given further on in this Annex.

In the calculations four groups of manufacturers are distinguished – with analysis carried out at the level of 21 sub-groupings as follows:

- 9 ACEA members, incl. US-imports of cars from the same company
- 7 JAMA members
- 2 KAMA members
- Other, including independent European manufacturers (not member of ACEA) and all other imports, appropriately grouped to reflect company type but not corporate groups

It should be noted that the results of the cost assessment model should not be interpreted as predictions of the strategies that individual manufacturers will follow to achieve the 2012-target. Consequently the estimated costs per manufacturer are not predictions of the actual burden that different target-instrument combinations will pose on different manufacturers. Rather, the above definitions of manufacturers / manufacturer groups and the corresponding 2002 input data on sales numbers average CO_2-emission per vehicle per segment for the different manufacturers are used as an example and starting point to asses how some aspects of the different ways in which manufacturers are represented in the market influence the costs under various target-instrument combinations. Obviously the real strategies of manufacturers are determined by a multitude of factors. While the model always assesses least cost solutions, manufacturers may decide to apply different CO_2-reduction measures to vehicles in different segments, e.g. based on the possibility of creating added value or the possibilities in different segments to absorb additional costs.

Below the calculation methods for assessing the 2008-situation and for the 18 different options for 2012 are briefly described.

The 2008-situation

The 2002 CO_2-emissions per vehicle per segment show large differences between manufacturers. These differences are determined by factors such as:

- the position and sales numbers of the manufacturers different models within a segment;
- the mass, resistance factors, performance and other vehicle characteristics in relation to the parameter determining the position of the manufacturers different models within a segment;
- the type and status of the engine and other power train technologies applied;

As the factors underlying these differences can not be individually identified for the different manufacturers, these factors cannot be taken into account in determining the manufacturers' strategies to achieve the 2008/9 target.

It is assumed that ACEA will reach the 140g/km target in 2008 as set by their voluntary agreement with the EC. For calculating the reductions per car per segment, it is assumed that the 2008 goal will be reached in such a way that the total costs for the ACEA-members are minimal and that per segment all manufacturers realise the same reduction per car. This way the costs per car in a given segment are the same for all manufacturers, so that the burden is shared in a fair way. The reductions per car for each segment are found using a solver-function which minimises the total costs (costs for realising 140g/km in 2008, starting from the base year 2002) for the ACEA-"bubble" by varying the reductions per car for the six segments under the condition that the resulting average emission per car in 2008 is 140g/km. When this minimum is reached, the reductions per car per segment are such that the marginal costs are equal for all segments.

A similar approach is followed for JAMA and KAMA. These associations operate under a voluntary agreement to reach 140 g/km in 2009. In the spreadsheet the intermediate year is always labelled as 2008. The fact that for JAMA and KAMA the intermediate year is actually 2009 does not significantly influence the results.

The group “Other” manufacturers is not bound to a commitment. For these manufacturers separate estimates have to be made for their development towards 2008. For the moment for each manufacturer (or manufacturer group) a different 2008 average CO_2-emission value is assumed, which assumes some reduction compared to 2002, and the reductions per car per segment for each manufacturer are estimated by means of a solver that varies these reduction figures until a minimal total cost solution is found for the manufacturer.

2012: Fixed target / per car

Under this option each car has to meet a fixed 120g/km CO_2-emission limit. Reduction values per car per segment and manufacturer are calculated from the difference between the 2008-value and the 2012 target, in this case the fixed 120g/km value. Using the cost curves and the sales numbers per segment, this directly yields the costs per segment, per manufacturer, for the manufacturer groups, and the total costs.

In the present case, as well as for some other target-instrument combinations, reduction values per segment per manufacturer can be negative, when the 2008 value was already below the 2012 target, in this case 120g/km for each vehicle. For the calculations it is assumed that the manufacturer for which this is true will reverse some of the reductions reached between 2002 and 2008 in order to save costs. The model could be adapted to prevent this kind of “reverse engineering”, but for the purpose of this project it was considered more illustrative to make situations visible in which the targets allow a CO_2-increase per car.

Average marginal costs for this option are calculated by performing the calculation for a goal of 120g/km exactly and for a goal of $120 - \Delta_{CO2}$, with Δ_{CO2} a small extra reduction, and dividing the difference in overall cost by the difference in total CO_2-emissions.

2012: Percentage reduction target / per car

Under this option the average emission per car of each segment of each manufacturer has to be reduced by the same reduction percentage, which is the percentage with which the overall average emissions per car have to be reduced to reach the 2012 goal based on the 2008 average (in this case a reduction of 14.3% to go from 140.1g/km in 2008 to 120.0 in 2012). Reduction values per car per segment and manufacturer are calculated by multiplying the 2008-values with this reduction percentage. Using the cost curves and the sales numbers per segment, this directly yields the costs per segment, per manufacturer, for the manufacturer groups, and the total costs.

Average marginal costs for this option are calculated by performing the calculation for a goal of 120g/km exactly and for a goal of $120 - \Delta_{CO2}$, with Δ_{CO2} a small extra reduction, and dividing the difference in overall cost by the difference in total CO_2-emissions.

It should be noted that this target-instrument combination can of course not be implemented in practice. There is no way to objectively determine with which 2002 or 2008 model a car in 2008 resp. 2012 is to be compared to assess whether or not CO_2-emissions have been reduced by a given percentage.

2012: Utility-based targets / per car

The concept of utility-based CO_2-limit functions

The concept behind utility-based CO_2-limit functions is that it may make sense to allow cars to emit more CO_2 per kilometre driven if they have a higher functional transport performance or "utility". For practical implementation this utility parameter (here named U) can obviously not be a function of the actual transport performance of the car (e.g. how many persons or goods are being transported at a given time), but should rather be a function of static characteristics of the car which can be objectively measured or defined. These characteristics can be purely functional aspects related to the carrying capacity of the car (e.g. volume, number of chairs, maximum payload), but could also include less practical aspects related to the level of comfort or maybe even "fun of driving" with which a certain transport performance can be carried out (e.g. expressed by means of engine power or acceleration characteristics).

In general one strives for a definition of the utility parameter $U(x,y,z,\ldots)$ which provides a utility-based CO_2-limit function $E(U)$ that allows bigger or more powerful cars a higher CO_2-emission for as far as the larger size and performance is considered useful or functional. The latter, of course, can only be established in a subjective way and is thus not a technical but rather a political issue. The utility parameter can also be interpreted as a parameter that defines comparable vehicles. Vehicles with the same utility are considered comparable with respect to aspects included in the utility parameter, or more generally with respect to the perception of the user.

The starting point for determining useful utility-based limit functions is plotting the 2002 CO_2-emission values as a function of different utility parameter. A utility parameter should provide sufficient differentiation between vehicles, i.e. the spread of vehicles along the x-axis of a $CO_2(U)$-plot should be sufficiently large, while vehicles with the same value of U should be sufficiently comparable. In view of the first aspect it may be tempting to look for utility parameters that show a strong statistical correlation with the CO_2-emissions of existing vehicles. Such a strong correlation is generally found using parameters that are strong determinants of vehicle efficiency. These, however, are exactly the parameters that should not be used as utility parameters. Measures to reduce CO_2-emissions aimed at manufacturers should be market neutral as much as possible and should thus not promote the production of vehicles with smaller utility. Instead they should stimulate manufacturers to improve the efficiency of vehicles while maintaining their utility value. The room to manoeuvre for manufacturers is then found in technical measures that target the determinants of vehicle efficiency (power train efficiency, vehicle mass, resistance factors, etc.).

As examples in this study the following two utility parameters have been explored:

- $U = V^{2/3} * P^{1/3}$, with V the car's external volume ($l*w*h$) and P the engine power, thus providing a mix of carrying capacity and vehicle performance;
- $U = l*w$ (pan area), which is used in many national fuel consumption labelling schemes as the parameter defining categories of comparable vehicles.

For the purpose of this modelling exercise a CO_2-emission limit function can be defined as:

$$E(U) = a*U + b$$

with U the utility of the car. Given that in 2012 an overall average of 120 g/km is to be reached the parameter a can be written as a function of b, the average utility values for the different segments, and the total sales numbers per segment. The parameter b can be chosen on the basis of an analysis of historic data of vehicles' CO_2-emissions as a function U, or on other considerations e.g. related to how the utility-based limit function is supposed to function.

In the model, emission limits are calculated per vehicle class based on the 2002 average utility value for that class, as derived from the Polk Marketing Systems data. More details on the implementation of the different utility parameters and the utility-based CO_2-limit functions used in the different variants are presented in section 4.4.2.

Fixed utility-based CO_2-limit function / per car

Under the "Fixed utility- based CO_2-limit function / per car" option each car has to reach the emission limit valid for its class. Reduction values per car per segment and manufacturer are calculated from the difference between the 2008-value and the 2012 target, in this case the different utility-based limits for the different segments. Using the cost curves and the sales numbers per segment, this directly yields the costs per segment, per manufacturer, for the manufacturer groups, and the total costs. Also in this case reduction values per segment per manufacturer can be negative, when the 2008 value was already below the utility-based limit value. It is assumed that the manufacturer, for which this is true, will reverse some of the reductions reached between 2002 and 2008 in order to save costs.

Average marginal costs for this option are calculated by performing the calculation for a goal of 120g/km exactly and for a goal of $120 - \Delta_{CO2}$, with Δ_{CO2} a small extra reduction, and dividing the difference in overall cost by the difference in total CO_2-emissions.

Optimised utility-based CO_2-limit function / per car

This option is implemented in the same way as the above described option, with the exception that the parameter *b* of the utility-based emission limit function is optimised to yield the lowest overall costs.

2012: Fixed target / per manufacturer

Under this option each manufacturer has to meet a fixed 120g/km limit for the average CO_2-emission per car of its fleet of newly sold cars in 2012. It is assumed that each manufacturer tries to reach this goal at minimum costs. For each manufacturer separately, the reductions per car for each segment are found using a solver-function which minimises the total costs for the manufacturer by varying the reductions per car for the six segments under the condition that the resulting average emission per car in 2012 is 120g/km. When this minimum is reached, the reductions per car per segment are such that the marginal costs are equal for all segments.

Marginal costs are different for different manufacturers, depending on their 2008 situation and their distribution of sales over different segments. Overall marginal costs for this option are calculated by performing the complete calculation for all manufacturers for a goal of 120g/km exactly and for a goal of $120 - \Delta_{CO2}$, with Δ_{CO2} a small extra reduction, and dividing the difference in overall cost by the difference in total CO_2-emissions.

2012: Percentage reduction target / per manufacturer

Under this option each manufacturer has to reduce the average CO_2-emission per car of its fleet of newly sold cars by a reduction percentage, which is the percentage with which the overall average emissions per car (all manufacturers) have to be reduced to reach the 2012 goal based on the 2008 average (in this case a reduction of 14.3% to go from 140.1 g/km in 2008 to 120.0 in 2012). It is assumed that each manufacturer tries to reach this goal at minimum costs. For each manufacturer separately, the reductions per car for each segment are found using a solver-function which minimises the total costs for the manufacturer by varying the reductions per car for the six segments under the condition that the resulting average emission reduction per car in 2012 equals the above mentioned percentage. When this minimum is reached, the reductions per car per segment are such that the marginal costs are equal for all segments.

Marginal costs are different for different manufacturers, depending on their 2008 situation and their distribution of sales over different segments. Average marginal costs for this option are calculated by performing the calculation for a goal of 120g/km exactly and for a goal of 120 – Δ_{CO2}, with Δ_{CO2} a small extra reduction, and dividing the difference in overall cost by the difference in total CO_2-emissions.

2012: Utility-based target / per manufacturer

Fixed utility based CO_2-limit function / per manufacturer

Under this option for each manufacturer a target for the average CO_2-emission per car of its fleet of newly sold cars in 2012 is determined by multiplying the sales in the different segments with the utility based emission limit of the segments, summing these emissions per segment to a total emission of the manufacturer and dividing this by the total sales of the manufacturer. In this case the same utility-based emission limits are used as in the case when a "fixed utility based CO_2-limit function" is applied to each car.

Also in this case the following two utility parameters are explored:
- $U = V^{2/3} * P^{1/3}$, with V the car's external volume ($l*w*h$) and P the engine power, thus providing a mix of carrying capacity and vehicle performance;
- $U = l*w$ (pan area), which is used in many national fuel consumption labelling schemes as the parameter defining categories of comparable vehicles.

More details on the implementation of the different utility parameters and the utility-based CO_2-limit functions used in the different variants are presented in section 4.3.5.

It is assumed that each manufacturer tries to reach this goal at minimum costs. For each manufacturer separately, the reductions per car for each segment are found using a solver-function which minimises the total costs for the manufacturer by varying the reductions per car for the six segments under the condition that the resulting average emission per car in 2012 is equal to the goal calculated as described above. When this minimum is reached, the reductions per car per segment are such that the marginal costs are equal for all segments.

Marginal costs are different for different manufacturers, depending on their 2008 situation and their distribution of sales over different segments. Average marginal costs for this option are calculated by performing the calculation for a goal of 120g/km exactly and for a goal of 120 – Δ_{CO2}, with Δ_{CO2} a small extra reduction, and dividing the difference in overall cost by the difference in total CO_2-emissions.

Optimised utility based CO_2-limit function / per manufacturer

This option is largely the same as the above described option, with the exception that the utility-based emission limit function now is the same as in the "optimised utility based CO_2-limit function / per car" case. For that case the parameter b of the utility-based emission limit function is optimised to yield the lowest overall costs.

2012: Fixed target / per manufacturer including emission trading

Under this option each manufacturer has to meet a fixed 120 g/km limit for the average CO_2-emission per car of its fleet of newly sold cars in 2012, but is allowed to trade emission credits. This means that a manufacturer which does not meet the target can buy emission credits from manufacturers for which the sales averaged CO_2-emission is below the target. It is assumed that each manufacturer tries to reach this goal at minimum costs, where the total costs are the costs for reducing the emissions of the vehicles produced by the manufacturer plus the costs of buying emission credits or the revenues from selling credits. The option of banking is not taken into account.

It can be proven that for each manufacturer minimum costs are reached when the marginal costs of reductions in the different segments are all equal to the value/price of the traded emission credits. As the latter are assumed to be established in a transparent market, the price of emission credits is the same for all manufacturers. In the calculation therefore the marginal costs for all segments are set equal to the price of emission credits for each manufacturer. The CO_2-reduction values per segment can then be calculated using the inverse of the marginal cost curve (CO_2-reduction as a function of marginal costs). Subsequently, using the costs curves, the costs per segment are calculated for each manufacturer and these costs are summed to calculate total costs for the complete market. Using a solver these total costs are then minimised by varying the price of emission credits (= marginal emission reduction costs).

Besides total costs also the trading volumes per manufacturer are calculated.

2012: Percentage reduction target / per manufacturer including emission trading

Under this option each manufacturer has to reduce the average CO_2-emission per car of its fleet of newly sold cars by a fixed reduction percentage, but is allowed to trade emission credits is he does not meet this goal or achieves a higher reduction percentage. The reduction goal is the percentage with which the overall average emissions per car (all manufacturers) have to be reduced to reach the 2012 goal based on the 2008 average (in this case a reduction of 14.3% to go from 140.1 g/km in 2008 to 120.0 in 2012). Again it is assumed that each manufacturer tries to reach this goal at minimum costs, where the total costs are the costs for reducing the emissions of the vehicles produced by the manufacturer plus the costs of buying emission credits or the revenues from selling credits.

Calculations for this case follow largely the same procedure as for the case of a fixed target per manufacturer including the possibility of emission trading. The only difference is that the target per manufacturer is determined at the level of the sales averaged CO_2-emissions instead of by sales-weighted averaging of the targets per segment.

2012: Utility-based target / per manufacturer including emission trading

Fixed utility based CO_2-limit function / per manufacturer including trading

Under this option for each manufacturer a target for the total CO_2-emission of its fleet of newly sold cars in 2012 is determined by multiplying the sales in the different segments with the utility based emission limit of the segments, and summing these emissions per segment to a total emission of the manufacturer. In this case the same utility-based emission limits are used as in the case when a “fixed utility based CO_2-limit function” is applied to each car.

It is again assumed that each manufacturer will adopt a rational strategy by which he will reduce emissions for the different segments until the marginal costs for the different segments are equal to the price of traded emission credits. Calculations for this case then follow the same procedure as for the case of a fixed target per manufacturer including the possibility of emission trading.

Optimised utility based CO_2-limit function / per manufacturer including trading

This option is largely the same as the above described option, with the exception that the utility-based emission limit function now optimised to achieve a minimal volume of traded emission credits. It is found in the calculations that the total costs are not influenced by the exact choice of the utility-based emission limit function, provided that this function is defined in such a way that the overall 2012 target is reached when these utility-based limits per segment are combined with the total sales volumes per segment.

For this case therefore first the same calculation is performed as for the fixed utility-based CO_2-limit function, after which a solver is applied to minimise the total trading volume by varying the parameter b of the utility-based CO_2-limit function.

Determination of utility-based CO_2-limit functions

As stated above, in this study the application of utility-based CO_2-limit functions is assessed for two different utility parameters:

- $U = V^{2/3} * P^{1/3}$, with V the car's external volume ($l*w*h$) and P the engine power, thus providing a mix of carrying capacity and vehicle performance;
- $U = l*w$ (pan area), which is used in many national fuel consumption labelling schemes as the parameter defining categories of comparable vehicles.

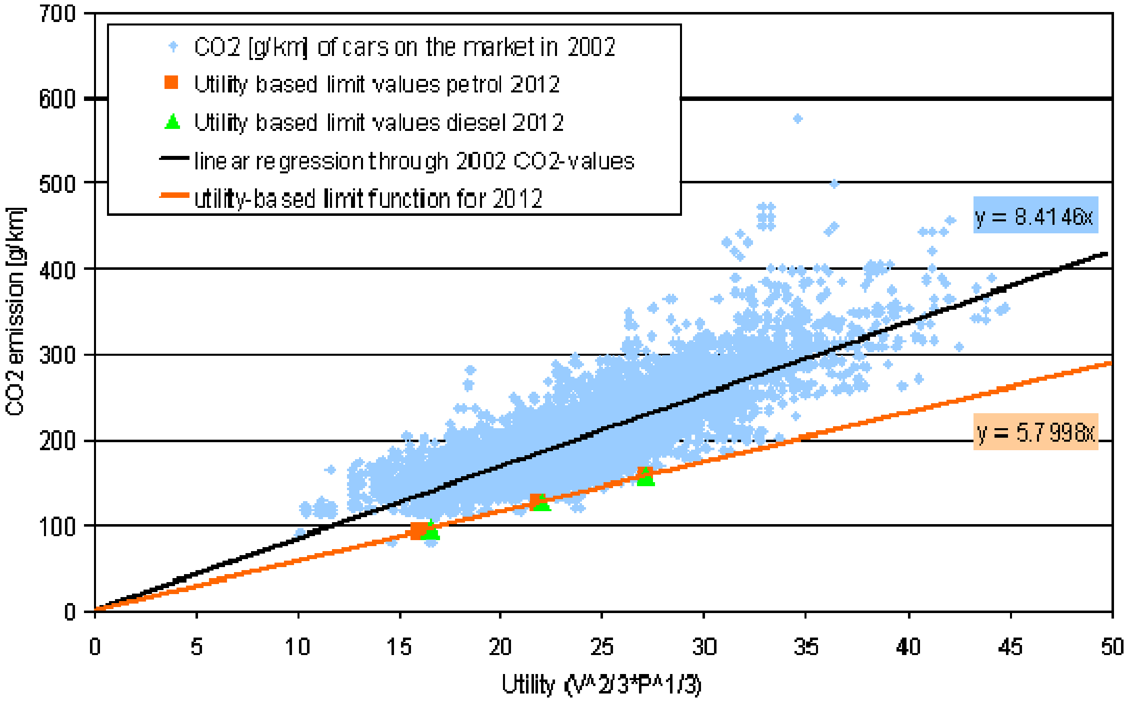
Based on the average value of the utility parameter per segment (derived from the 2002 Polk Marketing Systems data) CO_2-limit values per segment are calculated for this study using the linear relation:

$$E(U) = a*U + b$$

Given that in 2012 an overall average of 120 g/km is to be reached the parameter a can be written as a function of b, the average utility values for the different segments, and the total sales numbers per segment. The parameter b can be chosen on the basis of an analysis of historic data of vehicles' CO_2-emissions as a function of U, or on other considerations e.g. related to how the utility-based limit function is supposed to function. For the two utility parameters this analysis is presented in the figures below.

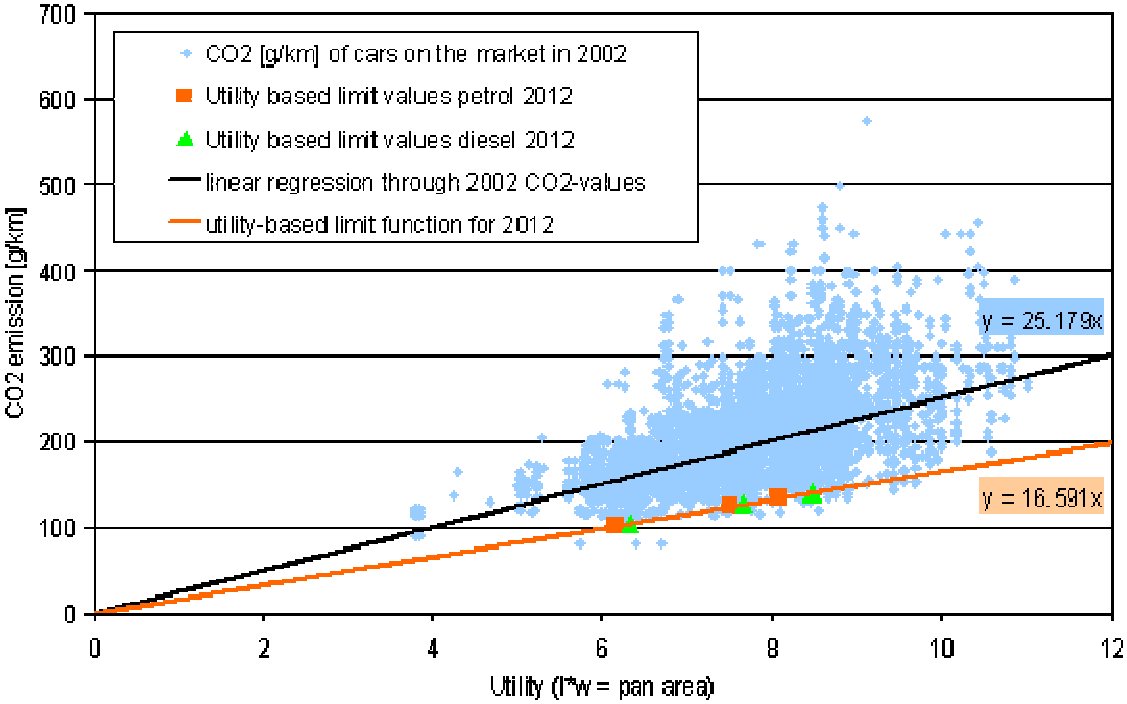
For both utility parameters the least square fit through the data points is found to have an intercept with the y-axis which is close to zero. In the above figures, therefore, trend lines are shown for which the intercept has been set to zero. Fixed limit functions for 2012 can now be derived by tilting the line (i.e. reducing parameter a) to such an extent that the sales-weighted average of the CO_2-limit values for the different segments equals the 120 g/km target.

*CO$_2$-emissions as a function of V$^{2/3}$*P$^{1/3}$ for vehicle models sold in 2002*



Source: based on Polk Marketing Systems data

*CO$_2$-emissions as a function of pan area (l*w) for vehicle models sold in 2002*



Source: based on Polk Marketing Systems data

Based on the analysis presented in the figures above the value for parameter *b* has been set to 0 for the scenarios with so-called fixed utility-based limit functions. As explained above the parameter b could also be chosen differently in order to change the way in which the utility-based limit function affects the different targets. As explained above, the parameter *a* can be written as a function of *b*, the target for the sales average CO_2 emissions (in this case a value between 140 and 120 g/km), the average utility values for the different segments, and the total sales numbers per segment. A different choice of the value for *b* thus also involves a different value for the parameter *a*. A positive value for *b* leads to a reduced slope of the CO_2 limit function, while a negative value leads to an increased slope.

Choosing a non-zero for the parameter *b* can be done e.g. to make sure that the targets are relatively more stringent for larger cars. In that case the additional costs will be relatively higher for larger cars which may help to reduce the autonomous market trend towards larger vehicles which tends to counteract measures aimed at overall CO_2 reduction. Such a choice, however, is to a large extent a political one. In this report we have explored the effects of changing the value of the parameter b for two other purposes:

- In the two "per car" scenarios we have used a solver function to optimise the value of b to yield the lowest overall costs to the manufacturer while reaching the 2012 target. The "per manufacturer" scenarios already involve cost minimisation algorithms applied per manufacturer so that a separate optimisation of b to minimise overall costs can not be performed without very time consuming iterations. For the "optimised" versions of the "per manufacturer" scenarios we have therefore used the values of *a* and *b* of the corresponding "optimised" versions of the "per car" scenarios.
- For the optimised limit functions in the scenarios with trading the parameter *b* has been optimised to yield the minimum overall volume of emission credits trading. All scenarios with trading reach the same minimum overall cost solution regardless of the target definition. Changing the value of parameter *b* in case of utility-based limit functions therefore does not influence the technologies to be applied by the different manufacturers in the different segments, but does influence the CO_2 surpluses or deficits per manufacturer per segment and consequently the need for emission trading between manufacturers.

Annex E TREMOVE output concerning fuel efficient air conditioning systems

Tremove basecase : Additional fuel consumption due to airco use in l/100km; mix (R134a FDC, R134a VDC, R744)

		Small gasoline	Medium gasoline	Big gasoline	Small diesel	Medium diesel	Big diesel	Small CNG	Medium CNG	Big CNG
DK,FI,IE,NO,UK,SE	2008	0.22	0.22	0.22	0.16	0.16	0.16	0.18	0.18	0.18
	2009	0.21	0.21	0.21	0.16	0.16	0.16	0.17	0.17	0.17
	2010	0.20	0.20	0.20	0.15	0.15	0.15	0.17	0.17	0.17
	2011	0.19	0.19	0.19	0.14	0.14	0.14	0.16	0.16	0.16
	2012	0.16	0.16	0.16	0.12	0.12	0.12	0.13	0.13	0.13
AT,BE,CZ,DE,CH,FI	2008	0.30	0.30	0.30	0.22	0.22	0.22	0.24	0.24	0.24
	2009	0.29	0.29	0.29	0.21	0.21	0.21	0.24	0.24	0.24
	2010	0.27	0.27	0.27	0.20	0.20	0.20	0.22	0.22	0.22
	2011	0.26	0.26	0.26	0.19	0.19	0.19	0.21	0.21	0.21
	2012	0.22	0.22	0.22	0.16	0.16	0.16	0.18	0.18	0.18
ES,GR,IT,PT,SI	2008	0.47	0.47	0.47	0.34	0.34	0.34	0.38	0.38	0.38
	2009	0.46	0.46	0.46	0.33	0.33	0.33	0.37	0.37	0.37
	2010	0.43	0.43	0.43	0.32	0.32	0.32	0.35	0.35	0.35
	2011	0.41	0.41	0.41	0.30	0.30	0.30	0.33	0.33	0.33
	2012	0.35	0.35	0.35	0.25	0.25	0.25	0.28	0.28	0.28

Tremove additional policy scenario **: Additional fuel consumption due to airco use in l/100km; mix (R134a FDC, R134a VDC, R134a improved, R744 and R744 improved)**

		Small gasoline	Medium gasoline	Big gasoline	Small diesel	Medium diesel	Big diesel	Small CNG	Medium CNG	Big CNG
DK,FI,IE,NO,UK,SE	2008	0.22	0.22	0.22	0.16	0.16	0.16	0.18	0.18	0.18
	2009	0.20	0.20	0.20	0.14	0.14	0.14	0.16	0.16	0.16
	2010	0.17	0.17	0.17	0.12	0.12	0.12	0.14	0.14	0.14
	2011	0.15	0.15	0.15	0.11	0.11	0.11	0.12	0.12	0.12
	2012	0.14	0.14	0.14	0.11	0.11	0.11	0.12	0.12	0.12
AT,BE,CZ,DE,CH,F	2008	0.30	0.30	0.30	0.22	0.22	0.22	0.24	0.24	0.24
	2009	0.26	0.26	0.26	0.19	0.19	0.19	0.22	0.22	0.22
	2010	0.23	0.23	0.23	0.17	0.17	0.17	0.19	0.19	0.19
	2011	0.20	0.20	0.20	0.15	0.15	0.15	0.17	0.17	0.17
	2012	0.20	0.20	0.20	0.14	0.14	0.14	0.16	0.16	0.16
ES,GR,IT,PT,SI	2008	0.47	0.47	0.47	0.34	0.34	0.34	0.38	0.38	0.38
	2009	0.42	0.42	0.42	0.31	0.31	0.31	0.34	0.34	0.34
	2010	0.36	0.36	0.36	0.26	0.26	0.26	0.30	0.30	0.30
	2011	0.32	0.32	0.32	0.23	0.23	0.23	0.26	0.26	0.26
	2012	0.31	0.31	0.31	0.22	0.22	0.22	0.25	0.25	0.25

Retail price (ex-tax) difference between fuel efficient and conventional ***In EURO 2000 purchase power***

	Small gasoline	Medium gasoline	Big gasoline	Small diesel	Medium diesel	Big diesel	Small CNG	Medium CNG	Big CNG
2008	0	0	0	0	0	0	0	0	0
2009	15	15	15	15	15	15	15	15	15
2010	33	33	33	33	33	33	33	33	33
2011	42	42	42	42	42	42	42	42	42
2012	19	19	19	19	19	19	19	19	19

Annex F Effect of deflated tyres on fuel consumption

Two sets of coast down measurements were conducted by LAT according to the legislated procedure, both with good repeatability:

- Base measurement was conducted with default (manufacturer) tyre pressure
- Deflated measurement was conducted with default-0.5bar tyre pressure

An important assumption that was made was that the effect of the tyre deflation/inflation on the vehicle speedometer for these pressure differentiations is negligible. (It is estimated to be about 1.5% of the vehicle speed which for low speeds (<60km/h) results in a differentiation of less than 0.9km/h)

Base and deflated coast down times comparison:

Speed km/h	Coast Down Times Base Corrected	Coast Down Times Deflated Corrected	Difference 1-Deflated/Base
120	6.24	5.97	4.6%
110	6.95	6.65	4.5%
100	7.82	7.36	6.3%
90	8.88	8.32	6.8%
80	10.14	9.30	9.0%
70	11.86	10.85	9.3%
60	14.24	12.62	12.9%
50	15.75	14.45	9.0%
40	17.49	16.13	8.4%
30	18.93	17.69	7.0%
20	19.94	19.16	4.1%

Driving resistances as a function of vehicle speed:

Driving resistance function and equivalent vehicle characteristics derived from coast down times [Res(u)= au^2+c in Nt]

	a	c	R^2	RMSE	Equivalent Cw	friction factor
Measured base	0.467	197.6	0.998	8.871	0.31	0.0124
Measured deflated	0.481	219.6	0.997	9.834	0.32	0.0138

A 0.5bar deflation of the tires has caused a 10% increase of the tire friction factor. A first run in advisor indicated that such an increase results in a 2.5% increase of the fuel consumption over NEDC. Such differentiations were expected.

Annex G Summary of the IEA Workshop on energy efficient tyres

Energy Efficient Tyres: Improving the On-Road Performance of Motor Vehicles

Paris, 15 – 16 November 2005

Prepared by Alan Meier[52], Matt Oravetz, Thomas Guéret

Background

Almost 20% of a car's fuel consumption is used to overcome rolling resistance in the tyres. Manufacturers have already achieved significant reductions in rolling resistance but, with today's high fuel prices, it makes sense to carefully examine the feasibility of further improvements.

The Workshop

Over 50 people met for two days to explore the relationship between a tyre's rolling resistance and a motor vehicle's fuel consumption. The participants included experts in tyres, materials and roads, government officials, representatives of major tyre manufacturers, NGOs and other interested groups. The discussions covered procedures to measure rolling resistance, ways in which rolling resistance could be reduced, and strategies to encourage greater use of fuel-efficient tyres. A final session focused on energy consumption of components not captured in the regulated fuel measurement tests and the impact of aftermarket products on fuel economy.

The workshop format consisted of invited presentations, each followed by a discussion. This format resulted in an unusually high degree of participation; most people intervened several times, often providing different perspectives and insights. The workshop was also unique in that the results of several new studies were released, thus greatly increasing the amount of publicly available data on low rolling resistance tyres. One study alone appeared to be larger--both in number of tyres and geographic coverage--than all previous studies and to contain better normalized data. The presentation of these new studies contributed to a focus on technical issues.

Materials and data from the workshop, in addition to links to other relevant information, are available at the International Energy Agency's Website: www.iea.org [53]

General Sense of the Group

This workshop was designed to be an exchange of ideas rather than to agree on specific findings or recommendations. Furthermore, several key groups and experts were absent so it would be inappropriate to propose definitive recommendations. Nevertheless, the IEA Secretariat observed that a general sense of this group did emerge on many issues. These include:

- Several methods of measuring rolling resistance exist and are necessary to meet different needs, such as for producing a relative ranking of competitive tyre products or predicting actual on-road performance. However, an internationally harmonized test method suitable for rating purposes is within grasp. A single method is attractive to tyre and car manufacturers, regulatory agencies and consumers.

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[53] Exact address is http://www.iea.org/Textbase/work/workshopdetail.asp?WS_ID=227

- Some manufacturers supported establishing mandatory efficiency levels (that is, maximum rolling resistance) for tyres. A mandatory programme would create a level playing field for all manufacturers.
- Manufacturers should not be forced to create fuel-efficient tyres by sacrificing safety or other performance characteristics, such as durability, wet-grip and noise. Previous multivariate analyses of data for existing tyres suggested that a weak trade-off existed between low rolling resistance and lower performance in these features. However, new, more consistent, data presented at this workshop demonstrated that this correlation no longer exists and that there were numerous tyres with very low rolling resistance and excellent performance in all other characteristics. Further analysis of data sets (such as those presented at this workshop) would be useful but is not necessary before moving forward.
- Tyres with low rolling resistance typically are more technically advanced and may cost more to produce; nevertheless, the consumer almost always quickly recovers the price differential through reduced fuel costs. A trade-off between tyre energy efficiency and other features may exist for a given technology but, over time, new technologies will allow simultaneous improvements in tyre efficiency and other key performance features and will reduce the price differential.
- A properly inflated tyre is the second feature of a fuel-efficient tyre. This aspect was acknowledged and quantified in the workshop. Proper inflation can be addressed through consumer programmes and currently available technologies to automatically sense low pressure and even self-inflate tyres. The United States recently enacted regulations to require low pressure sensing. In Europe, however, no regulations exist.
- Tyre noise, though not necessarily linked to fuel efficiency, deserves greater scrutiny when considering new tyre designs, technologies and policies. The design or selection of road surfaces offers a second path to reduced rolling resistance but its benefits are not yet fully appreciated.
- A “regulatory failure” exists for fuel-efficient tyres. The responsibility for tyres is dispersed among so many agencies and ministries in most governments that it is difficult to establish effective policies.
- Savings from low rolling resistance tyres may justify a procurement specification by government agencies. Government procurement specifications can have an enormous impact on the market because the government is typically the largest customer in a country. Furthermore, the impact may be amplified because the national specifications are often adopted by local governments.
- The energy consumption of specific components not captured in the vehicle test procedure (such as air conditioning and lighting) and products sold in the aftermarket (such as lubricants, luggage racks and tyre pressure monitoring systems) have an important and generally ignored impact on a vehicle’s fuel efficiency. For example, operating a vehicle’s air conditioner often increases fuel consumption 20% and lights raise total fuel consumption about 3%. Many opportunities to save energy exist; proper inflation of tyres, use of better lubricants and installation of more efficient air conditioners were among those described. Improvements to these individual components have savings potentials comparable to low rolling resistance tyres. These technologies are unlikely to be exploited because manufacturers have little incentive and consumers are unable to make informed investment decisions.

Developments

The presentation of new data, along with frank exchanges of views, led to numerous perspectives on the present situation and future of fuel-efficient tyres. The Secretariat noted the following developments:

- Data presented in the workshop showed two separate tyre markets, those tyres supplied with new vehicles (Original Equipment -- OE) and replacement tyres. This difference in rolling resistance between the two markets is greatest in North America, where auto manufacturers rely on low rolling resistance tyres to achieve mandatory vehicle efficiency limits. Additionally, the North American market favours long-life replacement tyres, which typically have higher rolling resistances than found in OE tyres. The European market is different; OE tyres are more available in the replacement market.

- European regulations only specify that the tyres used in the CO_2 emission test should be one of the types the auto manufacturer specifies as OE. This is a gap in the European Voluntary Agreement and could result in up to a 4% discrepancy between reported and actual fuel economy.
- Several different labelling schemes for tyres were proposed, explored and demonstrated to be technically feasible. A labelling scheme is attractive because it addresses the market failure arising from lack of information to the consumer. Manufacturers noted that individual efforts to label rolling resistance had been ineffective, perhaps because consumers preferred a third-party labelling system or perhaps because consumers considered fuel efficiency a low priority. For maximum effect, a label needs to take into account other features of the tyres and be linked to new or existing regulations.
- California will soon require tyre manufacturers to report rolling resistances of replacement tyres sold in that state. Based on a review of these and other data, California may establish minimum efficiencies for replacement tyres. Other states in the United States are likely to follow California's example. The European Union and Canada are also investigating policy options.
- A U.S. specification for federal acquisition of tyres would likely include requirements for low rolling resistance along with safety and durability criteria. The Federal Energy Management Program (inside the U.S. Department of Energy) plans to work with the General Services Administration and the Defense Logistics Agency -- the U.S. Federal government's two major supply agencies -- to evaluate current specifications and consider new ones. FEMP would like to develop and issue a specification in 2006 after reviewing and analyzing currently available data, as well as data collected as a part of California's current tyre testing and analysis.

Next Steps

The IEA will continue to collect information and welcomes further discussions. In the next few months, the IEA will make recommendations to the G8 countries regarding specific policies, including fuel-efficient tyres and other components, to encourage energy savings, taking into account the unique conditions found in each country.

Annex H Mathematical models of rolling resistance

Several different mathematical models are mentioned in relevant bibliography [Gillespie 1992], for quantifying rolling friction and thus the rolling resistance affecting the vehicle. However, the simplest and most common approach is to express rolling resistance as a function of the total vehicle weight and a dimensionless factor called rolling resistance coefficient f_r. The f_r factor expresses the effects of the complicated and interdependent physical properties of tyre and ground.

$$Fr = f_r \text{ x } W$$

Fr: Rolling resistance
f_r : Rolling resistance coefficient
W : Vehicle weight (mass x gravity)

The approach presented above results in rolling resistances that are independent from the vehicle speed and constant throughout the vehicle movement –provided that tyres, ground and vehicle mass do not change significantly. Nevertheless experiments in real vehicles have shown that rolling resistance is affected by the vehicle speed especially in the case of higher velocities. The structural deformation of the tyre that causes rolling resistance is related to the rotational speed of the tyre and consequently to the vehicle speed. In order to deal with this characteristic a second model is introduced particularly when a more accurate correlation between rolling resistance and vehicle fuel consumption is aimed. In this case rolling resistance coefficient is expressed as a linear function of vehicle speed. This results in the following formula:

$$Fr\ (V) = f_r\ (V) \text{ x } W$$

With f_r being equal to:

$$f_r = f_0 + f_s \text{ x } V$$

f_r: rolling resistance coefficient
f_0: Basic coefficient
f_s: Speed effect coefficient
V: vehicle speed

It is clear that this second model is a generalized expression of the first. It is mostly important when analyzing higher velocities (above 80km/h) where the effect of vehicle speed on the tyre rolling resistance is greater [Gillespie 1992]. At this point it must be noted that the two models are closely linked with the coast down curve, currently used for setting up the chassis dynamometer in the type approval test. When a manufacturer uses a measured vehicle coast down curve for the type approval test, he automatically adopts the second generalised model. Legislation however provides the possibility to use predefined rolling resistance values that simulate vehicle rolling resistances.

Annex I Summary of Member State Responses to the Questionnaire in relation to biofuels since the 2005 Member State reports on the implementation of Directive 2003/30/EC

Country	Action	Stage of development
France	Biofuel production programme updated with a new target set at 7% in 2010 and 10% in 2012. Lower tax exemption due to rising oil prices for biodiesel, ETBE and bioethanol	Implemented
Germany	New government has announced plans for a new biofuels mandate	Under discussion
Ireland	Measures in addition to the mineral oil tax relief scheme	Being considered
Latvia	Incorporate into the Biofuels Law a norm to allow seed oil as a type of biofuel	Ministry of Agriculture submitted a letter to the Committee of the national economy
Portugal	Total exemption of taxes is being modulated to prevent over compensation due to differences in production costs between fossil and biofuels. Implementation of a quota regulation higher than 1% expected for 2006.	Government proposal for a regulation
Slovakia	National programme of promotion of biofuels and amendment to law on mineral oils (possible tax exemption for biofuels)	National programme under consultation, amendment to law will occur after its introduction
Sweden	Investigation of green certification for biofuels to replace tax exemptions	Not earlier than 2008
Netherlands	Proposal for €70million in tax exemptions in 2006. 2007 introduction of a 2% biofuels obligation for fuel companies. Innovation programme for next generation biofuels – subsidy of €60million over 5 years	2006 proposals to be debated in Parliament
UK	Renewable Transport Fuels Obligation requiring fuel suppliers to ensure a minimum percentage of fuel is biofuel.	Announced in 2005; levels and buyout prices for 2008 to 2010 announced.

Annex J Evaluation of policy measures for N_1-vehicles from [TNO 2004]

In [TNO 2004][54] a range of policy measures has been identified for promoting the reduction of CO_2-emissions from N_1-vehicles. In chapter 6 of that report these policy measures are evaluated in relation to a number of criteria in order to assess the feasibility for application of each to N_1 vehicles. The criteria were based on an internal brainstorm and knowledge of the application of such instruments for similar purposes. The results of this evaluation are presented in Table 6.3 of that report and are copied in the Table below. The principal conclusions to be drawn from this Table are:

- The highest evaluation scores apply to monitoring, labelling, voluntary agreements and subsidies for new vehicles.
- Technical standards score much better for N1s than M1s, as a result of their relatively limited impact on the market and consumer choice. They could in the end prove the simplest choice. Further investigation is needed, however, to assess carefully the feasibility of class-based standards, and/or the value of the shortlisted utility parameter options.
- Taxes on fuel and purchases/registrations receive marginally positive scores as they could be effective, are practical to introduce and need few additional data requirements, but suffer from their political unacceptability to be used as a mechanism for reducing CO2-emissions, especially at EU level.
- Bubble concepts and emissions trading also receive a marginally positive scores, as they are potentially effective in terms of emissions reductions, as well as being cost-effective, but suffer from high data requirements and the need to develop more sophisticated monitoring systems and would therefore require time to bring into action.
- Public procurement also scored marginally positively, as potentially a significant impact on the vehicle parcs concerned, but suffers as only a small proportion of the total new vehicle fleet would be covered. Could be useful in stimulating early demand for innovative technologies, however.
- Vehicle conversions, scrappage incentives and circulation taxes were considered to be relatively inconsequential instruments when it comes to CO_2 reduction from new vehicles.

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[54] *Study contract on measuring and preparing reduction measures for CO_2 emissions from N_1 vehicles*, study for DG Environment carried out by TNO, IEEP and LAT/AUTh, 2004.

Instruments characterisation against different criteria

Type of Instrument	N1 possible application	Utility parameter needed	Performance against criteria – quantitative and qualitative. Quantitative: from –3 to +3; 0: no effect, +3 very good								Summary (not an average)
			Effectiveness - potential CO$_2$ reduction	Cost and efficiency	Impact on market	Impact on technological development	Impact on consumer choice	Data requirements	Practicality	Political acceptability	
Technology Standards	EU: CO$_2$-emissions for each class	N1 class may be adequate, or full utility function	+3: if set at a demanding level	-3: as no flexibility	-1: some might lose - either off the market or fined	+2: significant for some, but static for those that met the requirement	-1; some vehicles possibly off the market at least in the short term	+2: low requirements, but need emissions test data to set the standards	+3: easy linked to certificates of conformity	-1: as some costs and market impacts	+1: good on balance if suitable utility function agreed
Bubble concepts – averaging	EU: For each mfr.	N1 class may be adequate, or full utility function	+3: if set at a demanding level	-2: reduces costs	-2: still winners and losers	+2: impact where gains are easiest	-1: should be limited impact	+1: need fleet performance data for each mfr	+1: relatively straightforward	-1: effective, and impacts reduced	+2: limited risk
VA	EU: For each mfr or association	N1 class may be adequate, or full utility function	+3: if set at a demanding level, and effectively enforced	-1: should reduce costs further	-1: esp at assoc level, low market effects	+2: would stimulate cost-effective measures	-1: should be limited impact	+1: need fleet performance data for each mfr	+2: easy, but monitoring needed	+2: relatively acceptable	+2: in place for M1, but possible limit to effectiveness

Type of Instrument	N1 possible application	Utility parameter needed	Performance against criteria – quantitative and qualitative. Quantitative: from –3 to +3; 0: no effect, +3 very good								Summary (not an average)
			Effectiveness - potential CO_2 reduction	Cost and efficiency	Impact on market	Impact on technological development	Impact on consumer choice	Data requirements	Practicality	Political acceptability	
ET	EU: For each manufacturer	Not needed?	+2: likely positive effect if capped	-1: should reduce costs further	-1: should minimise market effects	+2: would stimulate cost-effective measures	-1: should be limited impact	-2: quite demanding data and control requirements	-2: demanding new arrangements needed	+1: positive aspects, but also risks	+1: positive aspects, but also risks
Taxes – fuel	Nat: differentiate according to CO_2	N.a.	+1: only indirect effect on purchase decisions	0: little or no effect on mfr costs	-1: limited effect on purchasing	+1: some value added	0: does not limit choice	+3: very limited new data requirements	+3: very few changes needed	-2: very unpopular	+1: useful contributor, but limited effect
Taxes – Registration/ purchase	Nat: make CO_2 related	Based directly on CO_2?	+2: if strongly differentiated	0: little or no effect on mfr costs	-2: some effect on purchasing if strongly differentiated	+2: should incentivise new technologies	0: does not limit choice	+2: low requirement, but need emissions test data to set the tax level	+2: quite straight-forward if there is existing system	0: feebate schemes could be acceptable	+1: useful contribution?
Taxes – Circulation	Nat: make CO_2 related	Based directly on CO_2?	+1: only limited effect on purchase decisions	0: little or no effect on mfr costs	-1: limited effect on purchasing	+1: some value added	0: does not limit choice	+2: low requirement, but need emissions data to set the tax level	+2: quite straight-forward	+1: some differentiation is accepted	0: limited effect?

Type of Instrument	N1 possible application	Utility parameter needed	Performance against criteria – quantitative and qualitative. Quantitative: from –3 to +3; 0: no effect, +3 very good								Summary (not an average)
			Effectiveness - potential CO$_2$ reduction	Cost and efficiency	Impact on market	Impact on technological development	Impact on consumer choice	Data requirements	Practicality	Political acceptability	
Subsidies for low emissions vehicles	Nat: e.g. for less than 120g/km	Based on class or utility function	+1: if strongly differentiated; limited effect on total sales	+1: could ease mfr costs for low CO$_2$ vehicles	+1: would benefit market leaders	+2: should incentivise new technologies	+1: could improve choice in new technologies	+2: low requirement, but need emissions test data to set the subsidy level	+1: quite straight-forward once benchmarks established	+1: popular, but potentially costly	+2: positive effects
Vehicle conversion incentives (e.g. to LPG)	Nat: subsidies for approved models Mfr: set benchmarks ?	N/A	0: limited effect on total sales	+1: could ease mfr costs for low CO$_2$ vehicles	0: little effect on mfrs	+1: incentive to limited range of technologies	0: little effect on choice	+2: low requirements, except benchmark levels	+1: quite straight-forward once benchmarks established	+1: low profile, limited cost	0: limited benefit overall
Scrappage incentives	Nat:	N/A	0: little effect on purchase decisions	+1: could stimulate demand and reduce mfr costs	+1: could stimulate market?	0: little or no effect	0: no effect	+2: low requirement, but need emissions test data to set the scrappage level	+1: quite straight-forward once benchmarks established	-1: potential costs, and some risks	0: very little impact

Type of Instrument	N1 possible application	Utility parameter needed	Performance against criteria – quantitative and qualitative. Quantitative: from –3 to +3; 0: no effect, +3 very good								Summary (not an average)
			Effectiveness - potential CO_2 reduction	Cost and efficiency	Impact on market	Impact on technological development	Impact on consumer choice	Data requirements	Practicality	Political acceptability	
Monitoring	EU Dir + Nat application	Based on class	0: little effect on purchase decisions	-1: imposes small extra cost	0: very little effect on market	0: no direct impact	0: no direct impact	-1: likely to set additional data requirements	+2: fairly straight-forward, as a model exists for cars	+1: necessary and not controversial	+2: important element of most policies
Labelling	EU Dir + Nat application	Class or utility function	+1: some positive effect on purchasing decisions?	-1: imposes small extra cost	+1: could benefit market leaders	+1: should give some incentive for new technologies	+1: could improve choices available	+2: low requirements, but need emissions test data to set the label band	+2: fairly straight-forward, as a model being developed for cars	+1: has visibility, but low cost	+2: low cost, uncertain benefit
Public procurement	Nat or local: set benchmarks for procurement	Class or utility function	+1: small effect over total parc, but could help take up of advanced technology	+1: could stimulate demand and reduce mfr costs	+1: would benefit market leaders	+2: should incentivise new technologies	+1: could improve choice available	+2: low requirements, except benchmark levels	+1: quite straight-forward once benchmarks established	+2: effective, but potentially costly	+1: could make positive contribution

Annex K TREMOVE output concerning fuel efficient driving

Sheet for constructing scenarios for generating output to TREMOVE on ecodriving

% of cars	new drivers / training license B lessons	new drivers training license B lessons / with GSI	existing drivers / with GSI	existing drivers / campaign	existing drivers / training course	existing drivers / training course / GSI	existing drivers / training with new car	existing drivers / training with new car / with GSI	existing drivers / training course company	existing drivers / training course company / with GSI	Average yearly effect	Average yearly costs
2008	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%	€ -
2009	2.5%	0%	0%	0%	1.5%	0%	0%	4%	1%	0%	0.3%	€ 0.33
2010	5%	0%	0%	0%	3%	0%	0%	8%	2%	0%	0.7%	€ 0.66
2011	7.5%	0%	0%	0%	4.5%	0%	0%	12%	3%	0%	1.0%	€ 0.99
2012	10%	0%	0%	0%	6%	0%	0%	16%	4%	0%	1.3%	€ 1.31
CO_2 reduction [%]	3%	4.5%	1.5%	3%	3%	4.5%	3%	4.5%	3%	4.5%		
cost of eco driving lessons [€]	0	0	0	0	100	100	100	100	100	100		
cost of pubic campain [€]	0	0	0	0	0	0	0	0	0	0		
cost of GSI [€]	0	54	33	0	25	33	0	33	0	33		
total cost per person [€]	0	54	33	0	125	133	100	133	100	133		
total cost per person per yr [€/yr]	0.0	1.3	1.3	0.0	5.0	5.3	4.0	5.3	4.0	5.3		
duration [yr]	40	40	25	25	25	25	25	25	25	25		

Assumption that '% of cars' equals '% of persons reached'

GSI	€	17.40	per GSI, retail price excl. tax
Training B-lessons	€	-	per person trained
Training course	€	100	per person trained
Public campaign	€	25	per person reached
GSI life		13	yr

Annex L Summary of Member State Responses to the Questionnaire in relation to the taxation of vehicles since the publication of COM(2005)264

Country	Action	Stage of development
Austria	As part of the Austrian Climate Change Strategy an adaptation of the RT to reflect CO_2 emissions is proposed	Government proposal
Belgium	A reduction in RT of €4100 for vehicles emitting less than 105gCO_2/km and €765 for vehicles emitting between 105 and 115gCO_2/km. A monthly tax on public service vehicles based on CO_2 emissions was also launched	Introduced in January 2005
France	RT on business cars linked to the label categories and CO_2 emissions: • 2 € /gCO_2/km for A vehicles • 4 € /gCO_2/km for B vehicles • 5 € /gCO_2/km for C vehicles • 10 € /gCO_2/km for D vehicles • 15 € /gCO_2/km for E vehicles • 17 € /gCO_2/km for F vehicles • 19 € /gCO_2/km for G vehicles	Voted on in November 2005
Germany	Restructuring CT based on CO_2 emissions	New government announced this intention and the UBA and ministry are developing the details
Ireland	Discussing the possibility of restructuring RT to reflect CO_2 emissions	In house study
Luxembourg	Considering changing CT based on CO_2 emissions	No government proposal yet – likely to be considered for 2007/08
Netherlands	RT based on CO_2 emissions linked to the label. Also the creation of a 'feebate', with a rebate for class A and B vehicles and additional charge for classes D to G	Discussed in Parliament November 2005 to be implemented by July 2006
Portugal	Proposal to alter RT to reflect CO_2 emissions	Included in the budget for 2006. Introduction likely by July 2006
Sweden	Proposal for three phase change to CT. First is a standard charge per vehicle, second is a charge per gram of CO_2 emitted above a threshold and finally for diesel vehicles an additional environmental factor is added	Proposal to be considered by parliament

Annex M Summary of Member State Responses to the Questionnaire in relation to labelling that have occurred since the ADAC study

Country	**Action**	**Stage of development**
Czech Republic	Introduce Directive 1999/94/EC	Implemented
France	A new CO_2 based labelling system based on the following thresholds: 100g/km, 120g/km, 140g/km, 160g/km, 200g/km and 250g/km	Notified to the Commission July 2005 and will be implemented by June 2006.
Germany	Considering labelling system beyond the requirements of the Directive	Internal debate
Netherlands	Link the label to registration tax and create a ‘feebate’, with a rebate for class A and B vehicles and additional charge for classes D to G.	Discussed in Parliament November 2005 to be implemented by July 2006.

Annex N Summary of Member State Responses to the Questionnaire in relation to public procurement

Country	Action	Stage of development
Austria	Public bus fleet in Graz is fuelled by biodiesel	Implemented
Belgium	50% new purchase or lease vehicles should have CO_2 emissions less than 145g/km for diesel and 160g/km for petrol cars	Implemented 2004
France	20% mandatory purchase applies to (LPG, NGV or electric) and all new vehicles must have CO_2 emissions less than 140g/km for Central Authorities	Implemented 1997 and September 2005 (CO_2 emissions)
Portugal	As part of the National Strategy for Energy; the public procurement of alternative technology vehicles (mainly PSVs)	Strategy proposal
Spain	Regional governments of Castilla Leon and Canarias have implemented public procurement of hybrid technology	Implemented
Sweden	Several authorities have clean public procurement policies	Implemented
Netherlands	Purchase of 10,000 vehicles Central government policy - Meet EURO IV and be in label categories A, B or C (Category D is allowed for government ministers). Planning a similar programme for local government	Implemented
UK	10% of fleet cars by 2006 Central government – alternatively fuelled vehicles (being reviewed likely to be replaced by technologically neutral target)	Under review