Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars

Service request #1 for Framework Contract on Vehicle Emissions

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Executive Summary

Introduction

Context of the study

In December 2008 the European Parliament and Council reached an agreement through a co-decision procedure on the details of the CO_2 legislation for passenger cars, laid down in Regulation No 443/2009[1]. Besides the target of 130 g/km for 2015 and details of the way it is implemented, Regulation No 443/2009 also specifies a target for the new car fleet of 95 g/km for the year 2020. In Article 13 of the Regulation it is stated that a review would be carried out by the European Commission no later than the beginning of 2013 in order to define the modalities of reaching this long term target. The support for this review is carried out within the Framework Contract on Vehicle Emissions by TNO, in association with AEA, CE Delft, Ökopol, Ricardo, TML and IHS Global Insight (Reference ENV.C.3/FRA/2009/0043). This report presents results of an evaluation of different modalities for implementing the 95 g/km target as well as an assessment of the costs for meeting this target.

Structure of the work

Work in this project was organised in the following tasks:

Task 1 *Cost and potential of CO_2 reduction options for 2020 and further*, involving assessment of manufacturer costs and reduction potentials of CO_2 reducing technologies for the longer term, construction of cost curves, assessment of current state-of-the-art technologies and a review of manufacturers' model cycles to assess feasibility of the timing for the target.

Task 2 *Alternative utility parameters*, involving consolidation of new vehicle sales database, detailed evaluation of footprint as an alternative to mass as utility parameter and a more general evaluation of other parameters for this purpose.

Task 3 *Modalities for 95 g/km in 2020*, containing a preliminary evaluation of options for modalities, an update of the cost assessment model for passenger cars and an assessment of average additional vehicle costs per manufacturers for manufacturer-based modalities. In addition this Task contains an assessment of the impacts of an additional vehicle-based CO_2 limit and of possibilities for a combined target for passenger cars and vans. Based on the results of these assessments proposals are developed for favourable modalities.

Task 4 *Investigation of further aspects*, looking at consequences of several possible additional provisions in the definition of the 2020 target, including a stepwise approach to the target, banking and borrowing, and mileage weighting. This task furthermore explores impacts of the legislation through CO_2 emissions of various life-cycle aspects, and of rebound effects resulting from reduced driving costs.

Task 5 *Best available technologies in 2007*, a review based on analysis of IHS databases, providing input to the definition of provisions for derogation in the present legislation, specifically the derogation of new market entrants selling between 10,000 and 300,000 vehicles in 2015. Results have been reported to the European Commission in a separate report.

Evaluation of modalities for implementing the 95 g/km target

Description of main elements of the modalities

The impacts of the 95 g/km target are not only determined by the target level, but also by various aspects of the way in which the target is implemented. These modalities can be chosen to meet additional goals with respect to e.g. minimizing additional manufacturer costs for reaching the target,

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[1] REGULATION (EC) No 443/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles, see: http://ec.europa.eu/environment/air/transport/co2/co2_home.htm

a fair distribution of the burden over different car manufacturers, allowing higher emissions for cars with a higher utility, and avoiding perverse incentives. The main modalities that can be adopted are:

- the obligated entities to which the CO_2 targets apply;
- the geographical area for which sold cars are taken into account;
- application of a utility-based limit function, including choices with respect to the utility parameter to be used and the shape of the limit function;
- penalties or excess premiums.

Options for additional provisions include e.g. a stepwise approach using annually decreasing targets between 2015 and 2020, an additional vehicle-based limit, and super credits for low-emitting vehicles.

Results of qualitative comparison of utility parameters

In Regulation No 443/2009 indicated that it would consider footprint as an alternative to mass for the utility parameter to be used for the 2020 target. Footprint could not be considered for the 2015 target due to the lack of available data from the Monitoring Mechanism. By now the Monitoring Mechanism has been amended to include footprint. In this project the scope for the evaluation of possible utility parameters was broadened by means of a preliminary assessment of a long-list of options. Criteria for the evaluation included measurability, objectivity of the measurement, possibilities / incentives for gaming[2], correlation with CO_2 emissions, relation with CO_2 reduction options, and use in CO_2 legislation in other regions.

Based on this review of possible utility parameters it was concluded that reference mass, footprint and footprint x height are the most promising candidates. Of these footprint x height was not further assessed mainly because it rewards higher vehicles such as SUVs. The most important advantages and disadvantages of mass and footprint are listed in Table 1 and Table 2.

Table 1 Pros and cons of reference mass as utility parameter

Reference mass	
Pros	**Cons**
Easily / objectively measured	Not a direct measure of utility
Accepted by industry (continuity with current legislation)	Possibilities for gaming depend on slope of limit function
Good correlation with CO_2 emissions	Easy options for gaming: “Brick in the boot”
	Makes weight reduction as CO_2 reduction measure much less attractive

Table 2 Pros and cons of footprint as utility parameter

Footprint	
Pros	**Cons**
Easily / objectively measured	Relatively tough on compact / high cars (e.g. MPVs)
Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions	May promote tendency towards larger cars unless compensated for such autonomous footprint increase
Better proxy for utility than mass	
Used in US legislation	
Good correlation with CO_2 emissions	

Pan area (length x width) and wheelbase were discarded as options for the reason that footprint is superior with respect to all criteria. Utility parameters based on number of seats and trunk volume would be the most true measure of “utility”, but are difficult to measure objectively, have poor correlation with CO_2 and provide many possibilities for gaming. Payload was discarded because it is a declared value rather than a measured value and because of poor correlation with CO_2. Utility parameters based on number of seats, trunk volume and payload combine the disadvantages of all three. Price was discarded because it is not a measure of functional utility, has a very uneven

[2] i.e. bringing a vehicle closer to its target by changing the value of the utility rather than applying CO_2 reducing measures

distribution around its average value, can not be objectively measured or verified. Furthermore it promotes gaming and gives credit to high performance cars.

The advantages of reference mass are that it can be objectively measured, is accepted by industry and has good correlation with CO_2. It is however a relatively poor measure of utility (in the sense that buyers will never buy a vehicle for its mass), it provides some room for gaming (but this can be compensated by choosing an appropriate slope for the limit function) and it makes weight reduction less attractive as a CO_2 reduction measure. Footprint can also be objectively measured, is a better proxy for utility than mass, is used in the US legislation, has good correlation with CO_2, and is considered to offer less opportunity for gaming. Possible disadvantages are that it might lead to relatively tough targets for compact / high cars (e.g. MPVs) and that it may promote a tendency towards larger cars.

Comparing the different pros and cons for mass and footprint the conclusion is that this preliminary evaluation did not identify a clear favourite. The main arguments for maintaining mass as utility parameter would be its acceptance by industry and the general desire to keep definitions for the 2020 as much as possible the same as for the 2015 target. The main arguments in favour of footprint are that it is a better proxy for the true utility of the vehicle and that it fully rewards the benefits of weight reduction as a CO_2 reducing option. The latter is relevant as advanced levels of weight reduction will be an increasingly important option for meeting targets for 2020 and beyond.

Results with respect to the utility-based limit function

In the current legislation a utility-based limit function is used to specify emission targets per vehicle depending on its utility value. Manufacturer targets are defined by sales-weighted averaging over the emission targets for all vehicles (models and variants) sold in the EU-27. The 130 g/km target for 2015 is implemented using a linear limit function.

The linear limit function will always go through the point defined by the average utility and the CO_2 target value. Starting point for determining the limit function for 2020 has been a sales-weighted least squares fit through the (utility value ,CO_2 emission) points for all vehicles included in a 2009 sales database. The limit function with so-called 100% slope is then defined by applying a constant reduction percentage to all points on this line, with the reduction equal to the relative difference between the 2009 sales-weighted average CO_2 value and the 2020 target of 95 g/km. Subsequently the slope can be varied by pivoting around the point defined by average utility and the CO_2 target value. This can be done to reduce incentives for gaming as well as for changing the impact of the target on smaller and larger vehicles. Lines with alternative slopes are identified by means of the ratio (expressed as x%) between the slope of the limit function and that of the 100% line defined as indicated above. This slope value can have a significant effect on the additional manufacturer costs and distributional impacts, and is therefore taken into account in the detailed cost assessment.

For the 2020 target besides the linear limit function two other variants have been considered:
- truncated linear limit functions with a floor and / or ceiling
    - i.e. linear sloped line targets with horizontal cut-offs at the upper and / or the lower end:
- non-linear limit functions
    - smoothened variants of the truncated linear limit functions similar to the “constrained logistic” function used in the initial proposal for the US legislation on CO_2 emissions for light-duty vehicles

The motivation for truncating the limit function would be e.g. to reflect possible flattening of the correlation between utility and CO_2 or to reduce the burden for small vehicles resp. limit the credits that large vehicles get for increasing utility. If a floor or ceiling is to affect a significant number of vehicles it has to intercept the linear limit function at a utility value that is well within the bandwidth defined by the cloud of data points identifying vehicles sold in 2009. From analysing the position of the limit function with 100% slope relative to the cloud of data points it has become apparent that in the European market situation floors and ceilings of non-linear limit functions do not have significant impacts unless they are set at unreasonable levels (> 80 g/km for the floor and < 140 g/km for the ceiling in order for each to affect 5% of the new vehicle fleet).

Since the non-linear curves ought to be based on the linear curves with cut-off, the same conclusions were drawn for the continuous limit functions with floors and / or ceilings. Conclusively, these types of limit functions can be considered to be interesting theoretical concepts, but are proven to provide no practical benefits in the European situation.

Conclusions with respect to other elements of the modalities

Obligated entities under the present regulation are manufacturer groups[3]. The geographical scope is the EU 27. Based on experience with the present regulation it is concluded that there are no reasons to changes either the regulated entities or the geographical area for the 2020 target.

In order for penalties (or excess premiums) to serve as a mechanism to enforce compliance the level of the penalty in € per g/km exceedance should be somewhat higher than the marginal costs of the last g/km reduction that is needed for meeting the target. This way penalties may also serve as a buy-out premium for manufacturers that are temporarily not able to meet their target. Estimates for the marginal costs for meeting 95 g/km are produced by the cost assessment model of which the results are discussed further on.

Selection of utility parameters / modalities for the detailed cost assessment

Based on the above, and in close consultation with the European Commission services, reference mass and footprint were selected as the utility parameters for which a detailed assessments of cost and distributional impacts was to be carried out. For both options only linear limit functions with different slopes are considered.

Cost curves for CO_2 reduction in passenger cars in 2020

Creation of cost curves for passenger cars in 2020

Starting point for the creation of cost curves, describing the additional manufacturer costs for achieving increasing levels of CO_2 reduction in different vehicle segments, was the collection of information on cost and reduction potentials of individual CO_2 reducing technologies. These technologies include various measures to improve engine efficiency, such as reduced friction, direct injection, various levels of engine downsizing and variable valve timing and actuation. In addition options for more efficient transmissions are included, as well as engine start-stop and various degrees of hybridisation, weight reduction, improved aerodynamics, low rolling resistance tyres, and improvements in ancillary systems and auxiliaries. Costs and reduction potentials are defined relative to 2002 baseline vehicles. The year 2002 was selected as baseline year because none of these technologies were applied at any significant scale yet in that year. The cost assessment model contains 2002 data for all manufacturers included in the analysis.

Data were collected from literature, in-house expertise and through questionnaires sent out to manufacturers and component suppliers as well as their European associations. Based on an evaluation of the different inputs, technology tables were constructed with selected values for costs and reduction potentials of different technologies, specified separately for 6 vehicle segments (small, medium-size and large vehicles on petrol resp. diesel).

Subsequently, by combining options that are technically compatible into packages of measures, a large number of possible technology packages were identified, each with a different overall CO_2 reduction potential and different overall costs. Cost curves can then be created by consecutively selecting the most cost-effective packages that enable increasing levels of CO_2 reduction. In drawing the cost curves a “safety margin” is taken into account to correct for the fact that simply combining the CO_2 reduction potentials of individual measures will often lead to overestimation of the overall CO_2 reduction potential of the complete package. This is because some measures partly overlap in their impact as they have an effect on the same source of energy loss. As examples the resulting cost curves for medium-size petrol and diesel cars are described by the green lines in Figure 1.

Scenario variants for the cost curves

In the course of the study two issues arose that justified critical evaluation of the cost curves as generated using the methodology described above. These issues are:

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[3] manufacturer group = ‘a group of connected manufacturers’ or ‘a manufacturer and its connected undertakings’

- Observed progress in CO_2 reduction in European new passenger car fleet in the 2002-2009 period
    - In the last decade CO_2 emissions of new passenger cars have decreased significantly. At the same time vehicle prices have not increased. This could be interpreted as an indication that part of the observed reductions in type approval CO_2 emissions over the last years may need to be attributed to other causes than application of technologies that are included in the cost curves used to assess the costs of meeting the targets for 2015 and 2020.
    - These other causes may include CO_2 reduction due to small technical improvements that are not mentioned in technical specifications of vehicles and are not included in the cost curves developed in this project and previous studies, effects of optimising the powertrain calibration by improving trade-offs against other parameters, and the possible utilization of flexibilities in the test procedure.
- Technical data becoming available from EPA studies in support of the US legislation on CO_2 emissions from light duty vehicles
    - These data seem to suggest that the costs of reducing CO_2 emissions in passenger cars could be lower than estimated in this study.

In the context of this study, and given the limited availability of necessary information, both issues could not be dealt with in detail. In order to obtain an indicative insight in the possible implication of these issues, however, it has been considered useful to develop indicative cost curves for three different scenario variants that can be used to perform a sensitivity analysis with the cost assessment model. The scenario variants are:

a) Alternative accounting for progress observed in the 2002-2009 period

- A variant including an additional reduction step based on the assumption that a given share of the reductions achieved in the 2002-2009 period can not be attributed to application of technologies that are included in the technology tables underlying the cost curves.
- The assessment model used in this study is based on cost curves defined relative to 2002 baseline vehicles and attributes reductions in CO_2 emissions observed between 2002 and 2009 (most recent database used to describe the current situation) to the use of a part of the reduction potential described by the cost curves. Due to the strong non-linearity of the cost curves the possibility that other causes may be responsible for the observed reductions between 2002 and 2009 could have a significant impact on the assessment of cost for moving from the 2009 values to the 2020 target values.
- For the size of the additional reduction step 10% was assumed for petrol vehicles and 9% for diesels. These values were estimated on the basis of a detailed comparison of 12 vehicle models sold in 2002 and 2010 and identification of the headline CO_2-reducing technologies used in the 2010 vehicles.

b) Alternative cost curves based on a modified technology table

- An evaluation of available results from the EPA studies in support of the US CO_2 target for passenger cars provided strong indications that the costs for meeting the European 95 g/km target for 2020 could be lower than the estimates based on the cost curves from this study. Due to large differences in technology definitions, baseline vehicles and drive cycles, however, the direct use of EPA data for the European assessment was considered not appropriate.
- To test the possible impact of the most striking differences between US data and cost and reduction figures used in this study a selection of data on cost and reduction potential derived from the EPA studies, specifically for full hybrids and the various levels of weight reduction, has been used to construct a modified technology table. Alternative cost curves have been constructed on the basis of this table.
- This variant is created to allow an indicative assessment of the possible implications that information from EPA studies underlying the US CO_2 legislation for cars might have for assessment of the costs of meeting the European target for 2020.

c) Combination of a) and b)

The resulting cost curves for medium-size petrol and diesel cars are presented in Figure 1 and compared to the original cost curves from this study. Around 40% reduction scenario a) and b) both provide a cost reduction of order of magnitude € 500 compared to the original cost curves. In that region scenario c) predicts costs that are another € 500 or so lower.

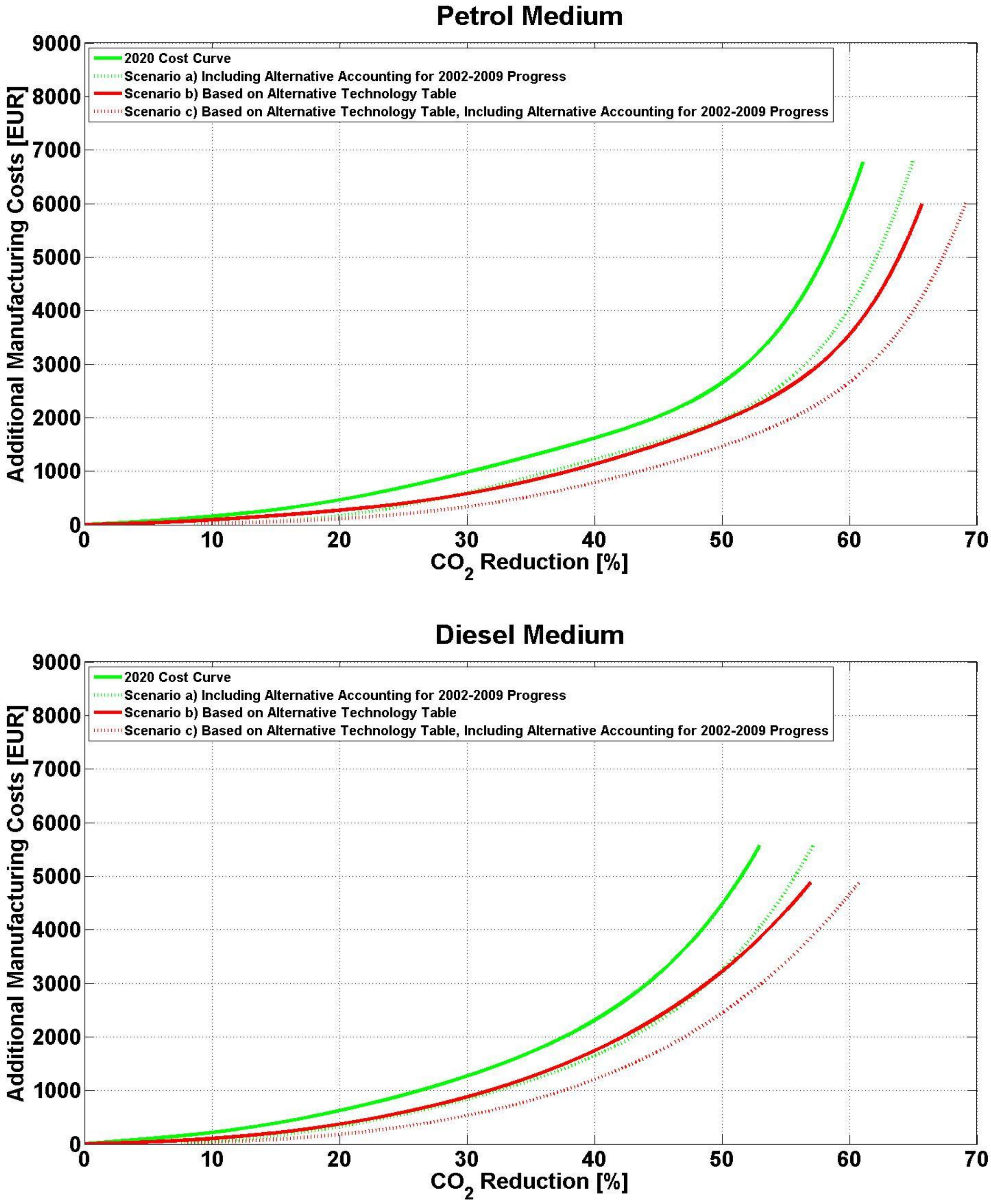

Figure 1 Cost curves for CO_2 emission reduction in medium size petrol and diesel vehicles in 2020, relative to 2002 baseline vehicles, and comparison with cost curve variants for scenarios a), b) and c).

Assessments with respect to the attainability of the 2020 target

Current state-of-the-art technologies for passenger cars

Many technologies indicated in the tables underlying the cost curves are already applied in the market today, especially in so-called “eco-models”. A review has been carried out to identify and analyse the lowest emitting vehicles currently on the market or close to market introduction in the B-, C- and D-segments, in order to arrive at a realistic “current state-of-the-art” technology and emission levels. For these vehicles technologies used to reduce CO_2 emissions were identified and their contribution to the achieved CO_2 emission levels was estimated. Price differences between these “eco-models” and comparable base models were compared with cost estimates for the applied technologies.

In the comparison between ‘standard’ and ‘eco’ models, the overall figures for the reduction in CO_2 emissions and the increase in price show strong variations between different brands / models. The price differential for ‘eco’ models is large in some cases, especially in the B- and C-segments, possibly as a result of pricing strategies justified in terms of factors such as “green image”, lifetime fuel saving and other financial benefits (e.g. reduced vehicle tax and traffic charging incentives). In other cases the price differential is small or zero. Thus the extent to which costs are passed on to customers is not clear from this analysis.

In many cases, the estimated additional costs to the manufacturer appear to be much smaller than the additional price charged to the consumer, suggesting additional profit is generated on these models. However, the analysis performed takes no account of engineering costs, which on a per-vehicle basis could be significant for ‘eco’ variants with relatively small production numbers, and still more significant in the case of more radical technologies such as those featured in the hybrid vehicles considered.

Also the values for reductions are often found not to match well with the estimated total for the technologies identified as being featured. This is not surprising, for a number of reasons. The analysis assumes a baseline specification which may not exactly apply for each model and manufacturer – i.e. the ‘standard’ vehicle’s level of technology and CO_2 reduction potential varies from case to case. Also the benefit extracted by the manufacturer from each technology may not be the maximum potential benefit, due to limiting factors specific to the particular model or for cost reasons, and not all technologies applied to ‘eco’ models may be evident from the information available. In this context it should be noted that the optimisation of fuel consumption and CO_2 emissions is a complex process in which the most significant gains can be achieved only if the implementation of headline technologies is accompanied by other incremental improvements in many different systems and components. The CO_2 reduction potential and limits of such detailed refinements will vary significantly from vehicle to vehicle.

Evaluation of model cycles

Model cycles of mainstream car models from different manufacturers and different market segments have been investigated to assess the impacts of their timing on the feasibility of the 95g/km target in 2020. The product development process is found to vary from 18 months to up to 5 years depending on whether an OEM is applying an existing technology to a new application or developing and implementing a new technology. The key factors which affect the lead times in the product development process are the level of change required (e.g. clean sheet design vs. major upgrade vs. minor upgrade) and collaboration, platform sharing, joint ventures and trading. OEMs will plan cycles of vehicle and powertrain development which indicate when vehicle models / engines will be upgraded/refreshed/replaced etc. These plans usually span up to 10 years but will be more detailed for the first 5 years in terms of capital investment and resourcing requirements. The key factors which affect cycle plans are budget, resource and economic constraints.

For the OEMs, selected vehicle models and engine platforms analysed in this study the following conclusions could be drawn:

- On average vehicle models have a platform change every 6 – 8 years and are refreshed with a face-lift between 2-4 years after a platform change.
- Engine platforms have a long lifespan, typically 10 – 15 years but during that time will have minor or major upgrades and additional variants added. There is no typical timing pattern for the introduction of new variants or upgrades (it is dependent on the OEM and engine platform) but in general minor upgrades/variants to engine platforms are added fairly frequently (e.g. higher power variant) and major upgrades/variants added less frequently occurring anywhere from 3 to 7 years (e.g. a turbocharged variant of a naturally aspirated gasoline engine).
- Vehicle platform changes / facelifts and engine variants / upgrades are staggered so that changes to all vehicle models or all engine platforms are not all made within the same year.
- There is a relatively good degree of fit between the engine cycle plans and the planned introduction dates for noxious emissions (Euro 5 and Euro 6).

- There is no distinct pattern/fit between the engine cycle plans and vehicle model platform changes compared to the CO_2 legislation introduction dates but there are some model platform changes and planned introductions of new engines in the 2012 – 2015 timeframe and some planned vehicle platform changes in the 2016 – 2020 timeframe (public domain data not available to comment on engine platform upgrades / introductions in this timeframe) which will contribute to the planned 2020 target of 95g/km for the OEMs, vehicle models and engine platforms analysed in this study.

The analysis above indicates that manufacturers' development cycles are well timed to meet planned introduction dates of noxious emissions but currently less aligned to the planned 95 g/km CO_2 target in 2020. OEM cycle plans typically span up to 10 years, which means that detailed plans (in terms of budget and resource requirements) for the next 5 years to 2015 and basic plans up to 2020 are likely to already be in place

The length of the product development cycle (up to 5 years in some cases) and the fact that OEMs may already have basic vehicle and engine cycle plans in place from 2015 up to 2020, highlights a potential need for 95 g/km CO_2 legislation to be finalised as early as possible and as a minimum 5 years before its implementation date. This will provide certainty for OEMs and enable them sufficient time to consider it in their vehicle and engine cycle plans whilst they are not heavily detailed and the product development processes are not yet underway.

Costs for meeting 95 g/km in 2020 using mass / footprint as utility parameters

Overall costs and distributional impacts based on main cost curves

Detailed cost assessments per manufacturer have been carried out for mass and footprint as utility parameters. The cost assessment model used for this exercise is an updated version of the model developed for studies in support of the 130 g/km target for 2015[4]. Options for implementing the 95 g/km legislation for passenger cars have been quantitatively assessed with respect to average additional costs per car for meeting the target and especially the distribution of required CO_2 reduction efforts and associated costs per vehicle over the various manufacturers / manufacturer groups selling cars in Europe and over the six market segments discerned in the model (small, medium and large vehicles running on petrol or diesel).

Setting a target for the sales weighted average CO_2 emissions per manufacturer implies that manufacturers are allowed to perform internal averaging, i.e. the excess emission of one vehicle that emits more that the target value can be compensated by other vehicles that emit less than their specific target values. Based on the cost curves and using average data per segment for each manufacturer derived from available 2002 and 2009 sales databases, the model calculates the distribution of reductions per segment that yields the lowest overall costs for meeting the sales averaged target, in terms of additional manufacturer costs. This solution is characterised by equal marginal costs (€ per g/km) in all segments.

The costs for meeting the 95 g/km target using mass and footprint as utility parameters are summarized in Table 3. Costs are expressed relative to 2009 as well as to a reference scenario in which the 130 g/km target is maintained beyond 2020. The difference between the two is the costs, in 2020, for reducing emissions from the 2009 levels to the levels needed to meet an average of 130 g/km.

4 TNO/IEEP/LAT 2006 - 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, October 2006
IEEP/ CE Delft / TNO 2007 - Possible regulatory approaches to reducing CO_2 emissions from cars. Contract Nr. 070402/2006/452236/MAR/C3, October 2007

Table 3 Results with respect to average cost impacts (expressed as absolute manufacturer cost increase) for meeting the 95 g/km target for passenger cars in 2020 with a 100% slope limit function and mass and footprint as utility parameters, relative to 2009 and to a reference scenario in which 130 g/km is maintained.

Utility parameter: reference mass Slope: 100%	**Additional manufacturer costs [€]**						
	pS	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Relative to 2009	2199	2390	3872	1719	2119	2697	**2188**
Relative to maintaining 130 g/km	1852	1653	1993	1552	1748	1930	**1750**

Utility parameter: footprint Slope: 100%	**Additional manufacturer costs [€]**						
	pS	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Relative to 2009	2166	2400	4189	1657	2145	3160	**2197**
Relative to maintaining 130 g/km	1818	1664	2310	1489	1775	2393	**1760**

Distributional impacts are illustrated in Figure 2 and Figure 3. When slopes of the utility-based limit function are varied, it is found that for various slope values one or more manufacturer groups are not able to meet their specific target. These are mostly manufacturers with relatively large vehicles, high petrol shares and small total sales. As a result of the latter, the overall target is only missed by a small amount.

The costs, to be made for reaching the target, increase with an increasing slope independent of the assessed utility parameter. However, the sensitivity of the average costs to the slope value is relatively small. The average costs for meeting the target appear slightly higher for footprint than for mass. However differences are negligible.

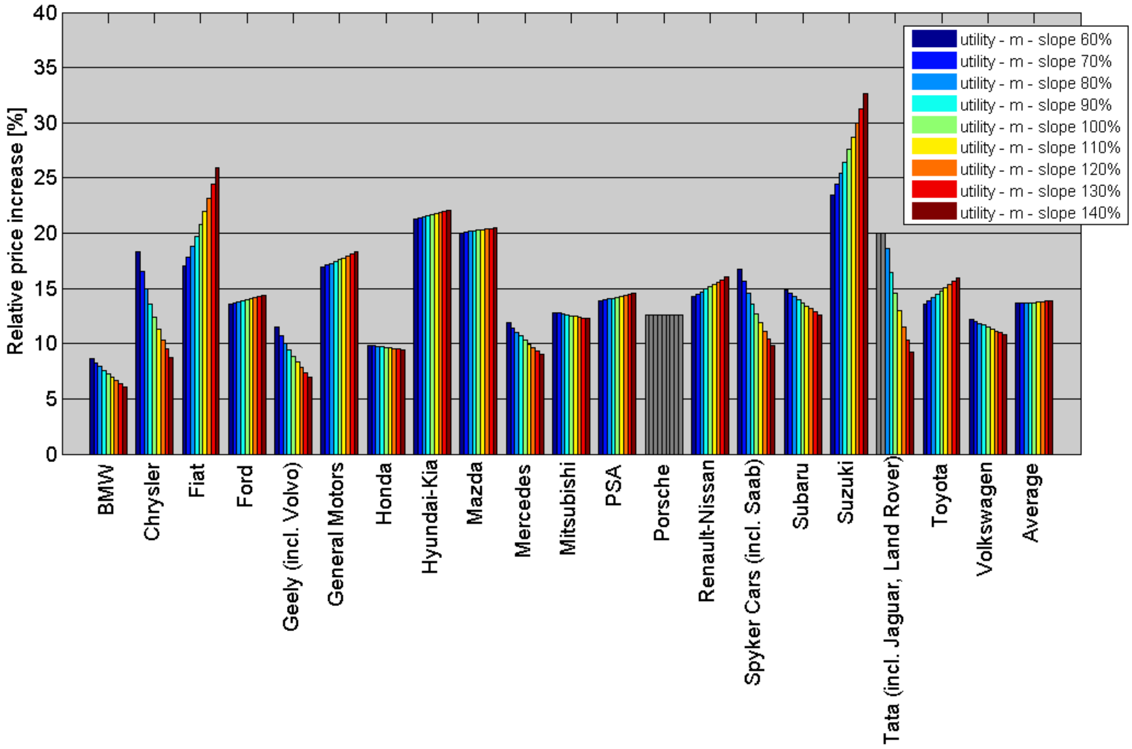

Figure 2 Relative retail price increase compared to 2009 per manufacturer for utility-based limits applied per manufacturer for **mass as utility parameter**. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

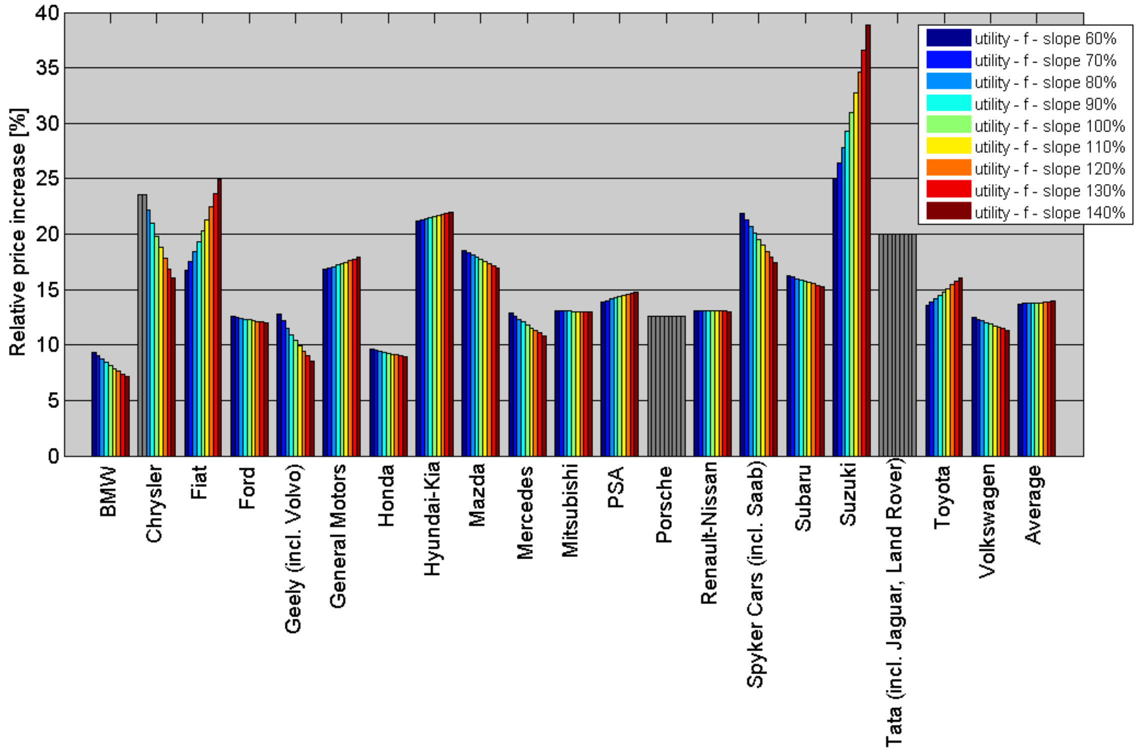

Figure 3 Relative retail price increase compared to 2009 per manufacturer for utility-based limits applied per manufacturer for **footprint as utility parameter**. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

How the costs per manufacturer depend on the slope of the limit function is mainly determined by the manufacturer's average utility value relative to the overall average. If the manufacturer's value is below the average the costs increase with increasing slope, and vice versa. The sensitivity depends on the distance of the manufacturer's average utility to the overall average.

In general the targets defined by limit functions based on mass as utility parameter are met by more manufacturer groups than for footprint based targets. For the specific manufacturers for which this applies the average footprint is further away from the overall average than is the case for their average mass.

Impact of electric vehicles on the costs for meeting the target

Assessing scenarios that include different levels of market penetration of various types of electric vehicles (EVs: plug-in hybrids, range-extended electric vehicles and full electric vehicles) shows that manufacturing and selling electric passenger vehicles can become a cost effective means for achieving the 2020 target of 95 g/km. Under a given sales-weighted target the estimated additional manufacturing costs for the electric vehicles are more than offset by reduced costs for CO_2 reduction in conventional vehicles (as based on the main 2020 cost curves described above). This is due to the low type-approval CO_2 values of plug-in hybrids and range-extended electric vehicles and the fact that full-electric vehicles count as zero-emission for the CO_2 legislation. This leads to a reduction of the efforts required to reduce CO_2 emissions in the remaining conventional vehicles and hence lower additional costs for these vehicles. The penetration of EVs leads to a slight reduction of the additional manufacturer costs for meeting the target, irrespective of the utility parameter.

Although the 'tank-to-wheel' (TTW) emissions from electric drive trains are zero, their complete 'well-to-wheel' (WTW) emissions obviously are not. Depending on the applied energy sources, the WTW emissions could be as high as the WTW emissions from cars running on fossil fuels. However, with clear objectives at the European level to improve decarbonisation of the electricity sector by 2020, it is likely that average WTW CO_2 emissions will be lower for vehicles driving on electric energy than for conventional vehicles.

Since currently full electric vehicles (FEVs) are attributed zero emissions within the fleet average system, there is no legislative incentive for manufacturers to improve the energy efficiency of FEVs. However, a strong incentive for that is likely to come from customer demands with respect to increased range and reduced costs.

In order to realistically account for the CO_2 impact of electric vehicles, it is necessary to understand their total CO_2 impact (including upstream emissions for electricity production and their impact on the real-world emissions of conventional vehicles) and to define an approach for handling them with respect to the European CO_2 regulation. The question of whether it is desirable to account for the WTW emissions depends on numerous economical, political and societal factors. Recommendations to resolve this future issue are not made within this study.

Marginal costs for meeting the target and implications for excess premiums

If the average CO_2 emissions of a manufacturer's 2020 sales of new cars exceed the manufacturer specific target, the manufacturer has to pay an excess premium for each car registered. According to Regulation No 443/2009, this premium amounts €95 for every g/km of exceedance from 2019 onwards.

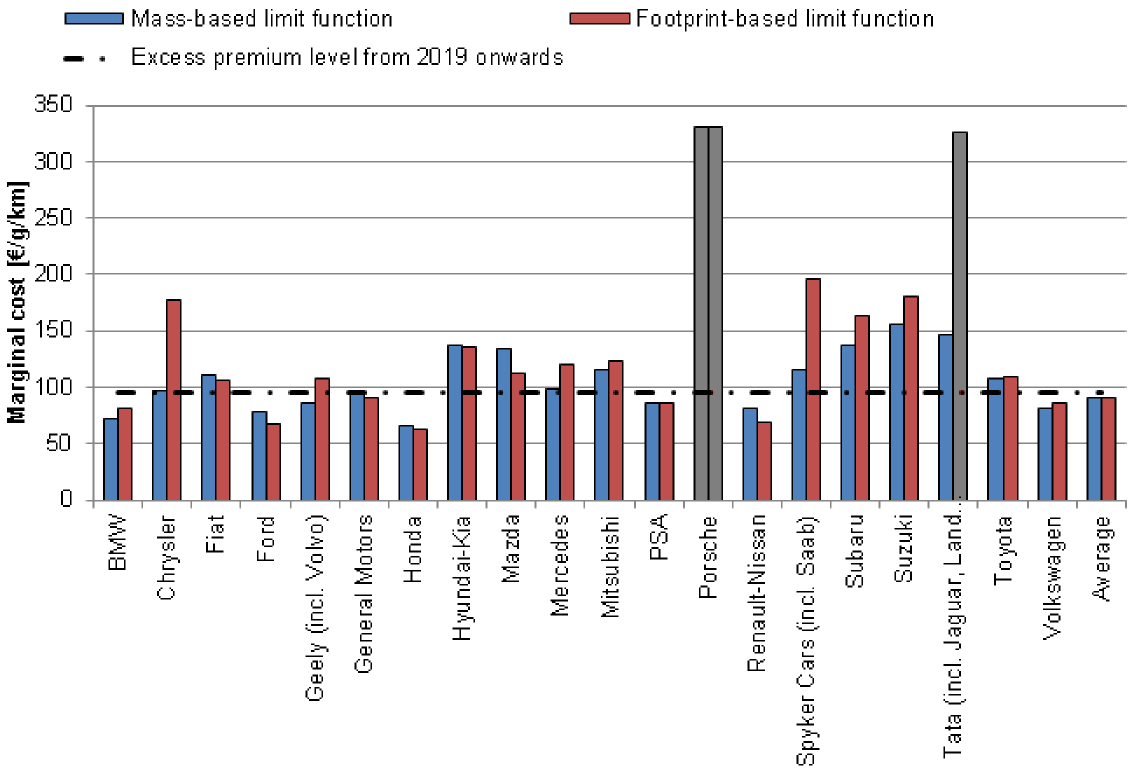

Figure 4 Marginal costs for realising the final g/km CO_2 reduction to meet the manufacturer specific target in 2020 for every analysed manufacturer group for both reference mass and footprint as utility parameter and a 100% slope limit function. The grey bars indicate manufacturers that can not reach their target even with the maximum reduction possible.

For every manufacturer Figure 4 depicts the marginal costs for realising the final g/km CO_2 reduction to meet the manufacturer specific target in 2020. The figure shows that the excess premium level from 2019 onwards is slightly higher than the average marginal cost for every manufacturer (which is € 91 g/km). Therefore, this level of excess premium should provide enough incentive for the majority of manufacturers to reduce the CO_2 levels of their vehicle fleet to the target rather than paying the penalty for exceeding the target. In order for the excess premium to be an incentive for all manufacturers (apart from the ones not being able to meet that target at all) to reach their equivalent of the 95 g/km target, the excess premium level should be much higher (of the order of € 200 per g/km).

Conclusions from the analysis of three scenarios with alternative cost curves

Table 4 and Table 5 present the impacts on the costs for meeting 95 g/km in 2020 of using alternative cost curves reflecting three scenarios that explore possible reasons for why costs might be lower than found in the assessment presented above:

a) Alternative accounting for progress observed in the 2002-2009 period
b) Alternative cost curves based on a modified technology table including data from EPA studies
c) Combination of a) and b)

Assessments for footprint as utility parameter yield similar results. As was to be expected from the comparison of cost curves in Figure 1, assuming that a large part of the progress made between 2002 and 2009 is to be attributed to other origins than application of technologies from the cost curves leads to costs for meeting the target that are about € 600 lower than for the case based on the original cost curves. Using alternative data for costs and reduction potentials of hybridization and weight reduction from EPA studies has a more limited effect. The combination of scenario a) and b) leads to costs that are about € 1000 lower than the base case.

Table 4 Comparison of the impact of different scenarios on additional manufacturer costs per segment relative to 2009, with reference mass as utility parameter and a 100% slope limit function

		Additional manufacturer cost relative to 2009 [€]			
Utility parameter	Slope	based on 2020 cost curves	based on "Scenario a)"	based on "Scenario b)"	based on "Scenario c)"
Mass	60%	2186	1596	1717	1203
	100%	2188	1595	1715	1198
Footprint	60%	2191	1601	1728	1213
	100%	2197	1605	1732	1210

Table 5 Comparison of the impact of different scenarios on additional manufacturer costs per segment relative to maintaining 130 g/km, with reference mass as utility parameter and a 100% slope limit function

		Additional manufacturer cost relative to 130 g/km target [€]			
Utility parameter	Slope	based on 2020 cost curves	based on "Scenario a)"	based on "Scenario b)"	based on "Scenario c)"
Mass	60%	1748	1159	1280	765
	100%	1750	1158	1277	760
Footprint	60%	1754	1164	1290	775
	100%	1760	1168	1294	772

Results for the scenarios a) to c) would change the conclusion from the assessment of impacts of introducing EVs by 2020 as presented above. The lower costs for meeting the target by means of reducing CO_2 emissions from conventional vehicles will mean that additional costs for manufacturing EVs will no longer be outweighed by reduced costs for reduced efficiency improvements in conventional vehicles.

Conclusions with respect to the choice of utility parameter and limit function

Comparison of reference mass and footprint based on additional manufacturer cost

The results of the cost assessment and distributional impacts do not significantly contribute to the selection of the preferred utility parameter. Differences in cost and distributional impacts are found to be too small to motivate the choice.

In the analysis of distributional impacts a footprint based limit function leads to an extra manufacturer group not being able to meet its target compared to the case with mass as utility parameter. However, the sales share of this manufacturer group is only 0.7% of total sales. Similarly to the cost comparison between the two parameters, this difference does not seem significant enough for selecting a favourable utility parameter.

Finally, the difference in distributional impacts between the mass and footprint-based limit functions, lies mainly with large petrol vehicles. These vehicles tend to have relatively higher costs for footprint than for mass. Therefore manufacturers such as Chrysler, Spyker (incl. Saab) and Tata (incl. Land Rover and Jaguar) have higher additional manufacturer costs for reaching their target. On the other hand, manufacturers with higher sales volumes, such as Ford, have lower manufacturer costs when a footprint-based limit function is applied.

Comparison of reference mass and footprint based on impacts of the penetration of low emitting vehicles

The penetration of various types of electric vehicles could potentially lead to a reduction of additional manufacturer costs to meet the target of 95 g/km. However, the impact from this penetration is very similar for both utility parameters. For scenarios with different levels of EV penetration the differences between the additional manufacturer costs based on either mass or footprint as the utility parameter are below 0.6%. This difference also seems too small to motivate the choice of the favourable utility parameter.

Comparison of reference mass and footprint in the context of applying an additional vehicle-based CO_2 limit

Conclusions with respect to the option of applying an additional vehicle-based CO_2 limit are presented below. Additional manufacturer costs, in case vehicles exceeding an additional vehicle-based CO_2 limit are excluded from the market, are found to be slightly lower for footprint compared to mass as utility parameter. On the other hand, the usage of footprint as utility parameter, leads to the exclusion of more vehicles, which can be perceived as a negative effect. Finally, the cost reduction per excluded vehicle is very similar for both utility parameters. The option to apply a vehicle-based limit function therefore provides no ground to decide upon a favourable utility parameter.

Choice of favourable utility parameter

Since no obviously favourable utility parameter arises from the cost assessments, the choice will need to be based on general pros and cons as discussed above. From these pros and cons two potential effects of the utility parameter choice seem more important than other ones.

Firstly, a relevant argument is that mass reduction will be an important measure for future CO_2 reduction beyond 130 g/km. If mass is used as a utility parameter, applying this measure is made unattractive, since it would lead to a stricter CO_2 target for a manufacturer. The European Commission has the possibility to adjust the limit function when changes in average mass are observed, and for the case of mass reduction this would lead to higher specific targets per manufacturer for given utility values. This would compensate the reduced effectiveness of weight reduction as CO_2 reducing measure in relation to a mass-based limit function. Nevertheless mass as utility parameter provides a first-mover dilemma to individual manufacturers. Since the choice for footprint as a utility parameter would not influence the CO_2 target of a manufacturer in case of light weighting its vehicles, this parameter seems favourable from this perspective.

Moreover the argument that footprint is a better measure for utility is a valid one from a consumer perspective. Consumers tend to buy certain vehicles because of their size, e.g. to transport more people or goods or to transport people with more legroom and comfort, while they do not purchase a certain car because it is heavy. Since footprint is a much better proxy for vehicle size and resulting utility than mass, footprint seems favourable from a consumer perspective and might increase the acceptance of legislation and other measures (e.g. CO_2 labelling or taxation schemes) based on this utility parameter.

As a result of these arguments, footprint seems to be the favourable utility parameter.

A risk of changing the utility parameter could be that European policy making on cars and CO_2 is perceived by stakeholders as inconsistent, and might make critical stakeholders wonder what changes are to be expected for a next generation standard beyond 2020. The evaluation of alternative utility parameters, however, has made clear that other options generally do not provide any significant advantages compared to footprint but usually do have disadvantages and aspects that make them less practical or even unfeasible in practice. Whereas mass was chosen for the 2015 target, partly because the at least equally attractive alternative of footprint was not available due to the absence of data in the Monitoring Mechanism, there are no alternatives in view now that are potentially better than footprint or mass but can not be applied yet for practical reasons.

Conclusions with respect to the slope of the limit function

A linear utility-based limit function is preferred over truncated utility-based limit functions with floors and ceilings, since in the European market situation floors and ceilings of non-linear limit functions do not have significant impacts unless they are set at unreasonable levels.

Having selected a linear function, the slope can be chosen such that vehicles with higher utility value are allowed proportionally higher CO_2 emissions. However, making the slope too steep can lead to gaming by manufacturers whereby increasing the vehicles utility would bring the vehicle closer to the target line despite additional emissions resulting from the increased mass or footprint. Analysis of various slopes indicates that a 100% slope might be preferred for the 2020 target.

The 100% slope for the 2020 mass-based limit function based on 2009 data is a much flatter absolute slope than the 100% slope for the 2015 limit function based on 2006 data. The 100% limit function for 2020 based on 2009 data is even slightly flatter than the limit function for the 130 g/km target for 2015, which was a 60% slope function based on 2006 sales data. As the 2015 limit function was found to be sufficiently flat to prevent gaming, the slope for 2020 does not need to be lowered below 100%. Footprint is a utility parameter that is more difficult to game with than mass, since changing it requires complex and expensive structural changes to the design and construction of the vehicle. However, to prevent incentives towards larger cars, also here the limit function cannot be too steep.

With respect to the distributional impacts of the slope the following can be concluded:
- Some manufacturers will not be able to meet the target irrespective of the slope, while for very low slope values for both mass and footprint as utility parameters one manufacturer group is not able to meet its specific target.
- A second general conclusion is that costs, to be made for reaching the target, increase with an increasing slope independent of the assessed utility parameter. However, the sensitivity of the average costs to the slope value is relatively small.
- Aiming for an even distribution of the distribution of costs per vehicle over manufacturers is a less appropriate criterion for the 2020 target than was the case for the 2015 target. Between 2002 and 2009 some manufacturers have made more progress than others, and striving for an even distribution of the costs for moving from the 2009 levels to the 2020 targets would punish early movers.

From the point of view of distributional impacts there is also no incentive to move to slopes lower than 100% for the 2020 target.

Conclusions regarding possible additional measures and provisions

Super credits

In the current legislation that was introduced to reach a target of 130 g/km by 2015, super credits were introduced in order to encourage the development and application of propulsion technologies that lead to very low or zero (tailpipe) CO_2 emissions, such as battery-electric or hydrogen fuel cell based powertrains. Such super credits are given to manufacturers until 2015 for every car sold that emits less than 50 gCO_2/km. In calculating the average specific emissions of CO_2, each new passenger car with specific CO_2 emissions of less than 50 g/km is counted as 3.5 cars in 2012 and 2013, 2.5 cars in 2014, 1.5 cars in 2015, and 1 car from 2016 onwards. In principle the super credits mechanism could be re-introduced after 2016 as long as it is discontinued before the next target year, since otherwise it would erode the net impact of the CO_2 legislation. If the super credits mechanism would be applied in the period between 2016 and 2020, the sales of very low CO_2 emitting vehicles (hydrogen or electric) might lead to a decreased incentive for car manufacturers to reduce CO_2 emissions of high emitters, since they can compensate for such vehicles.

Even when the mechanism is only applied between 2015 and 2020 it could result in higher net CO_2 emissions compared to a situation without super credits. This hazard only increases with more vehicles becoming eligible. As discussed above the 95 g/km fleet average target could already be such a strong incentive for manufacturers to market EVs that super credits will be unnecessary as a provision for the 2020 target.

Additional vehicle-based CO_2 limit

The current CO_2 legislation defines for each manufacturer group a specific target for the sales-weighted average CO_2 emissions of the new vehicles sold in 2015. For the 2020 target it could be considered to augment this approach by means of an additional vehicle-based CO_2 limit that requires the emissions of individual vehicles to be below a certain value. This limit may also depend on the vehicle's utility. Vehicles exceeding the limit in 2020 could be excluded from the market or manufacturers could be required to pay a buy-out premium for selling these vehicles.

A vehicle-based limit should ensure that manufacturers also focus on improving the efficiency of high emission vehicles rather than relying on low emission vehicles to offset them. Such a limit would reduce the flexibility that a simple fleet-average target offers the manufacturers, and this may increase the total costs. However, it could also act as a spur for the development of innovative solutions which would produce substantial cuts in vehicle emissions at the upper end of the market, and these solutions could then filter down to the lower and higher volume end of the market as costs reduce.

The analysis carried out in this study demonstrates that it would be feasible to incorporate vehicle-based CO_2 limits into emissions reduction legislation and that a limit could make a useful contribution towards achieving the overall 95g/km target. The cost curves developed for this study show that in most cases vehicle emissions could be reduced to the limit assuming that the correct incentives were in place to stimulate manufacturers to make these reductions.

Various options have been analysed whereby target levels were set in such a way that the different options would provide the same contribution towards meeting the sales-average 95 g/km target. As an example vehicle-based limit functions were defined in such a way that bringing all vehicle to at least the level specified by the limit would result in a sales weighted average of 115 g/km.

In this analysis a linear utility-based limit came out as the most cost-effective option. Truncated linear limit functions with a 'ceiling' result in less stringent limits for smaller vehicles and require a fairly low ceiling value to provide the same contribution to meeting the average target as for the case of a linear limit function. A flat limit has the greatest number of vehicles already under the limit, but is the most expensive of the four options, with disproportionately large reductions being required at the larger end of the market (both in terms of reference mass and in terms of footprint) and very little in the way of reductions being achieved at the smaller end of the market.

The level at which any limit is set will depend on to what extent it is desired that the limit acts to reduce fleet average CO_2 emissions towards 95g/km and the magnitude of the costs which the industry could be expected to bear. For the linear limit function each 5g/km reduction in average CO_2 emissions results in additional cost per affected vehicle in the region of €120 to €185. Particular attention should be paid to the gradient of the limit as this is the principle parameter which defines how the costs are spread across the market. If the gradient is set too steep then the costs shift towards smaller vehicles which tend to be priced lower and sold in greater volumes than larger vehicles.

The cost curves suggest that the reductions necessary to meet the limits can be made in the majority of cases, with only a few thousand vehicles (mostly low volume high performance vehicles) being unable to reduce their emissions to the limit. Revenue generated through a buy-out premium could therefore be expected to be small compared with the costs of emissions reductions and insufficient to justify a feebate (or bonus/malus) system whereby the manufacturers with a high emissions reduction performance would be rewarded using the buy-out credits charged to the manufacturers of vehicles which cannot be reduced below the limit. Instead the premium could exist to ensure that the manufacturers are more likely to adopt emissions reductions as the more cost-effective approach of complying with legislation.

A combined target for passenger cars and vans

Until now CO_2 legislation has been developed and implemented for passenger cars and light commercial vehicles separately. A reason for that is that the two vehicle categories represent different markets, with to a large extent unrelated vehicle models. Given the different characteristics and applications of passenger cars and vans, the two categories may have different CO_2 emission reduction potentials, both from a technical and from an economic perspective.

On the other hand there is also overlap between the categories. The class I and II segments of the van market contain a large share of passenger car derived vans. And even for dedicated van platforms, often engines and other powertrain components are shared with passenger car models.

The latter consideration has motivated the question of whether it would be feasible and beneficial to bring passenger cars and vans under a common regulatory target.

In general three approaches are identified to arrive at a combined target for passenger cars and vans:

1. allowing manufacturers to pool their targets for passenger cars and vans, whereby over- or underachievement in one market can be compensated by under- or overachievement in the other market;
2. setting a single target for the combined sales of passenger cars and vans in combination with a single utility-based limit function that is applied to both passenger cars and vans;
3. bringing vehicles / vehicle platforms that are designed to be both cars and vans at the same time under the passenger car legislation.

Approach 1) is technically feasible for the 2020 targets and does not appear to have major drawbacks in principle. The viability, however, needs to be determined by detailed impacts that go beyond generic arguments. These details can not be assessed at this point in time. An important condition for avoiding undesired consequences is that the marginal costs for meeting the separate targets for passenger cars and vans are about the same. Pooling on the basis of sales and mileage weighted CO_2 emissions is preferred to avoid that shifting reductions from vans to passenger cars leads to a lower net GHG emission reduction at the overall fleet level.

The impacts of approach 2) strongly depend on the choice of utility parameter. Setting a combined utility-based limit function is likely to lead to unattainable targets for either vans (mass) or passenger cars (footprint). The risk of undesirable distributional impacts (disproportionate impacts on a limited number of manufacturers) is considerable, especially given the fact that for reaching the 2020 target manufacturers will have to use a substantial part of the available reduction potential and are thus more likely to “hit the ceiling” of the cost curves.

The main problem with approach 3) is the legal definition of which vans would qualify for inclusion in the (possibly adapted) passenger car target. Also, this option reduces the room for internal averaging which manufacturers have available to meet the specific targets that are set for the remaining light commercial vehicles that do not fall under the passenger car target.

Important factors that hinder the establishment of a combined target without undesired impacts are that:

- the EU27 passenger car sales are 9 to 10 times larger than the sales of light commercial vehicles;
- the new van sales consist almost entirely of diesel vehicles, which have a more limited reduction potential and offer that reduction at a higher cost than petrol vehicles;
- not all manufacturers sell both passenger cars and vans, and even among those that do the proportions are very different.

All in all approach 1) appears the most feasible. However, overall the evaluation of existing evidence with respect to the different approaches does not seem to create a convincing motivation to strive for a combined target for passenger cars and vans. Since a final judgment on the approaches is strongly affected by detailed consequences of the specific way in which the targets are set, the subject would still benefit from closer scrutiny.

Trajectory of declining annual target values, possibly in combination with banking and borrowing

Regulation (EC) No. 443/2009 sets a target of 130 g/km to be met in the period 2015-2019 and a 95 g/km target to be met from 2020 onwards. Between 2015 and 2020 the excess emission, for which manufacturer groups have to pay a penalty, is determined relative to their 2015 target, determined per manufacturer group using the mass-based limit function.

A trajectory of declining annual targets, setting intermediate steps with constant yearly reductions between the 2015 target and the target level set for 2020, can be proposed for two different reasons. First of all it avoids that manufacturers postpone the introduction of fuel efficient technologies to the last years before the target has to be met. Such behaviour would lead to higher fleet-wide CO_2 emissions in the last years than the situation in which efficient cars are introduced earlier in anticipation of the target year. Secondly a trajectory of declining annual targets may increase the likelihood that manufacturer groups actually meet their 2020 specific emissions targets. Such a provision would then involve excess emission premiums relative to the annual targets rather than to the 2015 target.

The analysis carried out shows that a trajectory of declining annual CO_2 targets for manufacturers prior to the 2020 target year can prevent extra CO_2 emissions from the fleet over a longer time period. The impact of stepwise targets on the total annual CO_2 emissions from passenger vehicles in the 2015-2040 period is limited to a few percent relative to a worst case scenario in which manufacturers only implement the required reductions close to the 2020 target year. Still, this difference is equivalent to the effect of an approximately 3 g/km higher fleet average CO_2 level over the period between 2015 and 2040. This indicates that the effect of the declining targets – or of the absence thereof – can be significant, and hence that they should be considered as an additional provision and in particular as a risk management measure.

Banking and borrowing is a recommendable flexibility mechanism in addition to such a trajectory since such short periods between targets leave relatively little headroom for manufacturers to steer for these annual targets. This relates to their possibilities to adjust R&D programmes and model development cycles, but also to exterior developments (e.g. unexpected changes in sales distribution) that can influence a manufacturer’s average CO_2 emission levels. Allowing banking and borrowing offers manufacturers the opportunity to compensate for possible overshooting or undershooting the targets in certain years as a result of these control limitations.

The possible effect on fleet-wide CO_2 emissions of the introduction of banking and borrowing in addition to annual decreasing targets is small as long as the banked or borrowed emission allowances balance is neutralised by the end of the banking and borrowing period and this period is sufficiently short.

Banking and borrowing does not provide an incentive for manufacturers to postpone the application of CO_2 reducing technologies. Due to the strong non-linearity of the cost curves for CO_2 reduction, borrowing CO_2 credits prior to banking increases the net costs of meeting the target averaged over a longer time period. Therefore manufacturers will only delay their CO_2 emissions reduction if the costs of changing their model cycles are higher than the additional costs of compensating for their borrowed CO_2 credits. Hence it is safe to allow banking and borrowing.

In order to manage the risk of manufacturers not being able to balance out a negative amount of CO_2 credits, a maximum amount of borrowed CO_2 credits can be considered.

Mileage weighting

CO_2 regulation is currently defined in relation to the sales-weighted average of type approval CO_2 emissions expressed in gram per vehicle kilometre (g/km). Due to differences in real-world driving patterns and in lifetime mileages of different vehicle types and vehicle applications, this definition lacks a strong connection to the total amount of fuel that is actually consumed, and the environmental impact the purchase of a new vehicle entails.

In principle it is possible to link a vehicle's specific emissions with its total emissions in first order, given that the average usage patterns (mileage) are broadly known for all vehicle types. More detailed, 2nd order estimates of a vehicle's total emissions would require additional information on usage patterns (e.g. distribution over road types or speed-time profiles) in combination with knowledge of how these affect real-world fuel emissions.

As using more detailed estimates of real-world emissions would certainly not be feasible in a legislative context, the analysis carried out in this project has limited itself to making a first exploration of the possibility for and consequences of using a mileage weighted emission target in a regulatory approach to reducing CO_2 emissions from passenger cars. Mileage weighting does not replace sales weighting. Instead weighted averages are determined by multiplying CO_2 emission values if individual vehicles with the product of sales and mileage and dividing the sum of that over all vehicles by the sum-product of sales and mileage over all vehicles.

To be able to set and maintain a mileage weighted target a mileage value needs to be attributed to each vehicle sold. Since vehicles see an evolution of their usage pattern over their lifetime, namely by progressively reducing their annual mileage, lifetime mileage values would be needed to reflect a vehicle's contribution to total emissions. Although targets should still be made manufacturer-specific, mileage weighting does not imply the need to determine and work with manufacturer-specific mileages. In fact, the lifetime mileage value to be attributed at the vehicle level to establish this target can be determined on different levels of detail, and at least as a first-order approach, it would suffice to work with manufacturer-independent, fleet average values. This would make it easier to establish sufficiently representative values as it does not require monitoring the use of all cars. To reflect the fact that vehicles of different size drive different mileages, the mileage value could be defined as a function of the utility parameter. Acknowledging that lifetime mileages are markedly different for petrol and diesel vehicles (and possibly also for other propulsion systems) separate functions for mileage as function of utility should de defined for different fuel types / energy carriers.

To assess possible implications of mileage weighting calculations have been performed using the cost assessment model which was adapted to take account of average lifetime mileages for the 6 vehicle segments, derived from TREMOVE data. The cost model was run, for each of the utility parameters mass and footprint, with the objective of reaching the same amount of total CO_2 emissions as in the non-mileage-weighted case, per manufacturer, at minimal cost. The distribution of reduction efforts between segments thus becomes dependent on the corresponding lifetime mileages.

It was shown that the lifetime emissions total for all vehicles sold in 2020 can be achieved 2% less expensively (equivalent to € 600 million) when mileage is taken on board as weighting parameter in addition to sales. This is due to two reasons. Firstly, larger vehicles with higher emissions generally cover longer distances, thus increasing the emission reductions that can be captured with CO_2 reduction technologies applied to these vehicles. Furthermore diesel vehicles also drive more than petrol vehicles. Emission reduction in diesels is more expensive than for petrol, but due to the higher mileage a lower level of reduction per km is needed to reach the overall target.

Since this task could only consider mileage-based redistribution of the reduction effort (between segments) within the fleet of each manufacturer rather than between manufacturers, potential further cost savings may have been left out. Applying mileage weighting also leads to a different distribution of the contributions of different manufacturers to reaching the overall target. This may have additional cost impacts.

In any case, this task concluded that including mileage as a weighting parameter:

- can contribute to a greater efficiency in reaching EU GHG emission targets;
- makes the achieved net GHG emission reduction insensitive to the way in which manufacturers choose to distribute their reduction efforts over different market segments / models;
- will help to reach the intended overall GHG emission reduction in a more cost-effective manner by taking account of the fact that CO_2 emission reduction technologies have more impact in cars that drive more.

But more analysis is needed to assess the full effects of mileage weighting as well as to further determine practical implications.

A major concern that needs to be addressed is the establishment of robust and accepted mileage values, which at least should be recorded in function of an appropriate utility parameter and the fuel type, but possibly also specific for each manufacturer. This can be done through surveys or improved inspection/reporting procedures, for which discussions with the relevant sectors will be needed.

Conclusions with respect to additional issues affecting the impacts of CO_2 legislation for passenger cars

Greenhouse gas emissions of life-cycle aspects

Changes in vehicle technologies not only affect the CO_2 emissions in the use phase, but may also lead to changes in the GHG emissions occurring in other stages of the vehicle's life cycle, specifically the manufacturing of materials and components, vehicle manufacturing and vehicle disposal and recycling.

For the CO_2-reducing technologies that are expected to be applied to conventional vehicles in response to CO_2 legislation the emission improvements in the use phase are found to more than outweigh additional emissions from the manufacturing phase. Application of light-weight materials is found not to increase CO_2 emissions from vehicle production.

A review of recent life cycle assessment studies showed that for hybrid, plug-in hybrid and battery-electric vehicles GHG emissions in the production and end-of-life phase are significantly increased compared to conventional vehicles. For battery-electric vehicles the additional GHG emissions divided by the lifetime mileage are estimated to amount between 5 and 20 g/km. The value varies with battery size, type and energy density. However, there is quite a large variation in the literature on this issue, and differences between studies can not always be explained by these factors. Nevertheless it is clear that emission from production of battery-electric vehicles are non-negligible although in most countries still more than outweighed by the GHG emission advantages that these vehicles have in the use phase.

Rebound effects of improved fuel economy

CO_2 regulation has an impact on the purchase price of new vehicles, as well as on the cost of driving. This may affect both purchasing behaviour and driving behaviour. The initial hypothesis, which requires confirmation and quantification, is that lower driving costs will increase driven mileage, cause people to drive with less attention to their fuel consumption, and thus cause extra CO_2 emissions. This is a rebound effect that reduces the net impact of the regulation.

A first order assessment has been carried out on the basis of elasticities and other applicable economic methodologies found in literature as well as a detailed analysis of results from previous TREMOVE calculations, carried out in relation to the CO_2 legislation for passenger cars. The literature review concludes that the elasticity of fuel consumption with regard to fuel price is between -0.25 (short term) to -0.6 (long term). As a result a 27% improvement of fuel efficiency, associated with the step from 130 g/km to 95 g/km[5] leads to a net reduction in CO_2 emissions of 22.1% (ST) and 15.2% (LT) due to the rebound effect of lower cost of fuel. Elasticities for car ownership and usage in relation to purchase price could not be found in literature. The analysis of TREMOVE runs indicates that the combination of improved fuel efficiency and a price increase of 15% may lead to 1 - 2% additional fuel saving (positive knock-on consequence instead of rebound effect).

Considerations on the relation between costs and prices

Since the adoption of Regulation No 443/2009 CO_2 emissions from new cars have declined significantly. At the same time average car prices in the EU appear to have been decreasing in real terms in recent years. This could be interpreted as proof that CO_2 reductions are possible at negligible costs, suggesting that the costs of reducing CO_2 emissions from passenger cars have been overestimated in studies underlying the Impact Assessment carried out for Regulation No 443/2009.

In this as well as previous studies the additional costs for meeting the target are calculated relative to an “all-else-remaining-equal” baseline. Relative to this baseline the application of additional technology is expected to involve additional costs. How these costs affect prices first of all depends on ways in which manufacturers are able to pass through these costs. Whether pass through of costs consequently leads to net increase in real car prices depends on the baseline price development upon which the increases are superimposed. A multitude of factors determine the baseline price development. These include e.g. increased commonality of parts and sharing of platforms and powertrains, relocation of production and manufacturing, improved operations with respect to e.g. managing inventories and supplies, reducing manufacturing costs, reducing costs of other components than the ones applied to reduce CO_2 emissions, and increased pressure on other parts of the value chain to reduce costs. Furthermore vehicle prices are affected by resource prices, exchange rate fluctuations and changes in taxation. As a result it is concluded that the fact that average car prices appear to have declined in real terms over the last years does not provide evidence that ex ante assessments overestimated the costs for meeting the 130 g/km target. At the same time there is also no proof of the contrary.

[5] 27% = 1 – 95/130

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1 Introduction

1.1 Context and objective of this project

In COM(2007) 19[6] and SEC(2007) 60[7] the European Commission outlined its plans for a Community Strategy for reaching the EU objective of reducing CO_2 emissions from new passenger cars to 120 g/km in 2012. The Commission proposed an Integrated Approach. The main element of this approach was a regulatory framework for reducing the CO_2 emissions of the average new passenger car fleet to 130 g/km by means of improvements in vehicle technology. To bridge the gap between this new passenger car fleet average and the 120 g/km goal the Integrated Approach comprises additional elements, like setting minimum efficiency requirements for air-conditioning systems, compulsory fitting of accurate tyre pressure monitoring systems, setting maximum rolling resistance for tyres, use of gear shift indicators, efficiency target for vans and the increased use of biofuels. This strategy has been evaluated by the European Commission in 2010 [EC 2010].

In December of 2007 the Commission presented a detailed proposal[8] and accompanying Impact Assessment[9] for the regulatory framework to achieve a new car fleet average of 130 g/km.
In December 2008 the European Parliament and Council reached an agreement through a co-decision procedure on the details of the CO_2 legislation for passenger cars, laid down in Regulation No 443/2009[10]. Some important elements of the agreement include:

- Limit value curve: the fleet average to be achieved by all new passenger cars registered in the EU is 130 grams per kilometre (g/km). A so-called limit value curve implies that heavier cars are allowed higher emissions than lighter cars while preserving the overall fleet average. Manufacturers will be given a target based on the sales-weighted average mass of their vehicles.
- Phasing-in of requirements: in 2012 65% of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation. This will rise to 75% in 2013, 80% in 2014, and 100% from 2015 onwards.
- Long-term target: a target of 95 g/km is specified for the year 2020. The modalities for reaching this target and the aspects of its implementation will have to be defined in a review to be completed no later than the beginning of 2013.

A number of implementing measures, detailing various provisions and procedures of the CO_2 legislation for cars, are still to be designed and adopted through a comitology procedure. These implementing measures cover issues relating to[11]:

- special derogations for niche and small volume manufacturers and for market entrants;
- monitoring CO_2 emissions and other features (e.g. footprint) from newly registered light duty vehicles;
- the contribution of so-called “eco-innovations” to CO_2 reductions
    - These are technical measures applied to vehicles which reduce the energy consumption and CO_2 emissions under real-world driving conditions but that do not affect the CO_2 emissions as measured on the type approval test. Examples are waste heat recovery, solar roofs and LED lighting.

An important development, especially with respect to the target for 2020, is the on-going work in UN-ECE (GRPE) work on defining a new light-duty vehicle test procedure (with the focus on developing a representative and world-harmonised driving cycle). This revised test procedure should better reflect real-world driving conditions and should take into account whenever possible the contribution of eco-innovations. Adoption of a new test cycle would require translation of the 95 g/km target, defined on the NEDC cycle, to an equivalent target for the new cycle. Other changes in the test

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6 COM(2007) 19: Results of the review of the Community Strategy to reduce CO_2 from passenger cars and light commercial vehicles, 7.2.2007.
7 SEC(2007) 60, Impact Assessment, accompanying document to COM(2007) 19, 7.2.2007.
8 COM(2007) 856, Proposal for a Regulation of the European Parliament and of the Council setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles, 19.12.2007.
9 SEC(2007) 1723, Proposal from the Commission to the European Parliament and Council for a Regulation to reduce CO_2 emissions from passenger cars, DRAFT Impact Assessment, 19.12.2007.
10 REGULATION (EC) No 443/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community’s integrated approach to reduce CO_2 emissions from light-duty vehicles, see: http://ec.europa.eu/environment/air/transport/co2/co2_home.htm
11 See http://ec.europa.eu/clima/documentation/transport/vehicles/cars_en.htm

procedure (test conditions, tolerances) may also require further work in the definition of the 2020 target.

In the CO_2 and cars regulation (Regulation (EC) No 443/2009) it is stated in Article 13 that a review would be carried out by the European Commission no later than the beginning of 2013 in order to define the modalities of reaching the 95 g/km target for the new car fleet by 2020. The support for this review is currently being carried out within the Framework Contract on Vehicle Emissions by TNO, in association with AEA, CE Delft, Ökopol, Ricardo, TML and IHS Global Insight (Reference ENV.C.3/FRA/2009/0043).

1.2 This report

Work in this project is organised in the following tasks and subtasks.

1. Cost and potential of CO_2 reduction options for 2020 and further
Task 1.1 Cost and potential of CO_2 reduction options for the longer term
Task 1.2 Current state-of-the-art technologies
Task 1.3 Model cycles
2. Alternative utility parameters
Task 2.1 Database consolidation
Task 2.2 Footprint
Task 2.3 Transport utility
3. Modalities for 95 g/km in 2020
Task 3.1 Preliminary evaluation of options for modalities
Task 3.2 Update of cost assessment model for passenger cars
Task 3.3 Assessment of average additional vehicle costs per manufacturers for manufacturer-based modalities
Task 3.4 Assessment of impacts of vehicle based CO_2 limit
Task 3.5 Development of cost assessment model for assessment of combined target for passenger cars and vans
Task 3.6 Assessment of impacts of a combined target for passenger cars and vans
Task 3.7 Evaluation of results for various options and development of proposals for favourable modalities
4. Investigation of further aspects
Task 4.1 Consequences of additional provisions in the definition of the 2020 target
Task 4.2 Consequences of mileage weighting
Task 4.3 CO_2 emissions of various life-cycle aspects
Task 4.4 Rebound effects
5. Best available technologies in 2007
Task 5.1 Analysis of IHS database

Task 5 was a review providing input to the definition of provisions for derogation in the present legislation, specifically the derogation of new market entrants selling between 10,000 and 300,000 vehicles in 2015. Results have been reported to the European Commission in a separate report.

This report also contains an additional deliverable, included after the core work of Task 3 (Chapter 14). This note focuses on the link between the costs associated with the introduction of CO_2 reduction technology and car prices.

2 Cost curves for passenger cars on petrol and diesel

2.1 Introduction

This chapter describes the development of cost curves for CO_2 reduction in passenger cars by means of technical measures aimed at achieving CO_2 emissions of 95 g/km for new passenger cars in 2020. The applied method is similar to the method used in the 2006 study by TNO [Smokers 2006] in which costs curves for the 2012-2015 period were developed, and which have served as the basis for assessing impacts of the 130 g/km target set for 2015. In a more recent study [Sharpe & Smokers 2009] indicative long term cost curves, based on a limited number of technological measures and packages but including expected impacts of learning effects, were constructed as input for a first assessment of possible 2020 target levels. For a more detailed assessment of different modalities for implementing the agreed 95 g/km target, the current study reviews the development of costs and CO_2 reduction potentials of options already identified in the 2006 report, identifies new options and constructs cost corves for 2020 using a methodology that is largely the same as the one used for the 2006 study. The method description is partly taken from that 2006 study, but dissimilarities are mentioned explicitly. Also in this case the work was carried out in four main steps:

- collection of information on reduction potentials and costs of technological measures for reducing CO_2 emissions from passenger cars on petrol and diesel, on the basis of literature review, in house expertise and consultation of car manufacturers and component suppliers and their industry associations;
- identification per technical measure of the costs and CO_2 reduction potential to be used for constructing cost curves;
- estimating total costs and CO_2 reduction potentials of all possible packages of technical measures that can be combined;
- defining cost curves on the basis of the "clouds" of data points generated by the costs and CO_2 reduction potential of all feasible packages.

Differences mainly concern improvements in the approach for drawing cost curves on the basis of data for a large number of packages of individual measures.

In section 2.2, the methodological aspects are explained in detail, clarifying assumptions and definitions. Thereafter, in section 2.3 the technological options and the corresponding reduction potentials and costs are presented as well as the resulting cost curves. In section 2.5, the constructed curves are compared to curves presented in previous studies. Conclusions are drawn in section 2.7.

2.2 Methodology for developing cost curves

2.2.1 Goal of developing cost curves

This study 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 95 g/km goal. These measures include technical options to improve engine and powertrain efficiency and to reduce vehicle weight and resistance factors.

2.2.2 Approach

As stated before, the starting point for the analysis are the methodology and results of a previous 2006 TNO study [Smokers 2006]. Data collection formats and other parts of the methodology for that study were used now to assess the costs and reduction potentials of technical measures for the 2020 period.

As in the 2006 study, baseline vehicles are identified for three car segments and two fuel types, i.e. small / medium / large passenger cars on petrol and diesel. The baseline vehicle is defined as a passenger car lacking the CO_2 reduction technologies identified by the framework partners and the various parties that filled in the questionnaire. Since cars in the year 2002 fit these characteristics well, the average new sold car in 2002 is used as the baseline vehicle. All costs and reduction potentials for individual measures identified in this report are relative to that 2002 baseline vehicle. Therefore, the baselines are calculated as sales weighted averages of cars sold in the three segments in 2002.

These market segments are defined based on the typical marketing division as follows. Names in brackets are IHS Global Insight defined segments:

- A: City (A)
- B: Supermini (B)
- C: Lower Medium (C1 + C2)
- D: Upper Medium (D1 + D2)
- E: Executive (E1)
- F: Luxury (E2)
- G: Super Luxury / Sports (F1 + F2)
- Small MPV (MPV-B + MPV-C)
- Standard MPV (MPV-D)
- Luxury MPV (MPV-E)
- Compact SUV (SUV-A, SUV-B + SUV-C)
- Standard SUV (SUV-D)
- Luxury / Full Size SUV (SUV-E)

For the purpose of this study, “medium” is defined as segment C, while “small” and “large” encompass the classes below and above C, respectively.

As a starting point for discussions with and information collection from industry representatives and independent experts a table has been drawn up by the consortium, listing a wide range of relevant individual technical measures (introduced after 2002) at the engine, powertrain or vehicle level. This table has been completed by collecting information (e.g. costs and CO_2 reductions of technical measures) from the following sources:

- various stakeholders, e.g. car manufacturers, component suppliers and their European associations;
- independent experts within the consortium and
- additional literature review (e.g. [Lotus 2010], [Valentine-Urbschat & Bernhart 2009], [Hucho 2009] and [Imam et al. 2009]).

For collecting information from industry a questionnaire has been developed, with clear specification of the requested data and useful explanations. Consultation of the industry was coordinated through the associations ACEA and CLEPA and various individual manufacturers and component suppliers. The European Commission sent this questionnaire to ECEA and CLEPA, which also submitted responses to this questionnaire themselves.

Information from the various sources has been critically assessed in order to arrive at single point estimates for the costs and CO_2 reduction potential (as measured on the NEDC cycle) of individual technologies to be used as input for the formation of cost curves.

Subsequently, all possible packages of technical measures have been identified in which two or more of the above technical options can be combined for application in a vehicle. For each package the overall CO_2 reduction potential (in [%] compared to baseline) and additional costs (in [€]) of each possible package has been determined.

Finally the cost curve approach from [Smokers 2006] is used to assess additional costs at the vehicle level 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 respectively diesel.

2.2.3 Cost definitions

In the context of this study three main cost definitions are discerned:

- manufacturer costs = ex-factory costs assuming large-scale production volumes
- costs to society, to be used in the calculation of CO_2 abatement costs = all costs excluding taxes
- consumer costs = retail price including taxes

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.). As said, manufacturer costs are based on the presumption of large-scale production. (> 100,000 p.a. per manufacturer)

The costs of technical measures to reduce CO_2 emissions, which are assessed in the following chapter, are expressed as manufacturer costs.

2.2.4 Definition of CO_2 emission reduction potential

The 95 g/km target as defined for 2020 in the CO_2 legislation for passenger cars, laid down in Regulation No 443/2009, relates to the average emission of new passenger cars as measured in the Type Approval test. This test uses the NEDC driving cycle and prescribed testing conditions. As a consequence all CO_2 reduction potentials estimated in this report for the purpose of constructing cost curves are valid for the CO_2 emission as measured on the Type Approval test.

The real-world (RW) emissions and fuel consumption of vehicles can differ significantly from the values measured on the Type Approval (TA) test. 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 [Smokers 2006]. In that study an average factor of 1.195 is derived for use in assessments of net CO_2 emission reductions and fuel cost savings over the lifetime of a vehicle. 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 [Ligterink 2010] between these advanced vehicles and vehicles with more conventional power trains.

2.2.5 General considerations

In the assessments presented in section 2.3 the following considerations have been taken into account:

- Through economies of scale and learning effects production volumes influence production costs. Generally new technologies become cheaper as more are produced. The TNO-study in support of defining the Euro 5/6 legislation [Gense 2006] 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 this CO_2 focussed 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).
- Experience from [Smokers 2006] 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.
- Technical changes made to vehicles in order to comply with Euro 6 emission limits are considered to have no significant effect on the CO_2 emissions for new Euro 6 cars. For petrol vehicles this is based on the fact that the emission limits for new petrol Euro 6 vehicles are only marginally different from the limits for Euro 5. For Euro 6 diesel vehicles it is assumed that additional energy losses caused by the applied NO_x aftertreatment technology are compensated by the engine efficiency gains that can be obtained as a result of allowing higher engine out NO_x emission.
- Impacts of legislation concerning safety aspects and the end-of-life vehicle Directive are not taken into account.

2.3 Technical options to reduce CO_2 emissions at the vehicle level

2.3.1 Technological options for reducing TA CO_2 emissions from passenger cars

In [Smokers 2006] 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 up to 2015. In this study – namely task 1.1.1, which took the list in the Inception Report as a starting point – that list has been expanded to also include options that have recently become available but were not yet in the list or that may become available after 2015 to achieve further CO_2 emission improvement in the period up to 2020 and even beyond. As a starting point for the assessment the reduction potential of individual options is assessed relative to a baseline vehicle.

The baseline vehicles

Using Polk Marketing Systems data from 2002, six baseline vehicles lacking CO_2 reduction technologies have been identified, as depicted in Table 6. These values differ from the baselines defined in IEEP 2004, due to improved insights in the segmentation of specific passenger car models. The baseline technologies for these six baseline vehicles have been identified as presented in Table 7.

Table 6 Specifications of baseline vehicles, CO_2 emissions represent TA values

Averages	Petrol, Small	Petrol, Medium	Petrol, Large	Diesel, Small	Diesel, Medium	Diesel, Large	Grand Total
Total CO_2 (g/km)	148.7	188.6	264.2	122.8	157.0	212.9	166.6
Vehicle mass (kg)	956	1282	1698	1046	1396	1816	1246

Source: developed from Polk Marketing Systems data.

Table 7 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)

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

CO_2 reduction potential and costs of individual options

Based on an evaluation of the data obtained from literature (as listed in separate section 2.8) and from various stakeholders, as described above, a final data set has been constructed, describing the assumed CO_2 reduction potential and additional costs (in 2010 Euros) of the various individual technologies studied in this chapter[12]. These data, listed in Table 8 and Table 9, 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 2020 target of 95 g/km. These measures do not include full electrification, since this is not so much a technology to be applied to existing cars with existing petrol or diesel engines, but

[12] These estimated costs, reduction potentials and resulting cost curves are the consortium's view based on information supplied and does not necessarily represent the Commission's view.

rather a new powertrain technology. More information on key components in plug-in hybrid and electric vehicles can be found in task 1.1.9. On the other hand, since hybridisation is an adaptation to petrol or diesel cars, this technology is taken into account.

The cost data presented in Table 8 and Table 9 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. Naturally some of these technologies have already been introduced since 2002 for the purpose of achieving the 2015 target. The additional manufacturer costs do not represent the retail price increase. In fact, sales prices cannot be forecasted or derived from manufacturing costs with enough precision to drive policy choices. They are determined by (among other factors) OEM marketing and product development strategies and often have only limited relation with the actual costs to develop and build specific vehicles. Additional manufacturing costs can be estimated more robustly.

The data provided by the various car manufacturers and component suppliers were rather similar, especially when comparing the reduction potential per Euro. Moreover, these inputs were comparable with values estimated by TNO and Ricardo experts. Given this observation and 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, numbers presented in Table 8 and Table 9 will not be motivated in detail.

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.

Moreover from the tables it can be observed that the costs for micro hybridisation is different for the three different petrol segments but not for the three different diesel segments. For petrol cars additional battery capacity needs to be installed to operate lighting, cabin ventilation, in car entertainment and other electrical equipment during vehicle stand still with the internal combustion engine stopped. Contrarily, diesel cars already have this capacity installed for glow plug operation, which is not needed for re-starting. Therefore this capacity can be utilized to power other electrical components during idling. Besides additional battery capacity, a DC-DC converter is also needed to supply a steady voltage to said electrical components. This DC-DC converter is needed for petrol and diesel cars alike.

Moreover, in contrary to the 2006 study, in which cost curves for 2012-2015 were constructed, the measure “continuously variable transmission” is now taken into account. However, the measure “dual clutch transmission”, which is based on the same reduction aspect, is indicated as a more cost efficient measure. As a result the continuously variable transmission is not included in the most cost effective package of CO_2 reducing measures.

One further difference requires a reference: on the TNO 2006 study it was decided to attribute only 75% of the additional costs for hybridization (mild + full) to the CO_2 policy. The motivation for that was that hybrid powertrains not only reduce fuel consumption but were also believed to have features that increase the added value to the consumer. Examples of that are increased torque at low speed, increased peak power, seamless and automated transmission, which contribute to either performance or comfort.

In this study 100% of the costs for hybridization are attributed to the cost curve and the CO_2 policy. The reason for this is that the added value identified above is true in comparison with baseline vehicles, but is much less apparent in comparison to alternative technologies that may be applied to reach 95 g/km in 2020. Looking at vehicles that are already coming to the market one can see that e.g. combinations of direct injection in petrol engines, engine downsizing with application of turbo compression, and dual clutch transmission with more than 6 speeds are used to create vehicles with significantly lower fuel consumption and at the same time higher performance and smoother driving. Overall it is thus still true that technologies applied to meet future CO_2 targets can have added value in terms of performance and comfort, but quantifying the differences between different routes for reaching 95 g/km is a dubious exercise. Furthermore one can argue that although these technologies also bring added value to the user, the large-scale application of especially the more advanced and costly options would not be considered by manufacturers in the absence of CO_2 legislation. For these reasons it was decided to attribute all costs to the CO_2 policy in the current assessment.

As can be seen from the comparison of cost curves in section 2.5, the above described change in dealing with the costs of hybridization will not affect the costs for reaching 95 g/km. The lower envelope of the “clouds” of packages in the figures in Annex A is dominated by packages based on various levels of engine downsizing, so that changes in assumptions on hybrid technologies do not significantly alter the cost curves.

Table 8 Reduction potential and estimated additional manufacturer costs of technical options[13] to reduce CO_2 emissions of passenger cars on petrol, assuming large scale production by 2020

Technology options for petrol cars		Small		Medium		Large	
	Description	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]
Engine options	Gas-wall heat transfer reduction	3	50	3	50	3	50
	Direct injection, homogeneous	4.5	180	5	180	5.5	180
	Direct injection, stratified charge	8.5	400	9	500	9.5	600
	Thermodynamic cycle imporvements e.g. split cycle, PCCI/HCCI, CAI	13	475	14	475	15	500
	Mild downsizing (15% cylinder content reduction)	4	200	5	250	6	300
	Medium downsizing (30% cylinder content reduction)	7	400	8	435	9	510
	Strong downsizing (>=45% cylinder content reduction)	16	550	17	600	18	700
	Cam-phasing	4	80	4	80	4	80
	Variable valve actuation and lift	9	280	10	280	11	280
	Low friction design and materials	2	35	2	35	2	35
Transmission options	Optimising gearbox ratios / downspeeding	4	60	4	60	4	60
	Automated manual transmission	5	300	5	300	5	300
	Dual clutch transmission	6	650	6	700	6	750
	Continuously variable transmission	5	1200	5	1200	5	1200
Hybridisation	Start-stop hybridisation	5	175	5	200	5	225
	Micro hybrid - regenerative breaking	7	325	7	375	7	425
	Mild hybrid - torque boost for downsizing	15	1400	15	1500	15	1500
	Full hybrid - electric drive	25	2250	25	2750	25	3750
Driving resistance reduction	Mild weight reduction	2	128	2	160	2	192
	Medium weight reduction	6	320	6	400	6	480
	Strong weight reduction	12	800	12	1000	12	1200
	Lightweight components other than BIW	2	120	2	150	2	180
	Aerodynamics improvement	2	50	2	50	1.5	60
	Tyres: low rolling resistance	3	30	3	35	3	40
	Reduced driveline friction	1	50	1	50	1	50
Other	Thermo-electric waste heat recovery	2	1000	2	1000	2	1000
	Secondary heat recovery cycle	2	200	2	200	2	200
	Auxiliary systems efficiency improvement	12	420	12	440	12	460
	Thermal management	2.5	150	2.5	150	2.5	150

[13] In contrast to [Smokers 2006] this report distinguishes weight reduction on the 'body in white' and weight reduction on other components within the category of 'driving resistance reduction'.

Table 9 Reduction potential and estimated additional manufacturer costs of technical options[14] to reduce CO_2 emissions of passenger cars on diesel, assuming large scale production by 2020

Technology options for diesel cars		Small		Medium		Large	
	Description	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]
Engine options	Combustion improvements	2	50	2	50	2	50
	Mild downsizing (15% cylinder content reduction)	4	50	4	50	4	50
	Medium downsizing (30% cylinder content reduction)	7	400	7	450	7	500
	Strong downsizing (>=45% cylinder content reduction)	15	500	15	600	15	700
	Variable valve actuation and lift	1	280	1	280	1	280
Transmission options	Optimising gearbox ratios / downspeeding	3	60	3	60	3	60
	Automated manual transmission	4	300	4	300	4	300
	Dual clutch transmission	5	650	5	700	5	750
	Continuously variable transmission	4	1200	4	1200	4	1200
Hybridisation	Start-stop	4	175	4	200	4	225
	Micro hybrid - regenerative breaking	6	375	6	375	6	375
	Mild hybrid - torque boost for downsizing	11	1400	11	1500	11	1500
	full hybrid - electric drive	22	2250	22	2750	22	3750
Driving resistance reduction	Mild weight reduction	1.5	128	1.5	160	1.5	192
	Medium weight reduction	5	320	5	400	5	480
	Strong weight reduction	11	800	11	1000	11	1200
	Lightweight components other than BIW	1.5	120	1.5	150	1.5	180
	Aerodynamics improvement	2	50	2	50	1.5	60
	Tyres: low rolling resistance	3	30	3	35	3	40
	Reduced driveline friction	1	50	1	50	1	50
Other	Thermo-electric conversion	2	1000	2	1000	2	1000
	Secondary heat recovery cycle	2	200	2	200	2	200
	Auxiliary systems improvement	11	420	11	440	11	460
	Thermal management	2.5	150	2.5	150	2.5	150

[14] In contrast to [Smokers 2006] this report distinguishes weight reduction on the 'body in white' and weight reduction on other components within the category of 'driving resistance reduction'.

2.4 Generation of cost curves for packages of technical measures

Using the methodology as described in [Smokers 2006] those options from the lists in Table 8 and Table 9 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 $E_{package}$ of a vehicle with a package of n CO_2 reducing options is estimated as:

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

with δ_i the CO_2 emission reduction of technical option i relative to the CO_2 emission of the baseline vehicle $E_{baseline}$.

The additional manufacturer costs $C_{package}$ of a vehicle with a package of n CO_2 reducing options are calculated as:

$$C_{package} = \sum_{i=1}^{n} C_i$$

with C_i the additional manufacturer cost of technical option i.

Obviously the above formula for assessing the overall CO_2 reduction potential is a 1st order 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 hybridization 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 therefore be smaller than 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 is a time consuming and information intensive exercise that could not be performed within the budget and scope of this study. However, some information from available powertrain simulations has been incorporated in the process of drawing costs curves. This information has been used to develop a so-called "safety margin" that is used in this methodology to correct for possible double counting of reduction potentials.

This safety margin can considered to also serve an additional purpose. The cheapest packages for a given reduction level are 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.

It is reasonable to assume that the safety margin is the largest at the end of the cost curve, where many technologies are combined to reach high reduction potentials, and that the correction factor should decrease for points on the cost curve with smaller reduction levels. This has been implemented by defining a correction factor ($1 - \gamma$) that scales linearly with the reduction level, starting with $\gamma = 0$ in the origin of the outer envelope and increasing to a preset maximum value at the end point of the outer envelope.

For petrol vehicles the end points of the cost curves are determined using a safety margin γ of 15% (or correction factor of 0.85) applied to the theoretical maximum CO_2 reduction potential. This value for the safety margin was determined based on information available for vehicles in the medium-size category and was subsequently used also for the small and large vehicle categories. The 15% is based on a number of factors:

- Previous work conducted within the consortium which included extensive simulations; see for instance the Ricardo Low-carbon Roadmap [Ricardo 2009], [McLaggan 2007];

- An expert judgement of the total CO_2 reduction potential of an example full hybrid vehicle as available on the market today, but with additional light weighting measures assumed to be applied to both the body in white as well as other components.

For diesel cars a safety margin γ = 5% (correction factor 0.95) was applied to the end point. The process of defining the safety margin was much the same for diesel as for the petrol vehicles[15] but resulted in a lower value. This is caused by the fact that a significant part of the technologies included in the petrol cost cloud are aimed at improving part-load engine efficiency through reducing pumping losses. For diesel engines this is not the case and as such, a smaller safety margin was deemed to be appropriate.

In Figure 5 and Figure 6 the blue dots represent the costs (based on manufacturer cost estimates) vs. net CO_2 reduction of the various feasible packages. The green lines represent the constructed cost curves. Starting point for the x-axis and y-axis in these figures is a 2002 average baseline vehicle of a given class, without any applied CO_2 reduction measures. Similar cost curve figures in which the additional manufacturer costs are plotted as a function of absolute reduction of Type Approval CO_2 emissions are shown in Annex B.

[15] As no diesel hybrids are currently available on the market today, public domain data from prototype vehicles and production-intended vehicles such as the 3008 hybrid HDi was used.

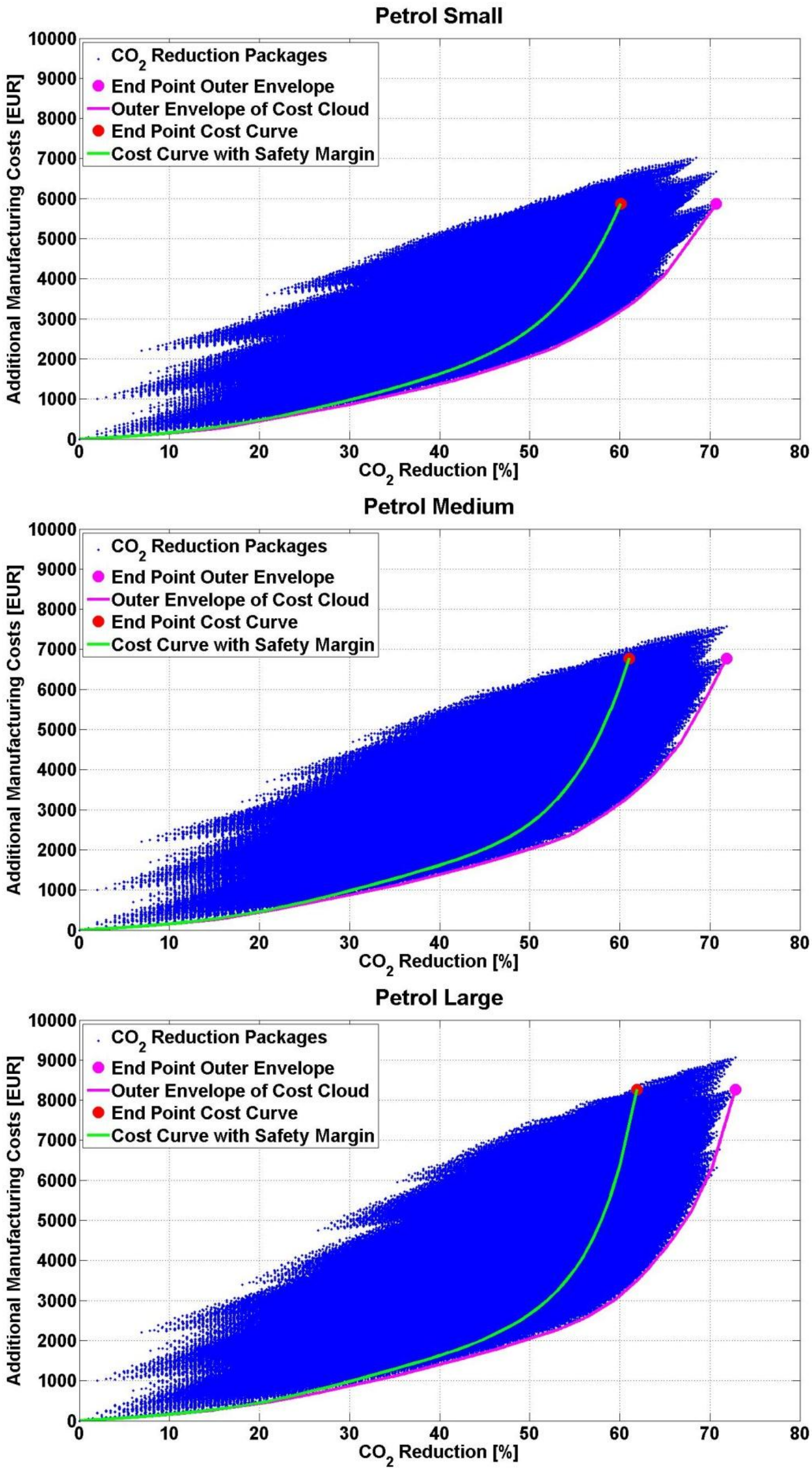

Figure 5 Development of cost curves for CO_2 reduction in petrol vehicles for 2020.

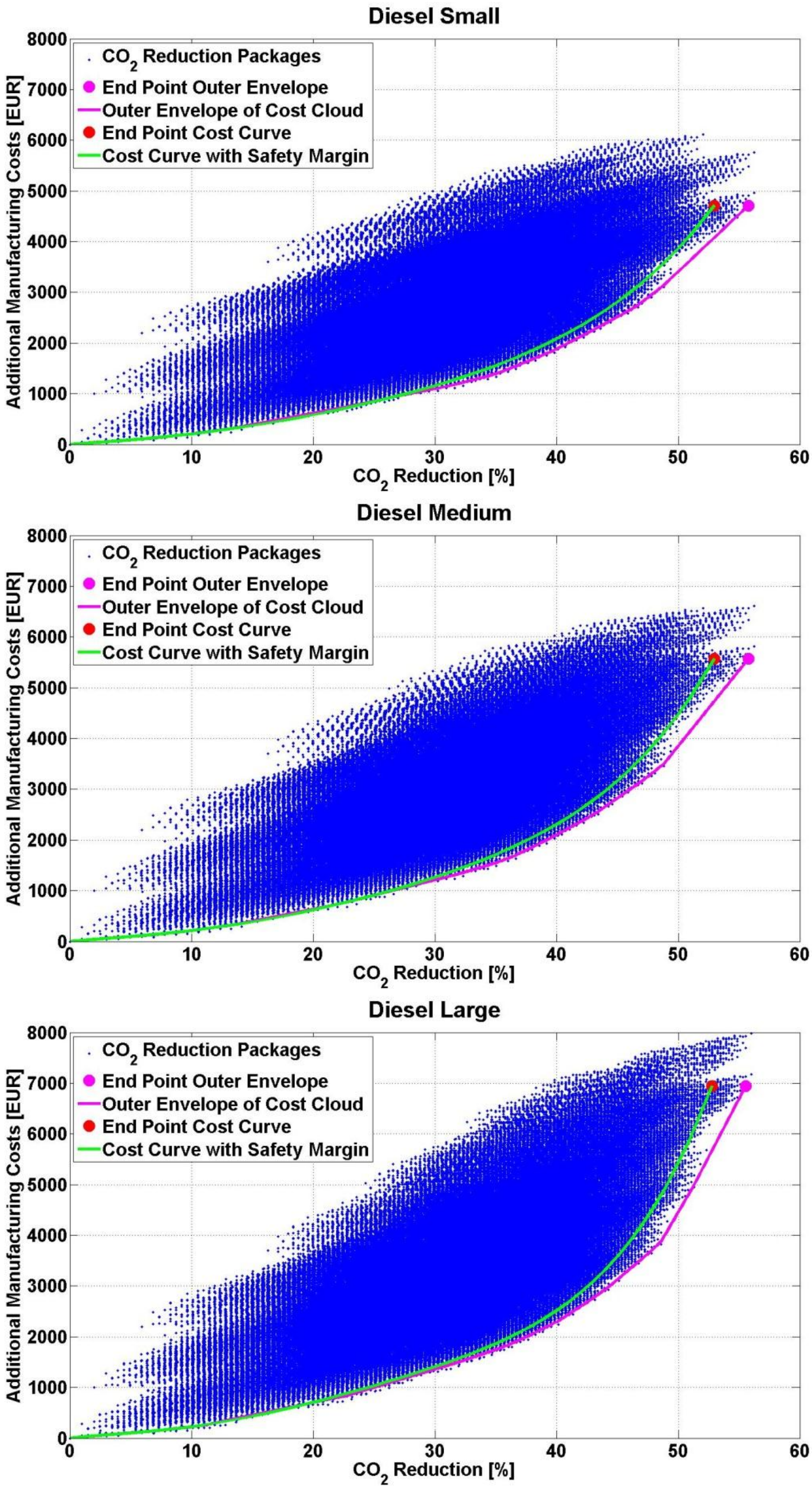

Figure 6 Development of cost curves for CO_2 reduction in diesel vehicles for 2020.

The method for defining the cost curves contains the following steps:

- Definition of the outer envelope
  - Starting point of the exercise is the outer envelope (magenta line in graphs above) of the cloud of data points indicating costs and reduction potentials of all feasible technology packages. The outer envelope is described by a set of anchor points.
- Definition of the end point:
  - At the right end side of the clouds there are two “protrusions” that have almost identical reduction potential but different costs. Given the almost equal reduction percentage, the least expensive package (i.e. the lower of two protrusions) is selected as reference for the end point of the cost curve.
- Application of the safety margin:
  - To obtain the cost curve (green line) the *x*-value (reduction %) of every anchor point on the outer envelope is multiplied by $(1 - \gamma)$ with γ linearly scaling from zero to its maximum value between $x = 0$ and the maximum reduction potential indicated by the outer envelope. This creates a set of anchor points for the cost curve.
- Fitting of polynomials:
  - The cost assessment model used to estimate the costs of meeting the target for individual manufacturer requires cost curves to be defined as continuous mathematical functions. To this end polynomials are fit through the cost curve anchor points generated by the steps described above.
  - To be able to accurately describe the non-linearities in the cost curves the curves have been fitted as n^{th} order polynomials ($y = \Sigma\, a^i\, x^i$ with $i = 1$ to n). To make sure that the marginal costs are monotonously increasing, the fits have been checked to meet the criterium that the 1st and 2nd derivative are positive in the range of reduction levels that are relevant for the assessment (near the origin some “wiggles” can be accepted).

This has resulted in the coefficients a_i for the general cost curve formula:

$$y = \sum_{i=1}^{9} a_i \cdot x^i$$

with x the CO_2 reduction in [%][16] and y the additional manufacturer costs in [€]. For the different size classes of petrol and diesel vehicles the values for the coefficients, together with the approximate end points of the cost curves (maximum achievable reduction and associated cost), are listed in Table 10.

Table 10 Coefficient values and end points for polynomial cost curves for petrol and diesel vehicles in 2020, relative to 2002 baseline vehicles

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S				8.134E+05	-9.302E+05	3.859E+05	-6.922E+04	1.319E+04	6.453E+02	60.1%	5870
p,M				1.207E+06	-1.386E+06	5.381E+05	-7.426E+04	9.017E+03	9.985E+02	61.1%	6775
p,L	9.431E+07	-2.233E+08	2.180E+08	-1.121E+08	3.226E+07	-5.187E+06	4.602E+05	-1.672E+04	1.574E+03	61.9%	8265
d,S					2.193E+05	-1.757E+05	5.709E+04	9.584E+01	1.657E+03	53.0%	4711
d,M					4.147E+05	-3.757E+05	1.308E+05	-9.708E+03	2.151E+03	53.0%	5571
d,L				-1.549E+05	1.069E+06	-8.804E+05	2.701E+05	-2.236E+04	2.585E+03	52.8%	6946

An overview of the resulting cost curves for petrol and diesel is presented in Figure 7 and Figure 8 respectively. From these figures it can be concluded that in general, achieving equal relative CO_2 reductions is more costly for larger vehicles than for smaller vehicles. On a detailed level, this trend can also be observed for individual measures, for example mild weight reduction, applying lightweight components other than BIW and low rolling resistance tyres. Moreover the cost curves for the three petrol vehicles classes are closer to each other than the three cost curves for diesel

[16] In [Smokers 2006] the CO_2 reductions of the assessed measures were defined as absolute values, based on the average TA CO_2 emissions within a segment (small, medium or large). However, since the TA CO_2 emissions within the three segments can still vary quite much per manufacturer, relative reductions seem more realistic for vehicles deviating from the average TA CO_2 emissions within a segment.

vehicles. This is the result of the cost effectiveness of the various measures being more alike for the three classes.

In the current study reductions are presented as relative values on the *x*-axis, while absolute reductions were used in [Smokers 2006]. As a result the cost curves of the three segments are closer together in this report. Many assessed measures result in equal relative reductions for the three segments. Since in general the absolute CO_2 emissions increase with vehicle size, the absolute reductions for these measures do as well.

The figures depicted in Annex A show the positions of the packages including the CO_2 reduction options ‘full hybridisation’ and/or ‘strong weight reduction’. The packages indicated as including ‘full hybridisation can also include the option of ‘strong weight reduction’. As the packages including ‘full hybridisation’ move up in the cloud with increasing vehicle size, it can be concluded that in absolute terms, the cost of a system for full hybridisation is higher for larger vehicles. The fact that the packages including ‘full hybridisation’ move upwards relative to the rest of the packages with increasing vehicle size, implies that costs of the option ‘full hybridisation’ increases more with vehicle size than other options.

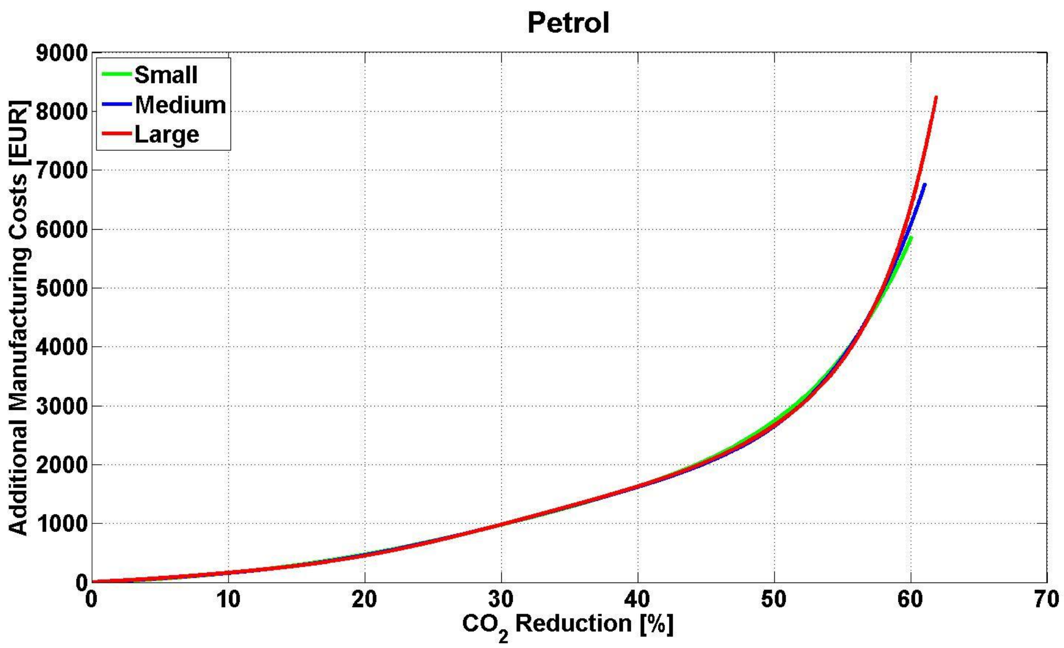

Figure 7 Cost curves for CO_2 emission reduction in petrol vehicles in 2020, relative to 2002 baseline vehicles.

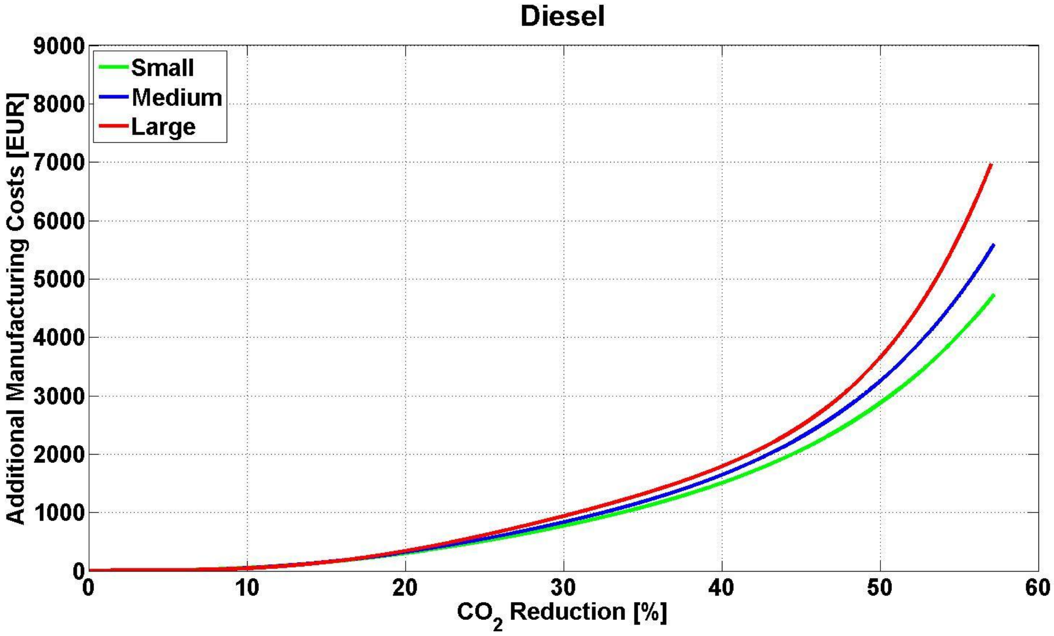

Figure 8 Cost curves for CO_2 emission reduction in diesel vehicles in 2020, relative to 2002 baseline vehicles.

2.5 Comparison between current and previously presented cost curves

As stated before, similar cost curves for achieving CO_2 reduction have been constructed in previous reports. In 2006 a thorough analysis using a methodology very similar to the one used in this report resulted in cost curves for the 2012-2015 timeframe [Smokers 2006]. These cost curves have been used to assess the feasibility of various target levels for 2012 and later for assessing impacts of the 130 g/km defined for 2015. In 2009, a simplified approach was used to generate indicative cost curves for achieving further CO_2 emission reductions in the longer term (2020) [Sharpe & Smokers 2009]. These were used in a preliminary assessment of the feasibility of reaching average CO_2 emissions of 95 g/km in 2020.

In order to compare the current estimates of costs of CO_2 reduction by 2020 with previously estimated costs, cost curves from the previous reports are depicted side by side with the current cost curves in the graphs below. Since in the 2009 report, cost curves were presented for two scenarios (strong engine downsizing and hybridisation) the figures below show two 2009 cost curves per segment.

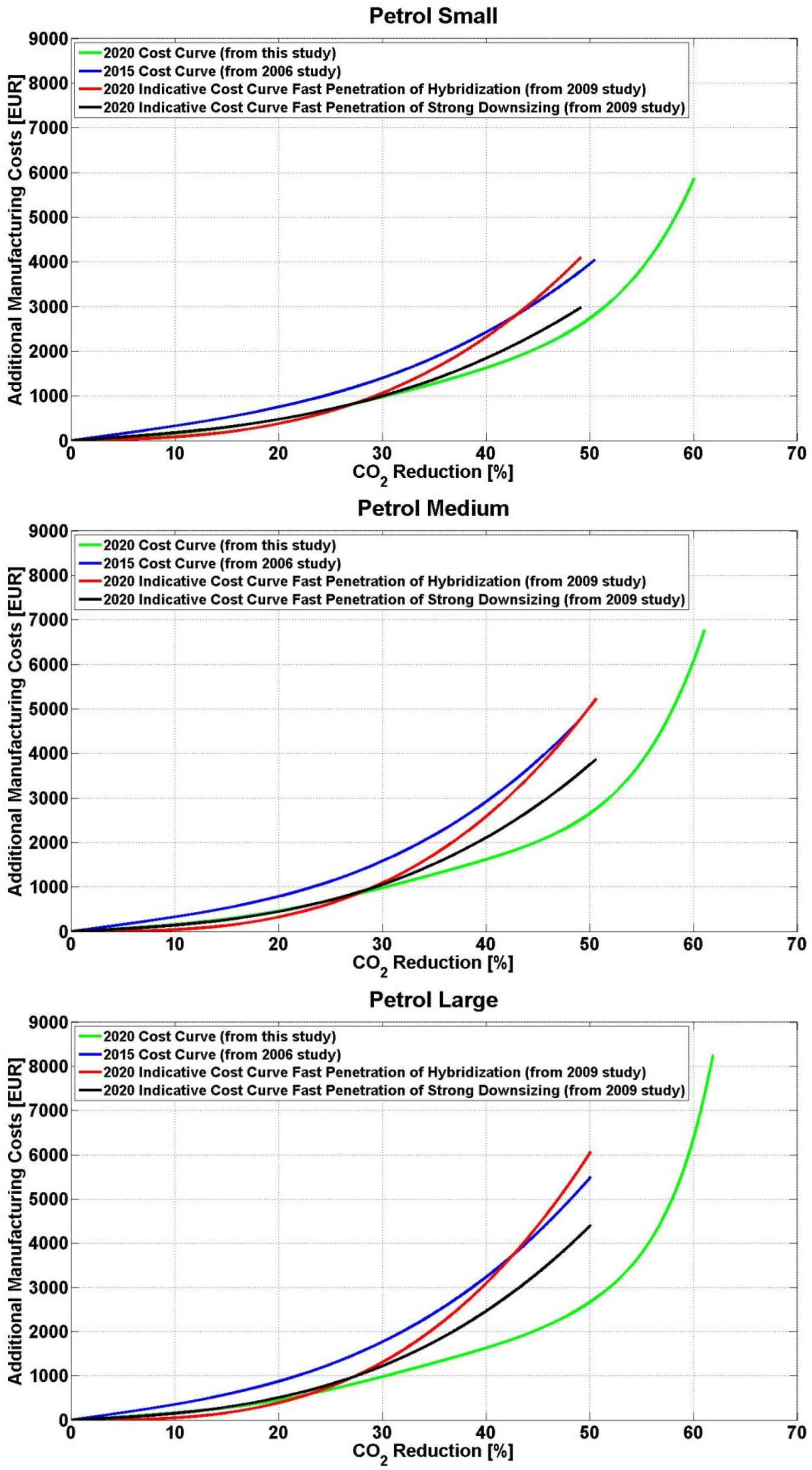

Figure 9 Current cost curves for petrol cars in 2020 compared to cost curves presented in [Smokers 2006] for the 2012-15 timeframe and in [Sharpe & Smokers 2009] for 2020.

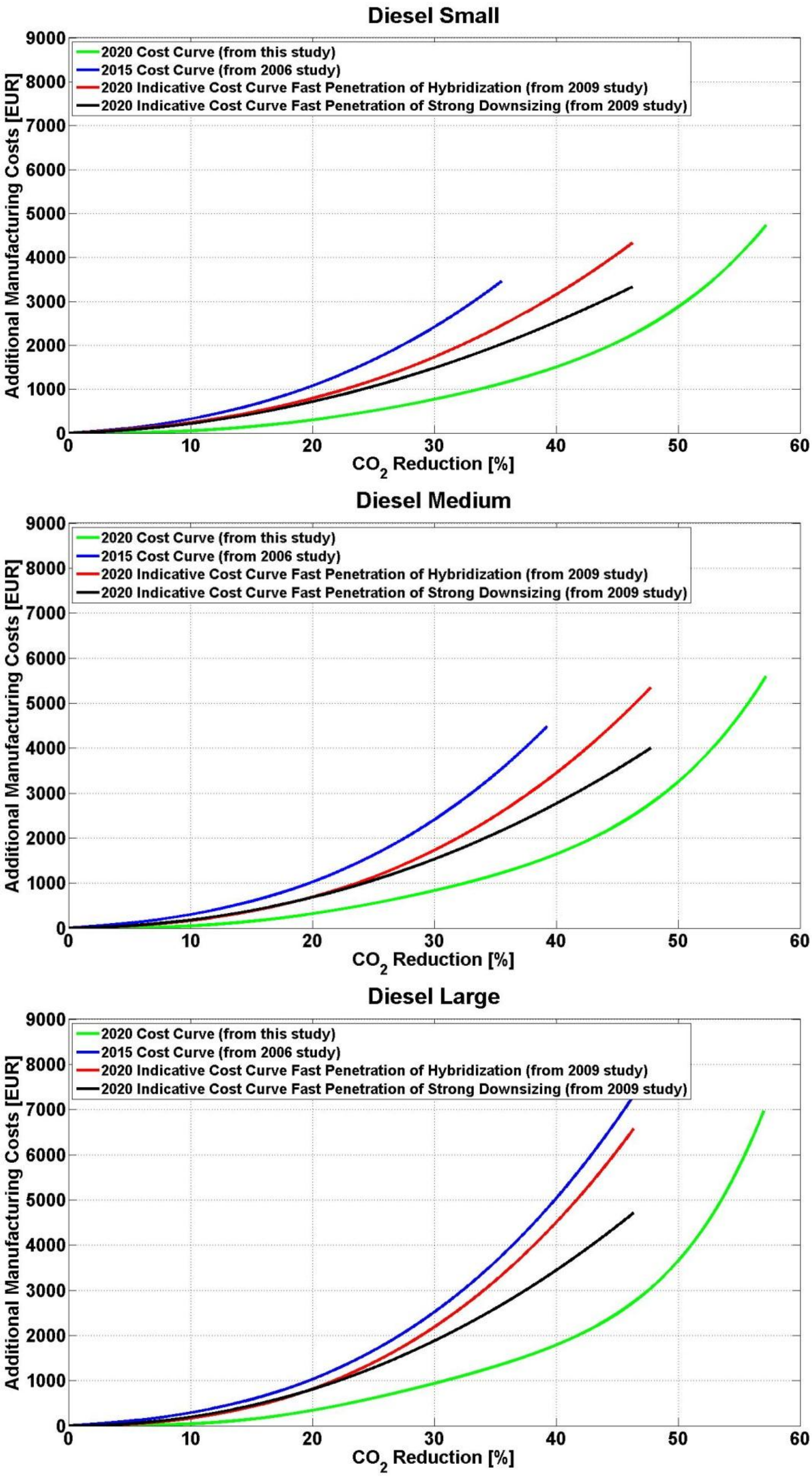

Figure 10 Current cost curves for diesel cars in 2020 compared to cost curves presented in [Smokers 2006] for the 2012-15 timeframe and in [Sharpe & Smokers 2009] for 2020.

In these figures it can be seen that the new cost curves (valid for 2020 and beyond) are all below the 2006 curves (valid for the 2012-2015 timeframe), implying that the estimated costs for the application of available technologies at maturity are already lower than previously expected and could be expected to become lower over time. Moreover, the maximum reduction potential according to the new 2020 curves is higher. For a perspective on the positioning of the options ‘strong weight reduction’ and ‘full hybridisation’, see Annex A.

When comparing the indicative curves for the 2020 time horizon from the 2009 study, based on a simplified approach, and the new 2020 curves from this study the following observations can be made:

- For small reduction potentials in petrol vehicles the new curves are quite similar to the ones from the 2009 study. For diesels the new curves indicate lower costs.
- In the 2009 study strong downsizing was explicitly treated in a separate scenario. The literature at that time indicated the potential of a strong cost advantage over hybridisation with similar reduction potential, making it an attractive option, but the technical maturity of the technology was not yet advanced enough to give confidence that the technology would actually work or be available in the period up to 2020. Based on recent evidence the new cost curves include strong downsizing as a feasible package in the same technology set as hybridisation.
- For large reduction potentials the new cost curves are well below the indicative curves from the 2009 study for both petrol and diesel.

In the comparison with previous studies the consistency between the current cost curves for 2020 and the cost curves from [Smokers 2006] for 2012-15 is most important as these were developed with the same methodology albeit for application to different time horizons.

Differences between the indicative 2020 cost curved from [Sharpe & Smokers 2009]. and the new cost curves from the current study relate to the fact that the earlier curves were indicative and based on a simplified methodology. For the new curves the inputs with respect to costs and potentials of new technologies have been completely updated. Also the new cost curves take into account a more substantiated motivation for the safety margins (as explained in section 2.4) than was the case for the indicative curves developed in 2009. As such the new curves thus fully replace the older indicative curves. The fact that in the higher reduction regions the new curves predict lower costs than the earlier indicative curves, leads to the conclusion that the new cost curves will lead to more positive conclusions on the feasibility of the 95 g/km target for 2020.

2.6 Scenario variants

In the course of the study two issues arose that justified critical evaluation of the cost curves as presented in section 2.4. These issues are:

- Observed progress in CO_2 reduction in European new passenger car fleet in the 2002-2010 period
  - In the last decade CO_2 emissions of new passenger cars have decreased significantly. At the same time vehicle prices have not increased. This could be interpreted as an indication that part of the observed reductions in type approval CO_2 emissions over the last years may need to be attributed to other causes than application of technologies that are included in the cost curves used to assess the costs of meeting the targets for 2015 and 2020.
- Technical data becoming available from EPA studies in support of the US legislation on CO_2 emissions from light duty vehicles
  - These data seem to suggest that the costs of reducing CO_2 emissions in passenger cars could be lower than estimated in this study.

In the context of this study, and given the limited availability of necessary information, both issues can not be dealt with in detail in this study. In order to get a feeling of the possible implication of these issues, however, it has been considered useful to develop indicative cost curves for three different scenario variants that can be used to perform a sensitivity analysis with the cost assessment model. The scenario variants are:

a) Alternative accounting for progress observed in the 2002-2009 period

- Variant including an additional reduction step based on the assumption that a given share of the reductions achieved in the 2002-2009 period can not be attributed to application of technologies that are included in the technology tables underlying the cost curves.
- The assessment model used in this study is based on cost curves defined relative to 2002 baseline vehicles and attributes reductions in CO_2 emissions observed between 2002 and 2009 (most recent database used to describe the current situation) to the use of a part of the reduction potential described by the cost curves. Due to the strong non-linearity of the cost curves the possibility that other causes may be responsible for the observed reductions between 2002 and 2009 could have a significant impact on the assessment of cost for moving from the 2009 values to the 2020 target values.

b) Alternative cost curves based on a modified technology table

- To test the possible impact of the most striking differences between US data and cost and reduction figures used in this study a selection of data on cost and reduction potential derived from the EPA studies, specifically for full hybrids and the various levels of weight reduction, has been used to construct a modified technology table. Using the methodology described in section 2.4 alternative cost curves have been constructed on the basis of this table.
- This variant is created to allow an indicative assessment of the possible implications that information from EPA studies underlying the US CO_2 legislation for cars might have for assessment of the costs of meeting the European target for 2020.

c) Combination of a) and b)

More detailed descriptions of the assumptions underlying these scenarios and the methodology for translating these assumptions into alternative cost curves are given in:

- Annex C for the issue of alternative accounting for progress observed in the 2002-2009 period;
- Annex D for the evaluation of information available from US EPA studies and comparison with SR1 data;
- Annex E for the generation of cost curves to assess possible implications of US data for the European cost assessment.

The resulting cost curves are presented in Figure 11 and Figure 12. Coefficients of the polynomials describing the cost curves are given in Table 11.

Implications of these scenario variants for the average costs for meeting the target are presented in section 10.5.

Table 11 Coefficient values and end points for polynomial cost curves for petrol and diesel vehicles in 2020, relative to 2002 baseline vehicles, representing three scenario variants.

Scenario a) Cost curves incl. alternative accounting for 2002-2009 progress

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S				7.145E+05	-7.982E+05	2.473E+05	7.937E+03	-3.277E+03	3.572E+02	64.1%	5895
p,M				1.275E+06	-1.655E+06	7.128E+05	-9.992E+04	6.760E+03	1.358E+01	65.0%	6795
p,L	3.024E+07	-6.709E+07	6.163E+07	-3.015E+07	8.508E+06	-1.473E+06	1.890E+05	-1.212E+04	4.965E+02	65.7%	8290
d,S					2.220E+05	-2.074E+05	7.218E+04	-6.282E+02	5.147E+01	57.2%	4736
d,M					3.222E+05	-3.025E+05	1.034E+05	-3.434E+03	5.665E+01	57.2%	5596
d,L				5.741E+05	-1.245E+05	-2.848E+05	1.578E+05	-1.466E+04	6.230E+02	57.0%	6971

Scenario b) Alternative cost curves based on modified technology table

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S			5.855E+05	-5.331E+05	1.006E+04	1.291E+05	-3.967E+04	8.037E+03	2.035E+02	64.7%	5187
p,M			2.308E+06	-3.708E+06	2.188E+06	-5.568E+05	5.835E+04	3.051E+03	3.949E+02	65.7%	5994
p,L			5.101E+06	-9.258E+06	6.405E+06	-2.076E+06	3.196E+05	-1.524E+04	5.278E+02	66.6%	7274
d,S					7.662E+04	-6.523E+04	3.117E+04	1.411E+03	4.571E+02	57.0%	4208
d,M					1.002E+05	-8.587E+04	3.924E+04	9.685E+02	6.101E+02	57.0%	4885
d,L				4.163E+05	-3.599E+05	8.095E+04	2.506E+04	-9.009E+02	9.073E+02	56.8%	5936

Scenario c) Alternative cost curves based on modified technology table + alternative accounting for 2002-2009 progress

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S			5.799E+05	-7.326E+05	3.134E+05	-5.815E+04	1.959E+04	-1.996E+03	2.510E+02	68.2%	5207
p,M			1.698E+06	-2.940E+06	1.954E+06	-6.307E+05	1.153E+05	-8.461E+03	3.863E+02	69.1%	6014
p,L			3.899E+06	-7.469E+06	5.485E+06	-1.917E+06	3.332E+05	-2.379E+04	7.817E+02	69.9%	7299
d,S					2.549E+04	-1.126E+04	1.569E+04	-1.059E+00	1.945E+02	60.8%	4233
d,M					6.072E+04	-4.470E+04	2.611E+04	1.162E+02	8.462E+01	60.8%	4910
d,L				8.894E+04	9.269E+03	-4.707E+04	3.236E+04	-2.666E+02	2.599E+01	60.7%	5961

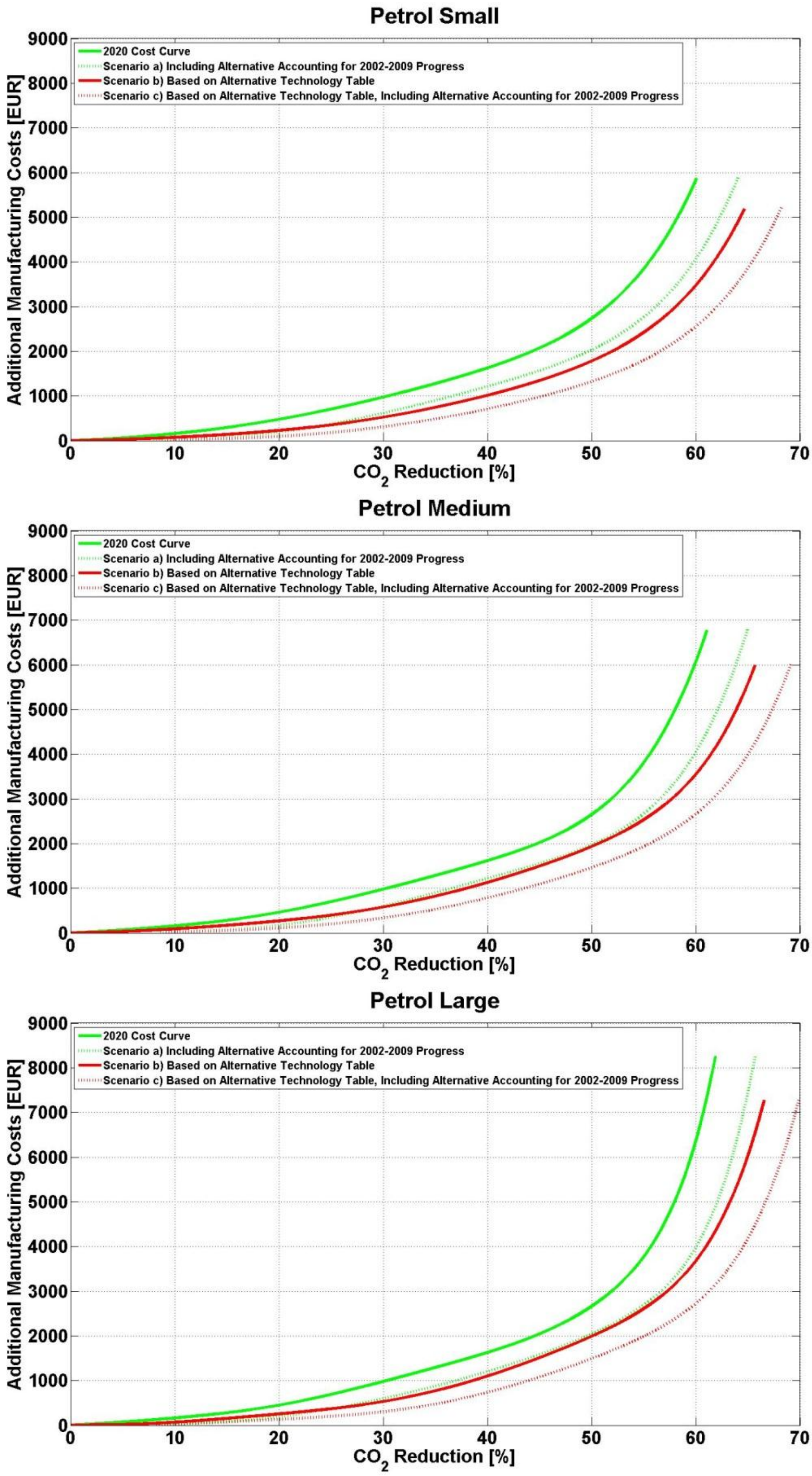

Figure 11 Graphical comparison of cost curve variants a, b and c with the original cost curves for CO_2 emission reduction in petrol vehicles in 2020, relative to 2002 baseline vehicles.

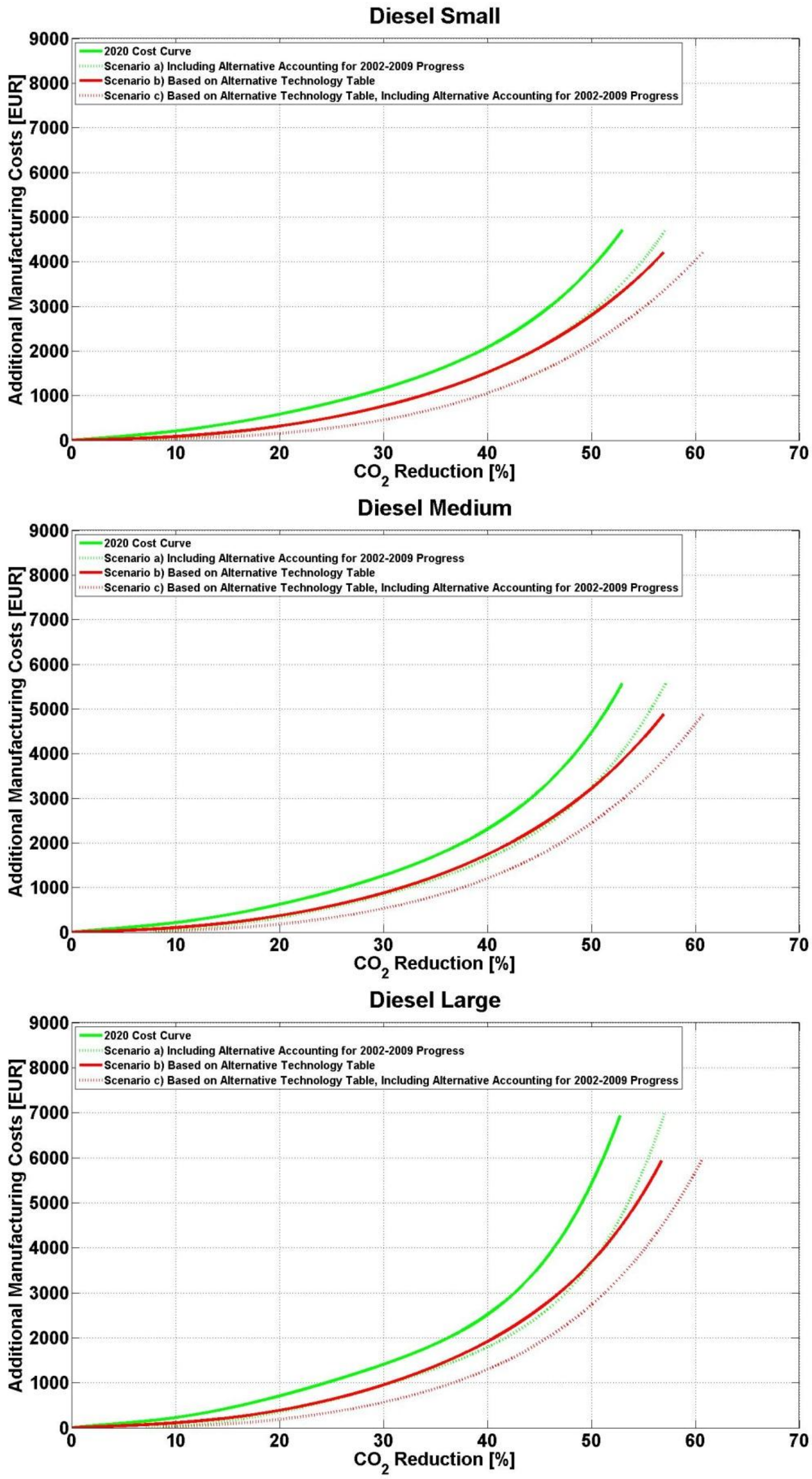

Figure 12 Graphical comparison of cost curve variants a, b and c with the original cost curves for CO_2 emission reduction in diesel vehicles in 2020, relative to 2002 baseline vehicles.

2.7 Conclusions

Cost curves for small, medium and large petrol and diesel vehicles were constructed for this report. They are based on the minimum costs for combinations of technological CO_2 reducing measures to baseline vehicles. Herein a safety margin is taken into account, since simply combining the CO_2 reduction potential of individual measures, tends to overestimate overall CO_2 reduction potential of the complete package. This is because some measures partly overlap as they have an effect on the same source of energy loss.

From analysing different packages can be concluded that the cost of a system for full hybridisation is in absolute terms, more expensive for larger vehicles. Moreover, the cost of packages including the option 'full hybridisation' increase more with vehicle size than other packages.

In general, achieving equal relative CO_2 reductions is more costly for larger vehicles than for smaller vehicles. On a detailed level, this trend can also be observed for individual measures. Moreover the cost curves for the three petrol vehicles classes are closer to each other than the three cost curves for diesel vehicles. This is the result of the cost effectiveness of the various measures being more alike for the three classes of petrol vehicles.

Finally, especially for petrol vehicles, the cost curve for medium sized vehicles is rather close to the other curves up to about 40% CO_2 reduction while it approaches the curve for small vehicles afterwards. An important contributing factor is that CO_2 reduction and costs for measures with rather low CO_2 impact, such as aerodynamics improvement, are often equal across segments, while stronger CO_2 reduction requires measures applied to the engine – which tend to be relatively more expensive for large vehicles than the additional reduction potential they offer.

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3 Cost and performance estimates for electric and plug-in hybrid vehicles

3.1 Objective

The objective of work reported in this chapter was to provide high level specifications for key components in plug-in hybrid and electric vehicles, ensuring that key vehicle performance and range criteria are met. Small, Medium and Large vehicle segments were to be covered with the following powertrain configurations:

1. Pure Electric Vehicle (EV)
2. Extended Range Electric Vehicle (EREV), series hybrid configuration
3. Plug-in Hybrid Electric Vehicle (PHEV), parallel hybrid configuration

Activities within this task included:

- Specification of minimum vehicle performance and range criteria with agreement required from TNO
- Development of a simple vehicle model to estimate vehicle energy consumption over NEDC, vehicle power requirement at cruise speeds and on gradients and vehicle acceleration times
- To use the model to specify battery capacity, electric motor and engine power required to achieve all performance and range criteria
- Estimation of the component masses and costs based on data received from the associated EC electric vehicle project

3.2 Performance and range criteria

Performance criteria were agreed with TNO in the following fields:

- Electric range
- Acceleration times from 0-50 km/h and 0-100 km/h (at kerb weight)
- Top cruise speed on a 4% gradient
- Gradeability at 15 km/h (at GVW)

Table 12 Criteria for each vehicle type and segment.

	Fuel	***Vehicle Segment***	***EV Range (km)***	***Powertrain Configuration***
1	Petrol	Small - B	50	PHEV
2	Petrol	Medium - C	50	PHEV
3	Petrol	Large - D	50	PHEV
4	Diesel	Small - B	50	PHEV
5	Diesel	Medium - C	50	PHEV
6	Diesel	Large - D	50	PHEV
7	Petrol	Small - B	50	EREV
8	Petrol	Medium - C	50	EREV
9	Petrol	Large - D	50	EREV
10	Diesel	Small - B	50	EREV
11	Diesel	Medium - C	50	EREV
12	Diesel	Large - D	50	EREV
13	-	Small - B	150	EV in 2020
14	-	Medium - C	175	EV in 2020
15	-	Large - D	200	EV in 2020
16	-	Small - B	250	EV in 2030
17	-	Medium - C	300	EV in 2030
18	-	Large - D	350	EV in 2030

Performance Requirement	***Small A segment***	***Medium C segment***	***Large D segment***
Acceleration 0-50 km/h	< 4.5s	< 4.0s	< 3.5s
Acceleration 0-100 km/h (PHEV)	< 14.0s	< 13.0s	< 11.5s
Acceleration 0-100 km/h (EREV & EV)	< 14.0s	< 13.0s	< 13.0s
Gradeability at 15 km/h	> 30%	> 30%	> 30%
Top cruise speed (PHEV)	160 km/h	180 km/h	200 km/h
Top cruise speed (EREV & EV)	125 km/h	125 km/h	125 km/h

3.3 Modelling methodology and assumptions

Vehicle modelling was performed using a simple, spreadsheet-based tool that calculates energy requirement at the wheels over the NEDC or power requirement for given speeds and gradients.

- The vehicle models are generic, based on mass, aerodynamic drag coefficient, frontal area and rolling resistance coefficient
- Second-by-second modelling of hybrid operation is not performed
- Overall electrical and thermal/mechanical powertrain efficiency values are assumed based on existing Ricardo data
- Vehicle masses are varied according to powertrain type, battery capacity, motor and engine power
- Component specifications are finalised by iteration of the model
- The same generic model is used to calculate the power requirements to achieve cruise speeds and gradeability targets

Acceleration modelling was performed by calculating vehicle speed at 0.1s intervals based on the following assumptions:

- The PHEV (parallel hybrid) will meet the acceleration target using combination of engine and motor power, therefore this will not be a defining criteria for these components
- The EV and EREV have single speed motor drives to cover the full speed range of the vehicle, up to top cruise speed
- The motor exhibits a constant torque characteristic below 1/3 of vehicle top cruise speed and a constant power characteristic above that speed
- On the above assumption, the vehicle performs constant torque acceleration up to 1/3 of top cruise speed and constant power acceleration above that speed

- The traction limit will not be broken in meeting the acceleration criteria
- Acceleration runs are performed at vehicle kerb weight
- Gradeability runs are performed at vehicle GVW

Further assumptions applied to all modelling work:

- For calculation of electric range on a common basis, all vehicles are assumed to be capable of driving the full NEDC under electric power alone. Note that this excludes the use of a simple power-split HEV configuration (e.g. Toyota Prius) owing to motor speed limitations
- All vehicles assumed to be front wheel drive
- Due to FWD layout and low braking power requirements of NEDC, 100% of braking can be performed regeneratively
- Equivalent PHEVs (i.e. the same segment and powertrain type) have the same operation strategy, regardless of whether gasoline or diesel engines are fitted
- Electric ranges are large enough that battery P/E ratio will not be critical in determining battery capacity
- EV and EREV performance criteria are taken as the same (except EV range) because drive for both configurations is by electric motor alone
- Generator power in the EREV (series hybrid) will be the same as the engine power
- 70% of battery SOC is usable for electric range

The following table shows the performance criteria used to define each component specification for each of the vehicle types. For defining motor power, acceleration and NEDC requirements are regarded as peak power (less than 30s), whereas top speed and gradeability are considered continuous power requirements. Where more than one criterion is shown, the maximum of the three values was taken:

Table 13 Performance criteria used to define each component specification for each of the vehicle types.

	Motor Power	**Engine Power**	**Battery Capacity**
PHEV (assume accel. and grade met by engine and motor combined)	NEDC	Top speed	EV range
EREV	Acceleration Top speed Gradeability	Top speed	EV range
EV	Acceleration Top speed Gradeability	N/A	EV range

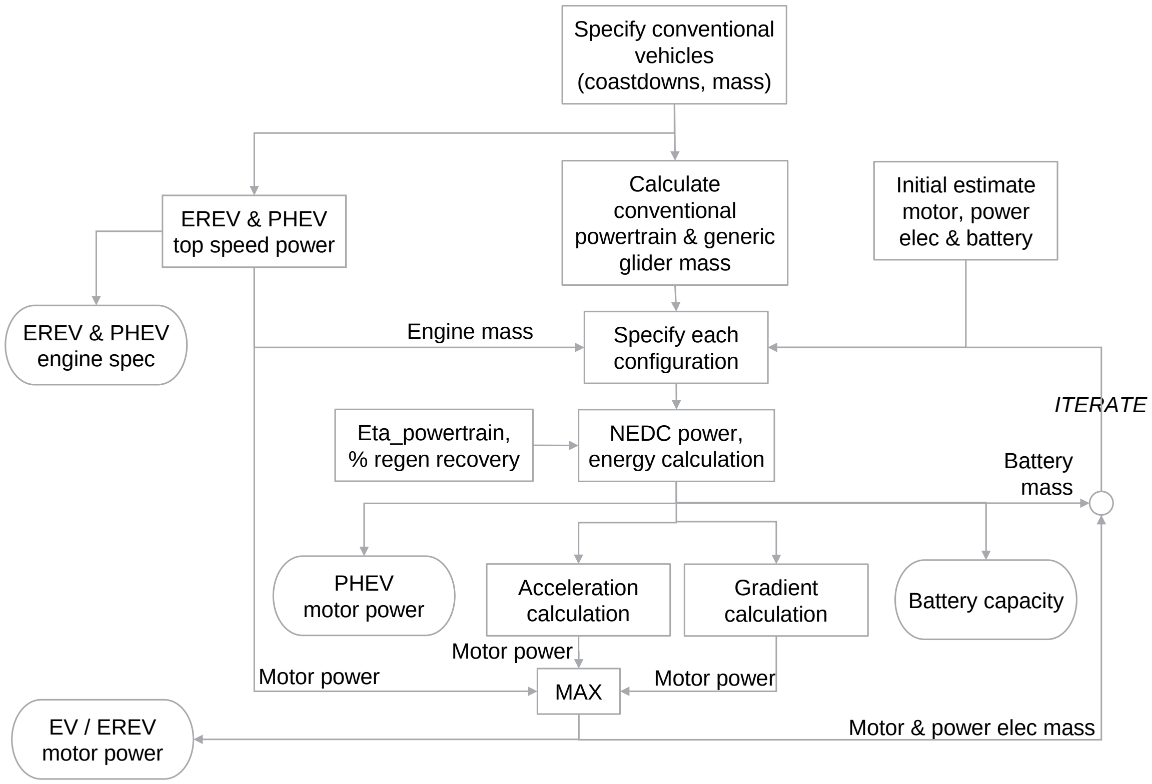


Figure 13 The overall modelling process.

3.4 Vehicle and component specifications

Vehicle and component data

At the time of this report, no results are yet available from the analysis of baseline vehicle characteristics using full Europe-wide data that is planned under this Service Request. For this task, vehicle segmentation is based on the criteria laid down by TNO, with some minor simplifications. Thus vehicle mass, payload and CdA are based on Ricardo analysis of data for the current top selling cars in each segment (2009 figures for UK market. Source: SMMT). The segmentation used is as follows:

- Small: B segment (dominates A & B segment sales)
- Medium: C segment
- Large: D segment (dominates D & E segment sales)

Specifications are taken as a sales-weighted average of those of the top 5 gasoline and top 5 diesel vehicles in each of the B, C & D segments. CdA is then scaled to reflect expected improvements to 2020. Rolling resistance coefficient is chosen to reflect low rolling resistance tyres currently available with a view to these being in general usage in 2020.

Table 14 Specifications for B, C and D segments.

Vehicle segment	*Vehicle kerb mass (kg) (conventional baseline)*	*Max. payload (kg)*	*CdA*	*Rolling resistance coefficient*
Small – B segment	1109	417	0.662	0.007
Medium – C segment	1264	571	0.628	0.007
Large – D segment	1443	521	0.525	0.007

Vehicle mass for the PHEV, EREV and EV configurations is calculated by subtracting the conventional powertrain mass (based on Ricardo analysis for each vehicle segment) and adding in the masses for the battery, electric motor, power electronics, HV harness, additional mass for electric air conditioning and HVAC, hybrid engine (not EV) and generator (EREV only).

The masses for the additional hybrid components are based on the following data received from ICF:

Table 15 ICF data for the additional hybrid components.

	Battery energy density (Wh/kg)	***Motor power density (kW/kg) (continuous)***	***Inverter power density (kW/kg)***	***Boost converter power density (kW/kg)***	***Control unit mass (kg)***
2012	105 Lithium Mn Spinel	1.25	9.5	4.5	8
2020	160 Silicon Lithium	1.40	11	5.5	5
2030	300 Silicon Li-S	1.60	13	6.5	5

Table 16 High voltage wiring harness data provided by ICF.

	Small – B segment	***Medium – C segment***	***Large – D segment***
HV wiring harness mass (kg)	15	17	19
HV wiring harness cost (Euro)	120	150	180

Engine mass data is based on Ricardo first order estimates of power density at 1 kW/kg for gasoline and 0.7 kW/kg for diesel. HVAC system mass is assumed to increase by 10% (ICF data) over the existing conventional system, for which Ricardo have provided the following estimates:

Table 17 Estimates for HVAC system masses provided by Ricardo.

	Small – B segment	***Medium – C segment***	***Large – D segment***
Baseline HVAC system mass (kg)	25	35	40
HVAC system mass increase (kg)	2.5	3.5	4.0

Component specification results

A summary of the component specifications for each vehicle is set out below, as derived by the process described in section 3.1. These components allow the vehicles to achieve the range and performance criteria set out in section 3.2. Component specification results are quoted to a resolution appropriate to the level of accuracy of calculation.

Table 18 Summary of the component specifications for each vehicle.

Vehicle Specification Summary									
	Vehicle Segment	***Powertrain***	***Fuel***	***EV Range***	***Battery Capacity***	***Motor Power (peak)***	***Engine Power***	***Generator Power (continuous)***	***Vehicle Total Mass***
	-	-	-	km	kWh	kW	kW	kW	kg
1	Small - B	PHEV	Petrol	50	5.9	28	58	-	1139
2	Medium - C	PHEV	Petrol	50	6.4	30	80	-	1316
3	Large - D	PHEV	Petrol	50	6.3	30	95	-	1487
4	Small - B	PHEV	Diesel	50	6.0	28	59	-	1165
5	Medium - C	PHEV	Diesel	50	6.5	30	81	-	1352
6	Large - D	PHEV	Diesel	50	6.4	30	96	-	1529
7	Small - B	EREV	Petrol	50	5.7	66	48	48	1165
8	Medium - C	EREV	Petrol	50	6.1	80	51	51	1335
9	Large - D	EREV	Petrol	50	6.0	84	51	51	1491
10	Small - B	EREV	Diesel	50	5.8	67	48	48	1187
11	Medium - C	EREV	Diesel	50	6.2	81	52	52	1359
12	Large - D	EREV	Diesel	50	6.0	85	52	52	1515
13	Small - B	EV 2020	-	150	16	62	-	-	1055
14	Medium - C	EV 2020	-	175	21	80	-	-	1331
15	Large - D	EV 2020	-	200	24	85	-	-	1498
16	Small - B	EV 2030	-	250	27	59	-	-	1036
17	Medium - C	EV 2030	-	300	36	77	-	-	1309
18	Large - D	EV 2030	-	350	42	81	-	-	1477

The greater engine power requirement for PHEV compared with EREV vehicles is a result of the higher top-speed criteria. The similar electric motor power requirements for Medium and Large EREV are due to the similar values of CdA for these two segments, which is the dominating factor for determining maximum speed.

As stated above, in this simple analysis it is assumed in the calculations that battery power ratings are not a critical factor in determining the component specifications. As confirmation that this assumption is valid for peak power levels, it can be seen that maximum P/E ratios for the vehicle specifications in the table above are approximately 12-14, for the EREV configurations. This may be regarded as slightly higher than ideal for a battery designed for best compromise between energy and power demands (e.g. ~8 for GM Volt). However it should be noted that for all the EREV and EV configurations above, motor power rating is determined not by actual power requirements, but by the minimum torque requirements of the gradeability specification. Thus for those vehicles the electric motor is over-specified in terms of power for all of the performance criteria given – the maximum P/E ratio actually encountered is somewhat less than this figure.

Battery continuous power ratings may be only 20-30% of peak ratings, due to the thermal limitations of the cell and particularly of the pack. This would tend to make top speed continuous power requirements more critical for the EREV and EV. However battery capacity limits pure electric driving under the specified top speed conditions to absolute maximum durations of ~20 minutes for the 2020 EV and only 5-6 minutes for the EREV (beyond which charge-sustaining operation would tend to reduce battery power consumption to zero). This is a short enough period of time that battery thermal considerations are unlikely to be critical. So the P/E ratio assumption may be regarded as valid, at least for this simple analysis.

Component & vehicle mass results

The following table shows the breakdown of powertrain component mass for each vehicle, calculated from the final derived technical specifications using the mass assumptions stated above. *(Mass assumptions for electrical powertrain components provided by ICF; mass assumptions for vehicle glider and conventional powertrain components provided by Ricardo)*

Table 19 Breakdown of powertrain component masses for each vehicle.

Component Masses Summary											
	Vehicle Segment	*Powertrain*	*Fuel*	*Battery Mass*	*Motor Mass*	*Engine Mass*	*Generator Mass*	*Inverter & Boost Converter Mass**	*Control Unit & Harness Mass***	*Added HVAC Mass*	*Total Added Mass*
	-	-	-	kg	kg	kg	kg	kg	kg	kg	kg
1	Small - B	PHEV	Petrol	37	15	58	-	8	20	2.5	141
2	Medium - C	PHEV	Petrol	40	17	80	-	8	22	3.5	170
3	Large - D	PHEV	Petrol	39	16	95	-	8	24	4.0	187
4	Small - B	PHEV	Diesel	38	16	84	-	8	20	2.5	167
5	Medium - C	PHEV	Diesel	40	17	115	-	8	22	3.5	206
6	Large - D	PHEV	Diesel	40	17	137	-	8	24	4.0	230
7	Small - B	EREV	Petrol	36	37	48	34	35	25	2.5	217
8	Medium - C	EREV	Petrol	38	44	51	37	40	27	3.5	241
9	Large - D	EREV	Petrol	37	47	51	37	41	29	4.0	246
10	Small - B	EREV	Diesel	36	37	69	34	35	25	2.5	239
11	Medium - C	EREV	Diesel	39	45	74	37	40	27	3.5	266
12	Large - D	EREV	Diesel	38	47	74	37	41	29	4.0	270
13	Small - B	EV 2020	-	103	34	-	-	22	20	2.5	182
14	Medium - C	EV 2020	-	134	44	-	-	29	22	3.5	232
15	Large - D	EV 2020	-	149	47	-	-	31	24	4.0	255
16	Small - B	EV 2030	-	91	30	-	-	19	20	2.5	162
17	Medium - C	EV 2030	-	121	38	-	-	25	22	3.5	210
18	Large - D	EV 2030	-	138	41	-	-	26	24	4.0	233

** = includes inverter and boost converter for motor and generator for EREV*
*** = includes separate control units for motor and generator for EREV*

3.5 Powertrain cost

Component cost data

Component costs to the OEM are based on the following data received from ICF.

Table 20 Component costs data provided by ICF.

	Battery cost (Euro)	*Motor cost (Euro)*	*Inverter cost (Euro)*	*Boost converter cost (Euro)*	*Control unit cost (Euro)*	*Harness cost (Euro)*
2012	200 + 700*kWh	50 + 8.0*kW	50 + 10*kW	10 + 3.0*kW	150	150
2020	200 + 400*kWh	40 + 6.4*kW	40 + 8.0*kW	8 + 2.4*kW	120	120
2030	200 + 230*kWh	32 + 5.1*kW	32 + 6.4*kW	6.4 + 1.9*kW	120	120

Table 21 Electric heat pump costs data provided by ICV.

	Small – B segment	*Medium – C segment*	*Large – D segment*
2012	900	1000	1100
2020	810	900	990
2030	730	810	900

Table 22 High voltage wiring harness data provided by ICF.

	Small – B segment	*Medium – C segment*	*Large – D segment*
HV wiring harness mass (kg)	15	17	19
HV wiring harness cost (Euro)	120	150	180

Engine and transmission costs for 2020 have been estimated by Ricardo, based on the following set of assumptions.

Assumptions for gasoline:

- PHEV models feature a downsized, turbocharged 3 or 4 cylinder engine with direct injection
- EREV models feature a naturally aspirated 3 or 4 cylinder engine with low feature content and focus on light weight
- Emissions requirements for 2020 do not impose significant additional aftertreatment costs for these engine types compared with 2010

Assumptions for diesel:

- PHEV models feature a downsized, highly boosted 3 cylinder engine
- EREV models feature a downsized, highly boosted 3 cylinder engine with reduced feature content and focus on light weight
- The emissions benefits of hybridisation offset the costs of additional content required to meet 2020 noxious emissions limits
- The reduced transient response requirements for hybrid engines allow some cost reduction compared with baseline conventional engines
- Both factors also partly offset the trend increase in base engine CO_2 reduction content

Assumptions for transmissions:

- PHEV vehicles feature electrically actuated dual-clutch transmissions
- EREV and EV vehicles do not require a stand-alone transmission – no speed reduction in drive to wheels by electric motors

Powertrain cost results

Costs for the powertrain components calculated from the derived specifications according to the stated cost assumptions can be seen in the table below. *(Cost assumptions for electrical powertrain components provided by ICF; cost assumptions for vehicle glider and conventional powertrain components provided by Ricardo)*

Table 23 Cost assumptions for the powertrain components.

Component Costs Summary											
	Vehicle Segment	***Powertrain***	***Fuel***	***Battery Cost***	***Motor Cost***	***Engine & Trans Cost***	***Generator Cost***	***Inverter & Boost Converter Cost****	***Control Unit & Harness Cost*****	***Added HVAC Cost***	***Total Added Cost***
	-	-	-	*Euro*	*Euro*	*Euro*	*Euro*	*Euro*	*Euro*	*Euro*	*Euro*
1	Small - B	PHEV	Petrol	2579	208	2000	-	337	240	810	6175
2	Medium - C	PHEV	Petrol	2752	222	2350	-	359	270	900	6853
3	Large - D	PHEV	Petrol	2711	220	2450	-	356	300	990	7027
4	Small - B	PHEV	Diesel	2604	210	2500	-	341	240	810	6705
5	Medium - C	PHEV	Diesel	2787	224	2800	-	364	270	900	7345
6	Large - D	PHEV	Diesel	2753	223	2900	-	361	300	990	7527
7	Small - B	EREV	Petrol	2493	464	1000	432	1423	360	810	6982
8	Medium - C	EREV	Petrol	2646	552	1100	463	1615	390	900	7665
9	Large - D	EREV	Petrol	2585	580	1100	462	1659	420	990	7796
10	Small - B	EREV	Diesel	2513	470	1400	436	1439	360	810	7428
11	Medium - C	EREV	Diesel	2667	558	1600	467	1632	390	900	8215
12	Large - D	EREV	Diesel	2607	586	1600	466	1677	420	990	8346
13	Small - B	EV 2020	-	6784	435	-	-	690	240	810	8960
14	Medium - C	EV 2020	-	8747	551	-	-	878	270	900	11346
15	Large - D	EV 2020	-	9766	582	-	-	929	300	990	12567
16	Small - B	EV 2030	-	6462	334	-	-	530	240	730	8296
17	Medium - C	EV 2030	-	8556	423	-	-	675	270	810	10733
18	Large - D	EV 2030	-	9748	447	-	-	715	300	900	12110

** = includes inverter and boost converter for motor and generator for EREV*
*** = includes separate control units for motor and generator for EREV*

3.6 Energy consumption and CO_2 emissions

Energy consumption in EV mode and tailpipe CO_2 emissions in charge sustaining mode (PHEV and EREV only) over the NEDC drive cycle is summarised in the table below (no heating or air-conditioning is applied during the cycle as per UNECE Regulation 101). The cycle CO_2 emissions are calculated based on the EV range and charge depleting CO_2 figure according to the following formula, taken from ECE regulation 101, Annex 8:

$$M = (D_e \cdot M_1 + D_{av} \cdot M_2)/(D_e + D_{av})$$

Where:

M = mass emission of CO_2 in grams per kilometre

M_1 = mass emission of CO_2 in grams per kilometre with a fully charged electrical energy/power storage device (known as “charge depleting” operation, i.e. no IC engine use)

M_2 = mass emission of CO_2 in grams per kilometre with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity, known as “charge sustaining” operation, i.e. no net battery drain)

D_e = vehicle’s electric range, according to the procedure described in Annex 9, where the manufacturer must provide the means for performing the measurement with the vehicle running in pure electric operating state

D_{av} = 25 km (assumed average distance between two battery recharges)

Table 24 Energy consumption in EV mode and tailpipe CO_2 emissions in charge sustaining mode over the NEDC drive cycle.

Energy Consumption & CO2							
	Vehicle Segment	***Powertrain***	***Fuel***	***NEDC EV Energy***	***NEDC EV Energy***	***NEDC Tailpipe CO2 (charge sustain)***	***NEDC Tailpipe CO2 (overall)***
	-	-	-	kJ/km	Wh/km	g/km	g/km
1	Small - B	PHEV	Petrol	300	83	89	30
2	Medium - C	PHEV	Petrol	322	89	98	33
3	Large - D	PHEV	Petrol	316	88	101	34
4	Small - B	PHEV	Diesel	303	84	83	28
5	Medium - C	PHEV	Diesel	326	91	91	30
6	Large - D	PHEV	Diesel	322	89	94	31
7	Small - B	EREV	Petrol	289	80	100	33
8	Medium - C	EREV	Petrol	308	86	110	37
9	Large - D	EREV	Petrol	300	83	112	37
10	Small - B	EREV	Diesel	291	81	95	32
11	Medium - C	EREV	Diesel	311	86	103	34
12	Large - D	EREV	Diesel	303	84	105	35
13	Small - B	EV 2020	-	277	77	-	-
14	Medium - C	EV 2020	-	308	85	-	-
15	Large - D	EV 2020	-	301	84	-	-
16	Small - B	EV 2030	-	274	76	-	-
17	Medium - C	EV 2030	-	305	85	-	-
18	Large - D	EV 2030	-	299	83	-	-

Note: The two pure modes of driving the vehicle are "charge sustaining" (no net battery drain) and "charge depleting" (no ICE engine use). The method employed for quantifying the relative amounts of each mode for homologation test purposes (and the only currently recognised basis for comparison with other vehicle types) is described by the formula shown above. Only the M2 test result has been calculated, i.e. tailpipe CO_2 (charge sustain). The M1 result is assumed to be zero for the vehicles considered i.e. the PHEVs and EREVs analysed have sufficient performance to complete the entire NEDC under electric power alone. The "overall" distribution of energy use is determined by the weighting formula. The energy results can be calculated through knowledge of the carbon/hydrogen ratio and calorific value of the fuels used.

4 Current state-of-the-art technologies for passenger cars

4.1 Objective

The objective of work reported in this chapter was to identify and analyse the lowest emitting vehicles currently on the market or close to market introduction, taking into account market segments, in order to arrive at a realistic "current state of the art" technology and emission levels.

Activities within this task included:

- Identification and review of low CO_2 models on the market in 2009 / early 2010 in the three most relevant market segments (B, C and D) and of relevant concept cars;
- Identification of technologies used to reduce CO_2 emissions and their contribution to the achieved CO_2 emission levels;
- Estimation of costs based on available information and comparison with price.

4.2 Identification of low CO_2 models

The aim of this task was to identify the lowest emitting CO_2 models currently on the market in 2009 / early 2010 or close to market introduction for each of a number of key market segments.

The market segmentation used followed the IHS Global Insight definitions, as shown in the table below:

- A: City (A)
- B: Supermini (B)
- C: Lower Medium (C1 + C2)
- D: Upper Medium (D1 + D2)
- E: Executive (E1)
- F: Luxury (E2)
- G: Super Luxury / Sports (F1 + F2)
- Small MPV – Small MPV (MPV-B + MPV-C)
- Standard MPV – Standard MPV (MPV-D)
- Luxury MPV (MPV-E)
- Compact SUV (SUV-A, SUV-B + SUV-C)
- Standard SUV (SUV-D)
- Luxury / Full Size SUV (SUV-E)

In order to capture the majority of the low-CO_2 technologies available across the different market segments, the approach taken was to focus on the primary vehicle segments. The primary market segments are those with the largest share of European sales: B (Supermini) at 30.5%, C (Lower Medium) at 24.1% and D (Upper Medium) at 11.5% (percentage sales in 2009, source: POLK). The approach is as follows:

- Identification of the lowest-emitting vehicles in each the three primary vehicle segments, covering the three lowest-emitting diesel vehicles and two lowest-emitting gasoline vehicles
- Analysis of low-CO_2 technologies employed in these market segments, covering cost to OEM, likely relative CO_2 benefits and sales price differential vs. equivalent "non-eco" models
- Assessment of low-CO_2 technologies in the remaining market segments, in order to identify any not covered by those detailed for the primary market segments

This approach was considered to be the most efficient way of gathering data on low-CO_2 technologies available across all market segments. The initial expectation was that no additional technologies would be identified for other market segments beyond those already identified for the B, C and D segments. This expectation was subsequently borne out in the assessment of the remaining market segments: no additional technologies could be identified, thus the technologies identified in this report apply not only those relevant to the primary vehicle segments but also to those relevant to other market segments.

For some segments, choosing the five lowest emitting CO_2 models would result in only models using diesel technology being identified. In order to provide a view of the "state-of-the-art" technology for gasoline technology as well as diesel, the approach was modified to review the three lowest CO_2 emitting diesel models and the two lowest CO_2 emitting gasoline models.

Best-in-class gasoline and diesel vehicles by segment for Europe were selected using a combination of the following databases and information sources:

- Kraftfahrt Bundesamt (kba) Passenger car Fuel Economy database
- UK SMMT (Society of Motor Manufacturers and Traders) New Car CO_2 report 2010
- ACT ON CO_2 New Car CO_2 Emissions: Top 10 search tool
- OEM press releases and model specifications
- POLK passenger cars database

To put this analysis in context a general review of the vehicle market is included. Total registrations of new passenger cars in 2009 in the EU-27 amounted to 13,975,000 and their average specific CO_2 emissions were 145.7 g/km, a 5.1% decrease compared to 2008. The development of average CO_2 emissions split by fuel type is shown in Figure 14 together with future CO_2 targets.

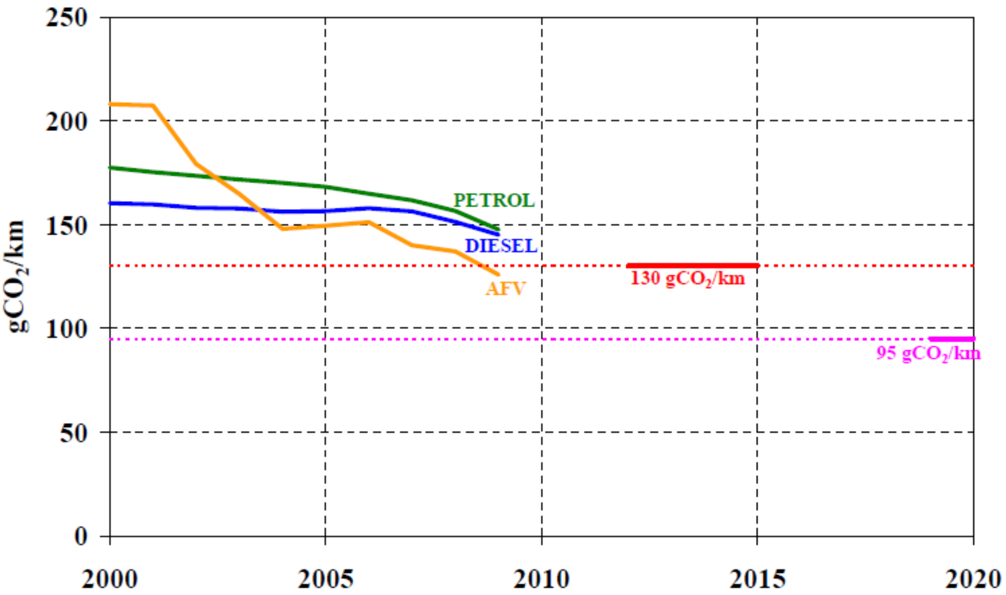


Figure 14 Average specific CO_2 emissions of new passenger cars in EU-27 by fuel type.

Source: COM(2010) 655 Final "Monitoring the CO_2 emissions from new passenger cars in the EU: data for 2009

The average specific CO_2 emissions were 147.6 g/km CO_2 for Gasoline, 145.3 g/km CO_2 for Diesel and 125.8 g/km CO_2 for Alternative Fuel Vehicles (AFV) in 2009. Average specific CO_2 emissions have been falling over the last nine years for new gasoline passenger cars and the last three years for new diesel passenger cars. The gap between the gasoline and diesel average specific CO_2 emissions has reduced over the last ten years and in 2009 was 2.3 g/km compared to 17.1 g/km in 2000.

For the first time in four years the market share of gasoline vehicles (51.1%) exceeded that of diesel (45.1%), with the remaining 3.8% attributable to Alternative Fuel Vehicles (AFV).

The following charts show the range of CO_2 values for new passenger cars sold in the European market for the three primary segments. There are then three sub plots which identify the CO_2 range for gasoline, diesel and hybrid (full/mild) vehicles (if applicable) within each of these segments.

All figures were taken from 2009 data and the sales weighted average CO_2 value is represented by a bold line within the range

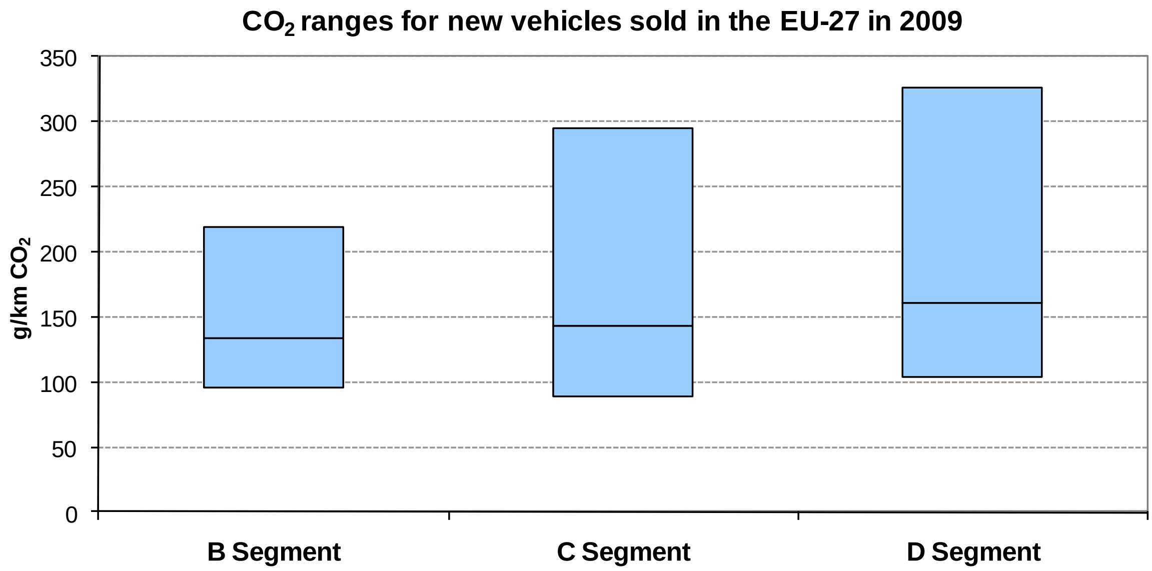


Figure 15 CO_2 ranges (highest, lowest and sales-weighted average values) for B, C and D segment vehicles sold in the EU-27 in 2009.

Source: POLK 2009

The upper limit of CO_2 emissions increases through the segments, as would be expected due to the increasing vehicle size. The C segment has a lower low limit value (89 g/km CO_2) than the B segment (96g/km). This is due to the presence of the Toyota Prius gasoline hybrid vehicle in the C segment – the best-in-class vehicles in other segments do not include full or mild hybrid vehicles.

It should be noted that the sales-weighted average is towards the lower end of the range of CO_2 values in each of the segments.

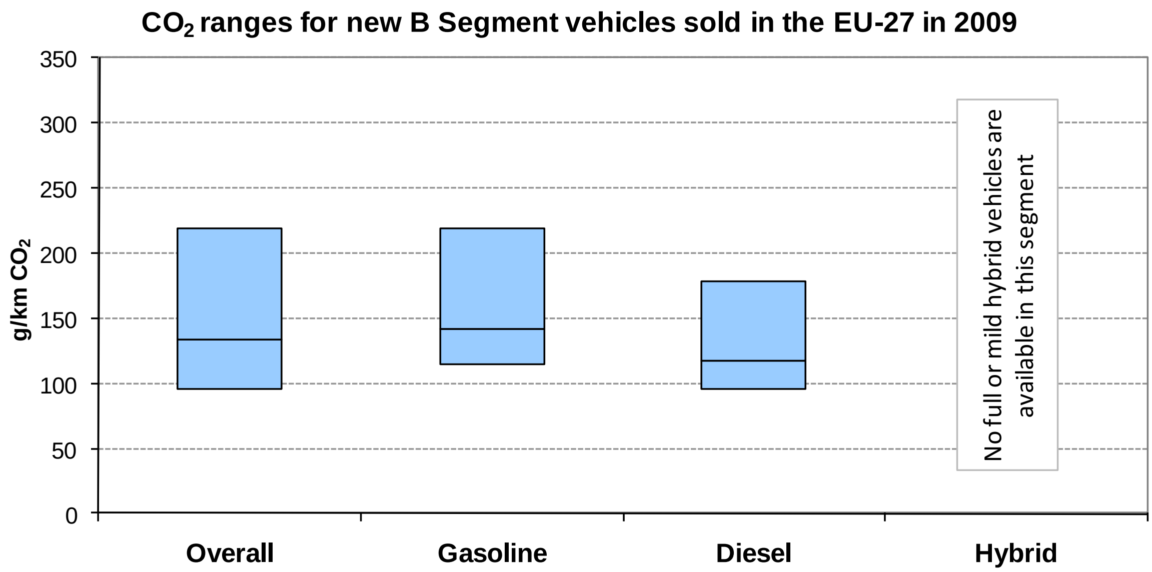


Figure 16 CO_2 ranges (including the highest, lowest and sales-weighted average values) for gasoline, diesel and overall for B segment vehicles sold in the EU-27 in 2009.

Source: POLK 2009

The B segment does not include any mild or full hybrid vehicles. Figure 16 shows that the B segment gasoline vehicles have a wider CO_2 emissions range than the diesel models and that the low, average and high values are above each respective value in the diesel range.

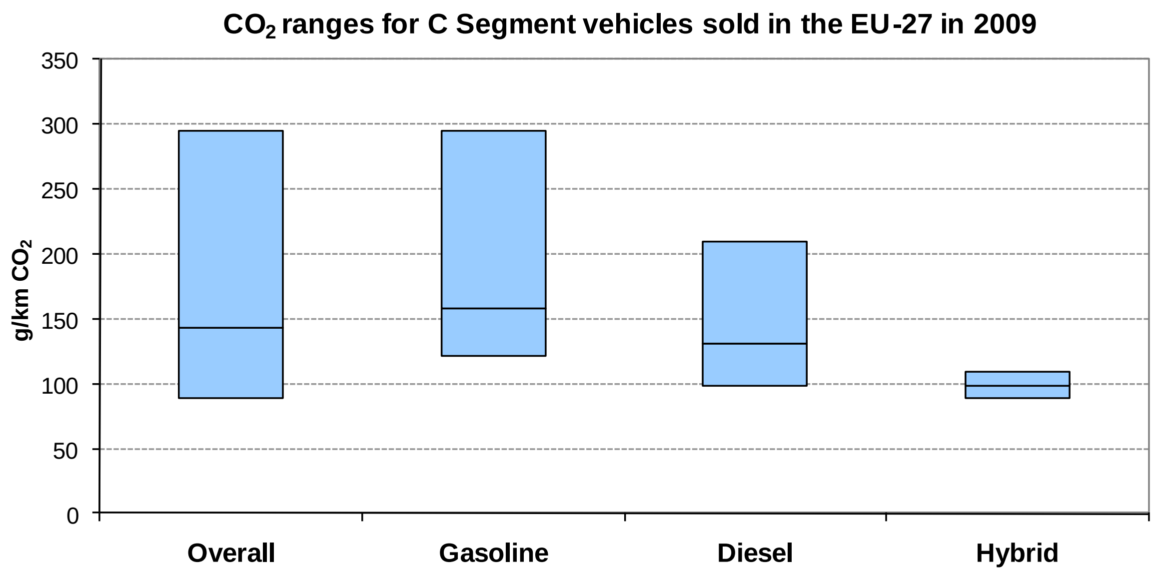


Figure 17 CO_2 ranges (including the highest, lowest and sales-weighted average values) for gasoline, diesel, hybrid technology and overall for C segment vehicles sold in the EU-27 in 2009.

Source: POLK 2009

As with the B segment, Figure 17 shows that the C segment gasoline vehicles have a wider CO_2 emissions range and that the low, average and high values are all above those identified for diesel and hybrid models.

The small range of CO_2 values for hybrid vehicles compared to gasoline and diesel is due to the limited number of full or mild hybrid models available in the C segment.

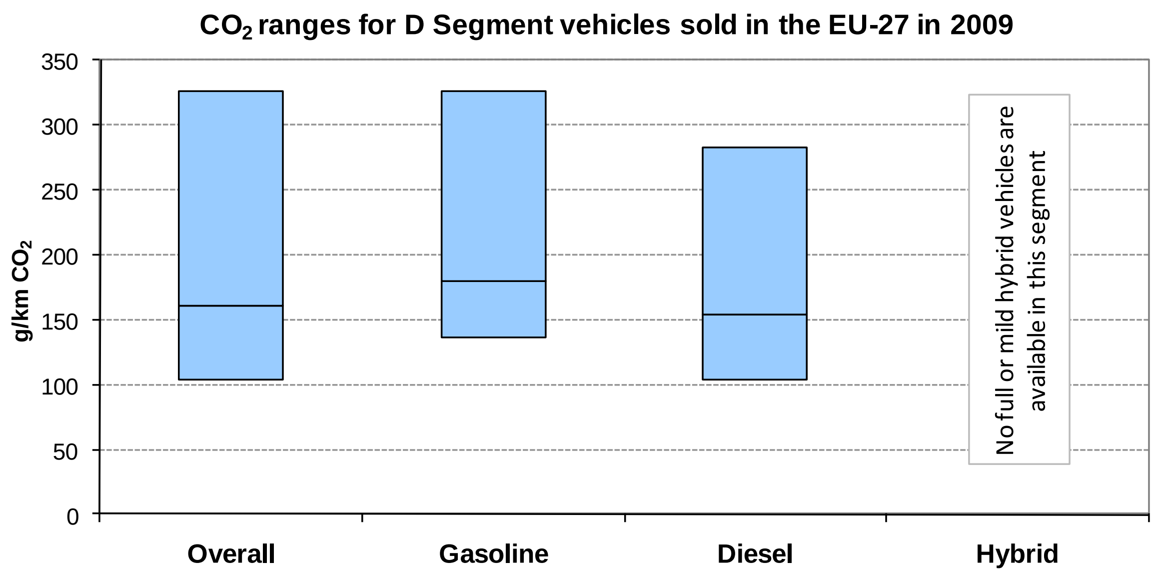


Figure 18 CO_2 ranges (including the highest, lowest and sales-weighted average values) for gasoline, diesel technology and overall for D segment vehicles sold in the EU-27 in 2009.

Source: POLK 2009

Again, the gasoline vehicles have a wider range of CO_2 emissions and higher low, average and high values when compared to diesel vehicles.

Figure 16, Figure 17, and Figure 18 identify that the average value, the highest value and the range of the CO_2 emissions increases as you move up through the segments. The only exception to this trend is the lowest CO_2 emissions values due to the hybrid vehicles present in the C segment.

Table 25 A summary of the lowest, sales-weighted average and highest CO_2 emissions values for each segment based on vehicles sold in the EU-27 in 2009

	Segment		
	B	*C*	*D*
Lowest CO_2 value (g/km)	96	89	104
Average CO_2 value (g/km)	134	143	161
Highest CO_2 value (g/km)	219	295	326
Range (g/km)	123	206	222

Table 26 identifies the lowest CO_2 emitting models by segment:

Table 26 Lowest CO_2 emitting models for B, C and D segments

Segment	**Fuel**	**Model**	**CO_2 (g/km)**
B: Supermini	Diesel	Volkswagen Polo BlueMotion*1	89
		Ford Fiesta ECOnetic*2	98
		Opel Corsa 1.3 CTDi ecoflex (70 kW)	95
	Gasoline	Toyota Yaris	118
		Mitsubishi Colt ClearTec	119
C: Lower Medium	Diesel	Volkswagen Golf BlueMotion	99
		Ford Focus ECOnetic	99
		Volvo C30 DRIVe	99
	Gasoline	Toyota Prius	89
		Honda Insight	101
		Audi A3 1.2 TFSI S tronic	123
D: Upper Medium	Diesel	BMW 320d EfficientDynamics	109
		Audi A4 2.0 TDIe Saloon	119
		Mercedes C220 CDI BlueEfficiency	127
	Gasoline	BMW 318i	146
		Audi A4 2.0 TFSI Saloon	149

**1 This figure is for the German market. The value identified for the UK market was 91g/km.*
**2 There are other models available with CO_2 emissions of 98 g/km (for example Seat Ibiza Ecomotive).*

Using the data above, Ricardo has defined benchmark values for the ‘best in class’ CO_2 emissions for each fuel type for each segment in the European market. An average of the three diesel vehicles and two gasoline vehicles has been used to calculate these values:

Table 27 Benchmark values for the ‘best in class’ CO_2 emissions provided by Ricardo.

	Diesel vehicles	**Gasoline vehicles**
B Segment	97 g/km	119 g/km
C Segment	99 g/km	123 g/km
D Segment	118 g/km	148 g/km

** This does **not** include the hybrid vehicles.*

4.3 Identification of technologies employed for CO_2 reduction

The tables in this section have been completed through a review of the manufacturers' specifications available via the internet and vehicle brochures. In many cases it was not clearly identified whether a technology was included on the vehicle as part of the standard package. In these situations, the tables have been populated with a dash. It should be noted that as a general rule stop-start technology does not include regenerative braking. Regenerative braking (smart alternator) is included as a separate technology to stop-start in the tables of the report.

In this section aerodynamic improvements, downsizing (a reduction in engine displacement or a reduction in the number of cylinders), weight reduction and transmission improvements in this section have been judged in comparison to the previous version of the vehicle model in question.

4.3.1 B Segment

Table 28 identifies some of the key vehicle parameters for the lowest CO_2 emitting models in the B segment followed by a checklist of some of the core technologies which have been implemented to reduce CO_2 emissions. This table enables direct comparison of the technologies which have been utilised across both diesel and gasoline vehicles.

No single technology or product is implemented across both diesel and gasoline models, however low rolling resistance tyres, aerodynamic improvements, automatic stop-start, weight reduction and transmission improvements are common to the three diesel models reviewed.

It is worth noting that the Toyota Yaris has been identified as having very few of the low CO_2 technologies listed in Figure 17 compared to the Mitsubishi Colt yet it has the lowest CO_2 emissions of the segment. This can be explained by the differences in performance parameters. The Toyota Yaris has a smaller engine than the Mitsubishi Colt (1 litre compared to 1.3 litres) and a lower maximum power output (51 kW compared to 70 kW), translating to a slower 0 – 100 km/h time (15.7s compared to 10.6 s). The Toyota Yaris achieves low CO_2 through the use of a small displacement engine and a lower performance than some other vehicles in the sector.

4.3.2 C Segment

Table 29 identifies the same parameters for the lowest CO_2 emitting diesel models in the C Segment.

Each of the three diesel models identified for the C segment has a large number of the core technologies which have been implemented to reduce CO_2 emissions. Common to all are:

- Low rolling resistance tyres
- Automatic start-stop
- Regenerative braking (smart alternator)
- Electric power steering
- Transmission improvements

Table 30 below identifies the same parameters for the lowest CO_2 emitting gasoline models in the C Segment. For the C segment only three gasoline vehicles that have been identified. The two lowest emission vehicles utilise full and mild hybrid technologies. Therefore a third gasoline vehicle which does not utilise mild or full hybrid technology has been included in the assessment to highlight other technologies being used to achieve low CO_2.

Table 28 Vehicle parameters and key technologies for lowest CO_2 emitting models in the B segment

	B Segment				
	Diesel			Gasoline	
Technology	**Volkswagen Polo BlueMotion**	**Ford Fiesta ECOnetic (5 door)**	**Opel Corsa 1.3 CDTi ecoFLEX (5 door)**	**Toyota Yaris**	**Mitsubishi Colt ClearTec (5 door)**
Engine displacement (L)	1.2	1.6	1.3	1.0	1.3
Engine Power (kW)	55	70	70	51	70
0-100 km/h (s)	13.9	12.3	12.3	15.7	10.6
Transmission	Manual 5	Manual 5	Manual 5	Manual 5	Manual 5
Fuel consumption: Urban (L/100km)	4.2	4.6	4.3	6.0	6.3
Fuel consumption: Extra-urban (L/100km)	3.1	3.2	3.2	4.5	4.3
Fuel consumption: Combined (L/100km)	3.5	3.7	3.6	5.1	5.0
CO_2 (g/km)	**89***[1]	**98**	**95**	**118**	**119**
Fuel tank (L)	45	40	40	42	47
Kerb weight (kg)	1,150	1,100	1,160	1,030	970
Max permissible laden weight (kg)	1,590	1,545	1,585	1,440	1,465
Low rolling resistance tyres	✓	✓	✓	✗	✓
Aerodynamic improvements	✓	✓	✓	–	–
Active aerodynamics	✗	✗	–	✗	✗
Gasoline Direct Injection				✗	✗
Automatic start-stop	✓	✓	✓	✗	✓
Regenerative braking (smart alternator)	✓	✗	✗	✗	✓
Electric power steering	–	✓	✓	✗	✓
Low viscosity engine oil	✗	–	–	–	✓
Mild/Full Hybrid	✗	✗	✗	✗	✗
Downsizing	✓	✗	✗	–	✗
Weight reduction	✓	✓	✓	–	✗
Transmission improvements	✓	✓	✓	–	✓
VVT	✗	✗	✗	✓	✓

✓ = implemented on this model ✗ = not implemented on this model – = not mentioned

**1 German market CO_2 emission figure.*

Table 29 Vehicle parameters and key technologies for lowest CO_2 emitting diesel models in the C segment.

Technology	C Segment – Diesel		
	Volkswagen Golf TDI BlueMotion	Ford Focus TDCi ECOnetic	Volvo C30 DRIVe
Engine displacement (L)	1.6	1.6	1.6
Engine Power (kW)	77	80	84
0-100 km/h (s)	11.3	10.9	10.7
Transmission	Manual 5	Manual 5	Manual 5
Fuel consumption: Urban (L/100km)	4.7	4.5	4.6
Fuel consumption: Extra-urban (L/100km)	3.4	3.4	3.3
Fuel consumption: Combined (L/100km)	3.8	3.8	3.8
CO_2 (g/km)	**99**	**99**	**99**
Fuel tank (L)	55	53	52
Kerb weight (kg)	1,314	1,357	1,363
Max permissible laden weight (kg)	1,750	1,880	1,780
Low rolling resistance tyres	✓	✓	✓
Aerodynamic improvements	✓	✓	✓
Active aerodynamics	–	✗	–
Gasoline Direct Injection			
Automatic start-stop	✓	✓	✓
Regenerative braking (smart alternator)	✓	✓	✓
Electric power steering	✓	✓	✓
Low viscosity engine oil	–	✓	–
Mild/Full Hybrid	✗	✗	✗
Downsizing	✓	✓	✗
Weight reduction	✓	✗	✗
Transmission improvements	✓	✓	✓
VVT	✗	✗	✗

✓ *= implemented on this model* ✗ *= not implemented on this model* – *= not mentioned.*

Table 30 Vehicle parameters and key technologies for lowest CO_2 emitting gasoline models in the C segment

Technology	C Segment – Gasoline		
	Toyota Prius IV *(Full Hybrid)*	**Honda Insight *(Mild Hybrid)***	**Audi A3 1.2 TFSI S tronic**
Engine displacement (L)	1.8	1.4	1.2
Engine Power (kW)	83	65	77
0-100 km/h (s)	10.4	12.5	10.5
Transmission	Power split CVT	CVT	7 speed DCT
Fuel consumption: Urban (L/100km)	3.9	4.6	6.5
Fuel consumption: Extra-urban (L/100km)	3.7	4.2	4.6
Fuel consumption: Combined (L/100km)	3.9	4.4	5.3
CO_2 (g/km)	**89**	**101**	**123**
Fuel tank (L)	45	40	55
Kerb weight (kg)	1,420	1,240	1,230 (unladen)
Max permissible laden weight (kg)	1,805	1,650	1,790
Low rolling resistance tyres	–	✓	–
Aerodynamic improvements	✓	✓	–
Active aerodynamics	–	✗	✗
Gasoline Direct Injection	✗	✗	✓
Automatic start-stop	Not relevant*	Not relevant*	✓
Regenerative braking (smart alternator)	✓	✓	✓
Electric power steering	✓	✓	–
Low viscosity engine oil	–	–	–
Mild/Full Hybrid	✓	✓	✗
Downsizing	✗	✗	✓
Weight reduction	✗	–	–
Transmission improvements	–	–	✓
VVT	✓	✓	✓

✓ *= implemented on this model* ✗ *= not implemented on this model* – *= not mentioned.*

* *Automatic start-stop is not an additional technology which can be included/not included on the hybrid arrangements of the Prius and Insight. It is part of the hybrid powertrain and cannot therefore be considered in isolation when analysing the CO_2 saving / increase in cost (€).*

Table 31 Vehicle parameters and key technologies for lowest CO_2 emitting models in the D segment

	D Segment				
	Diesel			Gasoline	
Technology	**BMW 320d Efficient-Dynamics**	**Audi A4 2.0 TDIe Saloon**	**Mercedes C220 CDI Blue-Efficiency**	**BMW 318i ES**	**Audi A4 TFSI Saloon**
Engine displacement (L)	2	2	2.1	2	2
Engine Power (kW)	120	100	125	105	155
0-100 km/h (s)	8	9.5	7.6	9.1	6.9
Transmission	Manual 6	Manual 6	Manual 6	Manual 6	Manual 6
Fuel consumption: Urban (L/100km)	5	5.8	6.2	8.1	8.3
Fuel consumption: Extra-urban (L/100km)	3.6	3.8	4	5.3	5.3
Fuel consumption: Combined (L/100km)	4.1	4.6	4.8	6.3	6.4
CO_2 (g/km)	**109**	**119**	**127**	**146**	**149**
Fuel tank (L)	61	65	66	63	65
Kerb weight (kg)	1,495	1,475	1,610	1,435	1,445
Max permissible laden weight (kg)	1,940	2,025	2,115	1,880	1,995
Low rolling resistance tyres	✓	✓	✓	–	–
Aerodynamic improvements	✓	✓	✓	✓	✓
Active aerodynamics	✓	–	✗	✓	–
Gasoline Direct Injection				✓	✓
Automatic start-stop	✓	✓	✗	✓	✓
Regenerative braking (smart alternator)	✓	✓	✗	✓	✓
Electric power steering	✓	–	–	✓	–
Low viscosity engine oil	✓	–	–	–	–
Mild/Full Hybrid	✗	✗	✗	✗	✗
Downsizing	✗	✗	✗	✗	✗
Weight reduction	✓	✗	✓	–	✗
Transmission improvements	✓	✓	✓	–	–
VVT	✗	✗	✗	–	✓

✓ *= implemented on this model* ✗ *= not implemented on this model* – *= not mentioned.*

4.3.3 D Segment

Table 31 identifies the same parameters for the lowest CO_2 emitting models in the D Segment.

Note that a new Mercedes C220 CDI model will be available on the market from March 2011 which will now be equipped with automatic stop/start technology. The new model will have a further improved combined fuel consumption of 4.4 L/100km and improved CO_2 emissions of 117 g/km.

A large number of the CO_2 emissions reducing technologies are implemented in the D segment, with improved aerodynamics being common across both diesel and gasoline models. With the launch of the new version of the C220 CDI in March 2011, auto stop/start will also be common across both diesel and gasoline vehicles.

4.4 Comparisons of CO_2 and cost estimates with OEM stated values

In this section, for each vehicle segment, a table has been populated to identify the sales price, the CO_2 emissions and some of the key vehicle parameters for the five lowest-emitting vehicles and their non-‘eco’ equivalents. A second table for each vehicle segment then provides estimates of the individual impact on CO_2 emission levels and the associated cost of each of the technologies identified. The sum of the estimated costs and CO_2 impacts of the technologies employed are then compared with the differences in sales price and CO_2 emissions between the lowest-emitting vehicles and their non-‘eco’ equivalents.

Only similar vehicles have been compared. The Toyota Yaris (B Segment), the Mercedes C220 Blue-Efficiency (D Segment) and the BMW 318i ES (D Segment) do not have direct alternatives but have been analysed to indicate what the estimate of additional cost of these technologies might be and an indication of what the additional CO_2 (g/km) might be if the low CO_2 technologies were not present.

The Toyota Prius and the Honda Insight also do not have direct alternatives but instead have been compared to representative models as the hybrid technologies are of particular interest. The Toyota Prius has been compared to the Toyota Auris V-matic. (Full details of the new Toyota Auris hybrid were not available at the time of writing this report to be able to use the Auris hybrid in place of the Prius). The Honda Insight has been compared to the Honda Jazz. Although the size of the Honda Insight, in terms of length and mass, is more comparable to the Honda Civic (see Table 32), the Insight and Jazz share the same vehicle platform. Therefore the Honda Jazz has been used to compare against the Honda Insight

Table 32 Comparison of Honda Jazz, Honda Insight and Honda Civic

	Honda Jazz	Honda Insight	Honda Civic
IHS Global Insight Segment	B	C1	C1
Vehicle Length, mm	3,900	4,396	4,255
Vehicle width, mm	1,695	1,695	1,765
Vehicle kerb mass, kg	1,086	1,240	1,244
0 – 100 km/h	12.5	12.5	13.0
CO_2, g/km	125	101	135

For these vehicles there are additional data in Table 37 and Table 38, identifying cost estimates for the mild and full hybrid technology.

It should be noted that in this section aerodynamic improvements, downsizing (a reduction in engine displacement or a reduction in the number of cylinders), weight reduction and transmission improvements have been judged versus the vehicles being used for comparison in order to make fair assessments between the two. Therefore some of the answers for these categories may be different compared to those listed in section 4.3.

Prices quoted in the following comparisons exclude sales tax and any registration costs. Except where indicated, they have been sourced from the German market, which is the largest single

European national market and may be seen as the most representative of the EU as a whole. Vehicle sales price comparisons have been made on the basis of comparable trim levels where possible.

Table 33 details the prices of two vehicles across the five main European markets, both the manufacturers' recommended basic retail price (excluding sales tax) and on-the-road prices. The On-the-road price includes sales tax, registration costs and delivery charges.

When account is taken of the current low exchange rate between the UK pound and the Euro (£1 = €1.19) compared to the exchange rate over recent years and it is assumed that sale prices in the UK will not yet have increased to compensate for this, Table 33 shows that prices in the German market are representative of those in the other main markets.

Table 33 Comparison of Basic and On-the-road prices for two vehicles for the 5 main European markets

Vehicle	Price	Country				
		France	Germany	Italy	Spain	UK*
Audi A3 1.2 TFSI S tronic 5 door	Basic price (€)	n.a.	€19,075.63	n.a.	n.a.	€17,423.57
	On-the-road price (€)	€25,430.00	€22,700.00	€26,650.00	€24,770.00	€21,675.85
Mercedes C220 CDI BlueEfficiency	Basic price (€)	n.a.	€30,975.00	€30,007.00	n.a.	€26,551.87
	On-the-road price (€)	€35,000.00	€36,860.25	€37,268.25	€36,350.00	€33,022.50

* *Conversion rate as at January 2011 £1 = €1.19 was used.*

n.a.: *not available in the price lists given.*
Basic price: *manufacturers' recommended retail price excluding any sales tax (e.g. VAT in UK).*
On-the-road price: *manufacturers' recommended retail price including sales tax, number plates, delivery, registration fee and annual circulation tax.*

Note: prices do not include any tax incentives (other than annual circulation tax) that may be available for low CO_2 vehicles in the markets reviewed.

Technology cost values quoted are as identified in Task 1.1 of this service request for each vehicle segment, based on typical values of ex-works cost to the OEM and Ricardo estimates if the technology is not specifically included in Task 1.1. The CO_2 benefit values quoted are over the NEDC and are also as identified in Task 1.1 or Ricardo estimates based on typical values for each vehicle segment. Within the scope of this work it has not been possible to investigate the details of implementation or make measurements for specific vehicles, so the values should be interpreted as a guideline only.

Costs for aerodynamic improvements have been indicated as zero, as the cost of implementation of vehicle body modifications cannot be quantified within an analysis of this type. Actual cost to the OEM will vary significantly depending on a number of factors, such as the details and extent of modifications, the nature of any bought-in parts and the extent to which modifications are carried out as part of a planned model facelift.

4.4.1 B Segment

Table 34 B Segment

	Diesel						Gasoline			
	Volkswagen Polo BlueMotion	Volkswagen Polo TDI*1	Ford Fiesta ECOnetic	Ford Fiesta Duratorq TDCI	Opel Corsa 1.3 CDTi ecoFLEX	Opel Corsa 1.3 CDTi ECOTEC	Toyota Yaris	n/a	Mitsubishi Colt ClearTec	Mitsubishi Colt
CO_2 (g/km)	89*2	99	98	107	95	115	118	n/a	119	143
Price exc. sales tax (€)	13,643	12,647	13,571	13,361	13,748	13,496	10,416	n/a	11,756	11,336
Engine displacement (L)	1.2	1.6	1.6	1.6	1.3	1.3	1.1	n/a	1.3	1.3
Engine Power (kW)	55	55	70	70	70	70	51	n/a	70	70
0-100 km/h (s)	13.9	13.9	12.3	11.9	12.3	12.3	15.7	n/a	10.6	11.1
Kerb weight (kg)	1,150	1,157	1,100	1,100	1,160	1,160	1,035	n/a	970	970

		Diesel									Gasoline		
		Volkswagen Polo BlueMotion			Ford Fiesta ECOnetic			Opel Corsa 1.3 CDTi ecoFLEX			Mitsubishi Colt ClearTec		
Purchase price (€) and CO_2 (g/km) difference vs baseline			€ 996	10		€ 210	9		€ 252	20		€ 420	24
		Is technology present?	Estimated cost (€)	Estimated CO_2 saving %	Is technology present?	Estimated cost (€)	Estimated CO_2 saving %	Is technology present?	Estimated cost (€)	Estimated CO_2 saving %	Is technology present?	Estimated cost (€)	Estimated CO_2 saving %
Technologies identified in literature review	Low rolling resistance tyres	✓	€ 30	3%	✓	€ 30	3%	✓	€ 30	3%	✓	€ 30	3%
	Aerodynamic improvements	✓	€ 0	1%	✓	€ 0	1%	✓	€ 0	1%	–	–	–
	Active aerodynamics	×	–	–	×	–	–	–	–	–	–	–	–
	Gasoline Direct Injection										–	–	–
	Automatic start-stop	✓	€ 175	4%	✓	€ 175	4%	✓	€ 175	4%	✓	€ 175	5%
	Regenerative braking (smart alternator)	✓	€ 40	2%	×	€ 40	2%	×	–	–	✓	€ 40	2%
	Electric power steering	×	–	–	✓	€ 20	1%	✓	€ 20	1%	–	–	–
	Low viscosity engine oil	×	–	–	–	–	–	–	–	–	✓	€ 8	1%
	Mild/Full Hybrid	×	–	–	×	–	–	×	–	–	×	–	–
	Downsizing	✓	€ 50	4%	×	–	–	×	–	–	×	–	–
	Weight reduction	✓	€ 128	1.5%	×	–	–	✓	€ 128	1.5%	×	–	–
	Transmission improvements	✓	€ 60	3%	✓	€ 60	3%	✓	€ 60	0	✓	€ 60	3%
	VVT	×	–	–	×	–	–	×	–	–	✓	€ 80	4%
Total:			€ 483	19%		€ 325	14%		€ 413	14%		€ 393	18%
Estimated additional CO_2 (g/km) for vehicle without listed technologies		20			16			15			26		

*1 German market figures used (UK figures differ, i.e. CO_2 was 112g/km).
*2 German market had a lower CO_2 figure than the UK (UK was 91g/km).

In the B segment (Table 34) each of the vehicles considered shows a marked difference in CO_2 emissions between the ‘standard’ model and the ‘eco’ model, whilst the performance characteristics (power and acceleration) are very similar. There is very little difference, if any, between the kerb weights of the ‘eco’ models versus the ‘standard’ vehicles.

Sales price differentials between ‘eco’ and ‘standard’ models vary widely, from €996 for the VW Polo BlueMotion to €210 for the Ford Fiesta ECOnetic. Estimated additional costs vary less from €483 for VW Polo Bluemotion to €325 for the Ford Fiesta ECOnetic.

In some cases the estimated additional costs are much less than the sales price differentials and in others the reverse is true. This indicates that the pricing of ‘eco’ models may be primarily dependent on manufacturers’ pricing strategies across the model portfolio, rather than directly related to the cost of additional equipment fitted.

The estimated CO_2 emissions reductions for the models assessed generally vary compared to the actual CO_2 emissions reductions between the ‘eco’ and ‘standard’ models. Two have a higher calculated value, one is lower and one is reasonably directly comparable (Mitsubishi Colt Cleartec).

For the cases where the estimated CO_2 emissions reductions are higher than the CO_2 reductions achieved (in the case of VW Polo BlueMotion and Ford Fiesta ECOnetic) it may be due to:

- The benefits of all of the technologies identified may not be directly additive and thus lead to an over-estimation of the total benefit of the technology combinations
- The standard model may already include one or two of the low CO_2 technologies employed on the ‘eco’ model variant and therefore some double counting may have taken place

For the case where the estimated CO_2 emissions reduction is smaller than the CO_2 reductions achieved (Opel Corsa 1.3 CDTi ecoFLEX) it may be due to:

- Improvements that are not direct technologies, such as improved engine calibration for low CO_2 or other minor engine modifications have not been accounted for
- Not all technologies applied to the ‘eco’ model may be evident from the information available

4.4.2 C Segment

Diesel

In the C segment, as in the B segment, each of the diesel vehicles considered (Table 35) shows a notable difference in CO_2 emissions between the ‘standard’ models and the ‘eco’ models, whilst the performance characteristics in terms of engine power and acceleration time are the same.

There is no difference in kerb mass between the two VW Golf models or the two Ford Fiesta models, whereas the Volvo C30 DRIVe is heavier than the ‘standard’ model by 24 kg. All models considered have an incremental cost for the ‘eco’ variant with sales price differentials varying from €336 to €2,626.

It should be noted that individual manufacturers’ pricing strategies do not seem to be consistent between segments: incremental pricing of ‘eco’ models are considerably different for Focus versus Fiesta and Golf versus Polo models respectively. The actual CO_2 emissions reductions of the ‘eco’ models compared to the ‘standard’ models are in the range of 15 – 20 g/km. The estimated CO_2 emissions reductions are in line with these values.

Table 35 C Segment Diesel

	Diesel					
	Volkswagen Golf TDI BlueMotion	Volkswagen Golf TDI	Ford Focus TDCi ECOnetic	Ford Focus TDCi	Volvo C30 DRIVe	Volvo C30 D2
CO_2 (g/km)	99	119	99	115	99	114
Price exc. sales tax (€)	17,836	17,500	19,222	16,596	18,681	18,177
Engine displacement (L)	1.6	1.6	1.6	1.6	1.6	1.6
Engine Power (kW)	77	77	80	80	84	84
0-100 km/h (s)	11.3	11.3	10.9	10.9	10.7	10.7
Kerb weight (kg)	1,314	1,314	1,357	1,357	1,363	1,339

		Diesel								
		Volkswagen Golf TDI BlueMotion			Ford Focus TDCi ECOnetic			Volvo C30 DRIVe		
Purchase price (€) and CO_2 (g/km) difference vs baseline			€ 336	20		€ 2,626	16		€ 504	15
		Is technology present?	Estimated cost (€)	Estimated CO_2 saving %	Is technology present?	Estimated cost (€)	Estimated CO_2 saving %	Is technology present?	Estimated cost (€)	Estimated CO_2 saving %
Technologies identified in literature review	Low rolling resistance tyres	✓	€ 35	3%	✓	€ 35	3%	✓	€ 35	3%
	Aerodynamic improvements	✓	€ 0	1%	✓	€ 0	1%	✓	€ 0	1%
	Active aerodynamics	✓	€ 50	1%	–	–	–	–	–	–
	Gasoline Direct Injection									
	Automatic start-stop	✓	€ 200	4%	✓	€ 200	4%	✓	€ 200	4%
	Regenerative braking (smart alternator)	✓	€ 40	2%	✓	€ 40	2%	✓	€ 40	2%
	Electric power steering	–	–	–	✓	€ 20	1%	–	–	–
	Low viscosity engine oil	–	–	–	✓	€ 10	1%	–	–	–
	Mild/Full Hybrid	×	–	–	×	–	–	×	–	–
	Downsizing	×	–	–	×	–	–	×	–	–
	Weight reduction	×	–	–	×	–	–	×	–	–
	Transmission improvements	✓	€ 60	3%	✓	€ 60	3%	✓	€ 60	3%
	VVT	×	–	–	×	–	–	×	–	–
Total:		–	**€ 385**	**14%**	–	**€ 365**	**15%**	–	**€ 335**	**13%**
Estimated additional CO_2 (g/km) for vehicle without listed technologies			16			17			15	

Table 36 C Segment Gasoline

	Gasoline				
	Toyota Prius	**Toyota Auris V-matic (manual)**	**Honda Insight**	**Honda Jazz (manual)**	**Audi A3 1.2 TFSI S tronic**
CO_2 (g/km)	89	153	101	125	123
Price exc. sales tax (€)	21,638	16,386	16,765	10,546	19,076
Engine displacement (L)	1.8	1.6	1.4	1.2	1.2
Engine Power (kW)	73 (system power 100kW)	97	65	66	77
0-100 km/h (s)	10.4	10	12.5	12.5	10.5
Coefficient of drag	0.25	0.29	0.25	-	
Kerb weight (kg)	1,420	1245-1295	1,240	1,086	1,230

		Gasoline								
		Toyota Prius			Honda Insight			Audi A3		
Purchase price (€) and CO_2 (g/km) difference vs baseline			**€ 5,252**	**64**		**€ 6,219**	**24**	**123 g/km CO_2**		
		Is technology present?	**Estimated cost (€)**	**Estimated CO_2 saving %**	**Is technology present?**	**Estimated cost (€)**	**Estimated CO_2 saving %**	**Is technology present?**	**Estimated cost (€)**	**Estimated CO_2 saving %**
Technologies identified in literature review	**Low rolling resistance tyres**	✓	€ 35	3%	✓	€ 35	3%	–	–	–
	Aerodynamic improvements	✓	€ 0	1%	✓	€ 0	1%	–	–	–
	Active aerodynamics	–	–	–	×	–	–	–	–	–
	Gasoline Direct Injection	×	–	–	×	–	–	✓	€ 180	5%
	Automatic start-stop	✓	Cost and benefit included in full hybrid technology		✓	Cost and benefit included in mild hybrid technology		✓	€ 200	5%
	Regenerative braking (smart alternator)	✓			✓			✓	€ 40	2%
	Electric power steering	✓	€ 20	1%	✓	€ 20	1%	–	–	–
	Low viscosity engine oil	–	–	–	–	–	–	–	–	–
	Mild/Full Hybrid	✓ (Full hybrid)	€ 3,020	25%	✓ (Mild hybrid)	€ 1,220	15%	×	–	–
	Downsizing (inc. T/C)	×	–	–	×	–	–	✓	€ 250	5%
	Weight reduction	×	–	–	×	–	–	–	–	–
	Transmission improvements	–	–	–	–	–	–	✓	€ 60	4%
	VVT	✓	€ 80	4%	✓	€ 80	4%	✓	€ 80	4%
Total:		**–**	**€ 3,155**	**34%**	**–**	**€ 1,355**	**24%**	**–**	**€ 810**	**25%**
Estimated additional CO_2 (g/km) for vehicle without listed technologies		**46**			**32**			**41**		

Gasoline

For the gasoline vehicles (Table 36), vehicle-level differences are more significant between hybrid and nearest equivalent models. There is evidence that the hybrid vehicles have been developed with a strong focus on low fuel consumption, such as in vehicle aerodynamics: both Prius and Insight have drag coefficients of 0.25, which is considerably lower than the segment average of circa 0.33 Cd. Another example in the case of the Toyota Prius is a minimal vehicle weight penalty despite its use of relatively heavy electrical components.

The CO_2 emissions figure for the Toyota Prius is 89 g/km compared to 153 g/km for the Auris. The price differential is also significant at €5,252. When comparing the performance of the two vehicles, the maximum engine power of the Auris is 97 kW and that of the Prius is 73 kW, however the maximum system power of the Prius is 100 kW so comparable to the Auris. Comparing the acceleration times the Auris achieves 0 – 100 km/h in 10s and the Prius in 10.4s. Taking into account the additional mass of the Prius this is comparable.

The CO_2 improvement for the Honda Insight versus the Honda Jazz model is 24g/km, and the price differential is €6,219. This price differential not only reflects the generally higher incremental costs of hybrids versus other CO_2 reducing technologies but also the difference in vehicle segment and size (the Insight is a bigger vehicle than the Jazz). The price differentials for the hybrid models are significantly higher than the equivalent price differentials for the diesel models considered.

A simple analysis of estimated powertrain system costs for the two hybrid vehicles is shown in the table below. All cost data assumes an ex-works cost to the OEM and does not include R&D costs, OEM overheads, marketing budget or profit margins. The analysis includes main powertrain components only, and does not account for any changes in ancillary systems, such as special heating & ventilation equipment. Electrical component costs have been calculated as far as possible using the assumptions provided by ICF for Task 1.1.9 of this Service Request. ICF prices used are those given for 2012. The assumption of full-scale production, on which the prices are based, may be taken as valid, since annual production numbers of Prius and Insight are already greater than 200,000 units / year. Other data is sourced from the US Department of Energy / Oak Ridge National Laboratory (ORNL) study “Technology and cost of the MY2007 Toyota Camry HEV final report” (2007).

It should be noted that this analysis takes no account of cost differences for vehicle structure and components, which may be present owing to the different set of design priorities that will be applied to fuel economy flagship vehicles such as these. Such comparisons are beyond the scope of this work, but cost differences are likely to be significant.

For the Audi A3 1.2 TFSI no ‘standard’ vehicle without CO_2 reducing technologies is available for comparison. Therefore the analysis for this vehicle just shows the estimated incremental cost and CO_2 benefit that is provided by the identified low CO_2 technologies. The analysis indicates that the additional cost of the low CO_2 technologies is circa €810 and that the benefit provided by these technologies is 25%. This suggests that without these technologies the CO_2 emissions of the vehicle could be closer to 164 g/km compared to the 123 g/km of the current model.

Table 37 Toyota Prius (2009).

Component	Rating / details	Estimated cost (€)	Source
Additional components			
Motor	60 kW	530	TNO / ICF (1)
Generator	30 kW	290	TNO / ICF (1)
Inverter	90 kW total	950	TNO / ICF (1)
Controller	-	150	TNO / ICF (1)
Boost converter	Assume 60 kW	190	TNO / ICF (1)
Battery pack	1.3 kWh	1,110	TNO / ICF (1)
Power electrical harness	-	150	TNO / ICF (1)
DC-DC converter	1.2 kW	120	ORNL (2)
Regenerative braking system	-	80	ORNL (2)
Power split transmission	-	320	ORNL (2), Ricardo analysis
	Total	**3,890**	
Omitted components			
Engine de-feature	Starter, alternator, full VVA	220	Ricardo
Transmission		600	Ricardo
Clutch		50	Ricardo
	Total	**870**	
Overall cost increase		**3,020**	

Table 38 Honda Insight (2010).

Component	Rating / details	Estimated cost (€)	Source
Additional components			
Motor	10 kW	130	TNO / ICF (1)
Inverter	10 kW	150	TNO / ICF (1)
Controller	-	150	TNO / ICF (1)
Battery pack	0.6 kWh	620	TNO / ICF (1)
Power electrical harness	-	150	TNO / ICF (1)
DC-DC converter	1.0 kW	100	ORNL (2), Ricardo analysis
	Total	**1,300**	
Omitted components			
Engine de-feature	Starter, alternator	80	Ricardo
	Total	**80**	
Overall cost increase		**1,220**	

(1) Impacts of Electric Vehicles – Deliverable 2 “Assessment of electric vehicle and battery technology” report, ICF, CE Delft, Ecologic, December 2010.
(2) US Department of Energy / Oak Ridge National Laboratory (ORNL) study “Technology and cost of the MY2007 Toyota Camry HEV final report” (2007).

4.4.3 D Segment

For three out of the five vehicle models reviewed the manufacturers do not differentiate by having an ‘eco’ and ‘standard’ variant of the same model. That is, in the case of the Mercedes C220 diesel as well as the BMW 318 and Audi A4 TFSI gasoline models these are the only options.

Diesel

As with the previous segments, each of the vehicles considered in the D Segment show a notable difference in the CO_2 emissions from the ‘standard’ model to the ‘eco’ model, however the performance characteristics (power and acceleration) vary from a decrease from ‘standard’ to ‘eco’ for the BMW 320d models, to an increase from ‘standard’ to ‘eco’ for the Audi A4 diesel models.

Thus in the latter case, the additional cost of the ‘eco’ variant buys the vehicle purchaser not only improved CO_2 emissions and fuel economy, but also improved performance.

There is €0 price difference between the BMW 320d models and €1,765 between the Audi A4 models.

For the BMW 320d Efficient Dynamics, many individual technologies are employed to reduce CO_2 emissions, resulting in an estimated CO_2 emissions reduction of 22 g/km versus the ‘standard’ model.
This is higher than the actual difference noted between the ‘eco’ and ‘standard’ variants. The fact that the actual CO_2 reduction is less than the sum of the estimated potential benefits of each individual technology could be due to the diminishing returns that can be achieved from multiple measures that target similar sources of energy loss.

It should be noted that the ‘standard’ model already has a relatively low CO_2 value at 125 g/km. There is no difference in price between ‘eco’ and ‘standard’ models but the analysis estimates an additional cost of €649 for the technologies employed.

For the Audi A4 2.0 TDIe there is just an 8 g/km CO_2 difference between this and the ‘standard’ model. It should be noted that the ‘eco’ model has a higher power than the ‘standard’ model, 100 kW versus 88 kW. In general variants in a model range with the same technology, with a higher maximum power have higher CO_2 emissions. If the ‘standard’ model had an equivalent power to the ‘eco’ model then the difference between the two CO_2 figures would likely be larger and therefore closer to the 13 g/km estimated by the analysis shown in Table 39.

The actual price differential between the two models is €1,765 compared to an estimated additional cost of the technologies present of €365.

Gasoline

For the BMW 318i and the Audi A4 2.0 TFSI no ‘standard’ vehicle without CO_2 reducing technologies is available for comparison. Therefore the analysis for these vehicles just shows the estimated incremental cost and CO_2 benefit that is provided by the identified low CO_2 technologies.

For the BMW 318i the analysis indicates that the additional cost of the low CO_2 technologies is circa €525 and that the benefit provided by these technologies is 15%. This suggests that without these technologies the CO_2 emissions of the vehicle could be closer to 172 g/km compared to the 146 g/km of the current model.

For the Audi A4 2.0 TFSI the analysis indicates that the additional cost of the low CO_2 technologies is circa €525 and that the benefit provided by these technologies is circa 17%. This suggests that without these technologies the CO_2 emissions of the vehicle could be closer to 180 g/km compared to the 149 g/km of the current model.

Table 39 D Segment Diesel and Gasoline

	Diesel					Gasoline	
	BMW 320d Efficient-Dynamics	BMW 320d SE	Audi A4 2.0 TDIe Saloon	Audi A4 2.0 TDI	Mercedes C220 Blue-Efficiency	BMW 318i ES	Audi A4 2.0 TFSI Saloon
CO_2 (g/km)	109	125	119	127	127	146	149
Price exc. sales tax (€)	28,823	28,823	26,555	24,790	30,975	24,286	29,370
Engine displacement (L)	2	2	2	2	2.1	2	2
Engine Power (kW)	120	135	100	88	125	105	155
0-100 km/h (s)	8	7.5	9.5	10.7	7.6	9.1	6.9
Kerb weight (kg)	1,495	1,505	1,475	1,470	1,610	1,435	1,445

		Diesel						Gasoline					
		BMW 320d Efficient-Dynamics			Audi A4 2.0 TDIe Saloon			BMW 318i ES			Audi A4 2.0 TFSI Saloon		
Purchase price (€) and CO_2 (g/km) difference vs baseline			€ 0	16		€ 1,765	8		146 g/km			149 g/km	
		Is technology present?	Estimated cost (€)	Estimated CO_2 saving (%)	Is technology present?	Estimated cost (€)	Estimated CO_2 saving (%)	Is technology present?	Estimated cost (€)	Estimated CO_2 saving (%)	Is technology present?	Estimated cost (€)	Estimated CO_2 saving (%)
Technologies identified in literature review	Low rolling resistance tyres	✓	€ 40	3%	✓	€ 40	3%	–	–	–	–	–	–
	Aerodynamic improvements	✓	€ 0	0.8%	✓	€ 0	1%	✓	€ 0	0.8%	✓	€ 0	0.8%
	Active aerodynamics	✓	€ 60	0.8%	–	–	–	✓	€ 60	0.8%	–	–	–
	Gasoline Direct Injection							✓	€ 180	5.5%	✓	€ 180	5.5%
	Automatic start-stop	✓	€ 225	4%	✓	€ 225	4%	✓	€ 225	5.0%	✓	€ 225	5.0%
	Regenerative braking (smart alternator)	✓	€ 40	2%	✓	€ 40	2%	✓	€ 40	2.0%	✓	€ 40	2.0%
	Electric power steering	✓	€ 20	1%	–	–	–	✓	€ 20	1.0%	–	–	–
	Low viscosity engine oil	✓	€ 12	1%	–	–	–	–	–	–	–	–	–
	Mild/Full Hybrid	×	–	–	×	–	–	×	–	–	×	–	–
	Downsizing	×	–	–	×	–	–	×	–	–	×	–	–
	Weight reduction	✓	€ 192	1.5%	×	–	–	–	–	–	×	–	–
	Transmission improvements	✓	€ 60	3%	✓	€ 60	3%	–	–	–	–	–	–
	VVT	×	–	–	×	–	–	–	–	–	✓	€ 80	4%
Total:		–	€ 649	17%	–	€ 365	13%	–	€ 525	15.0%	–	€ 525	17.3%
Estimated additional CO_2 (g/km) for vehicle without listed technologies			22			18			26			31	

4.5 Conclusions

As noted above, in the comparison between 'standard' and 'eco' models, the overall figures for the reduction in CO_2 emissions and the increase in price often do not match well the sum of the individual estimates for the technologies identified as being featured. This is not surprising, for a number of reasons:

- CO_2 benefits tend to reduce as multiple CO_2-reducing technologies are added that target the same sources of losses i.e. there is likely to be a non-linear summation when including several technologies
- The analysis assumes a baseline specification which may not exactly apply for each model and manufacturer – i.e. the 'standard' vehicle's level of technology and CO_2 reduction potential varies from case to case
- The benefit extracted by the manufacturer from each technology may not be the maximum potential benefit, due to limiting factors specific to the particular model or for cost reasons
- Not all technologies applied to 'eco' models may be evident from the information available

The latter two points are particularly significant. The optimisation of fuel consumption and CO_2 emissions is a complex process in which the most significant gains can be achieved only if the implementation of headline technologies is accompanied by other incremental improvements in many different systems and components.

The CO_2 reduction potential and limits of such detailed refinements will vary significantly from vehicle to vehicle. The following list gives an indication of the most significant such factors and their typical levels of CO_2 reduction potential and cost, based on Ricardo's experience:

- **Lightweighting**. Approximately 0.6% CO_2 emissions reduction is achieved for each 1% saving in total vehicle mass. Cost levels are likely to be very variable depending how savings are achieved. A drive cycle CO_2 emissions benefit is only achieved if weight reduction measures are sufficient to reduce the vehicle's inertia class for testing. Brake energy recovery (e.g. mild / full hybrid) tends to reduce the benefit available from lightweighting.
- **Engine calibration**. Improvements in engine combustion efficiency can usually be achieved by re-optimisation of engine calibration with a higher priority on fuel consumption. Any improvements will typically be at the expense of other factors, such as noise. Levels of potential for improvement will depend on the 'standard' vehicle's selected calibration tradeoffs and extent of existing optimisation. Cost of implementation of improvements is close to zero except for development costs.
- **Engine downspeeding**. Reduction in frictional losses can be achieved by reducing engine speed over the drive cycle, such as by the use of longer final drive ratios. The limiting factor is the engine's low speed torque. Typically, up to ~5% NEDC CO_2 reduction can be achieved using existing technology, however there may be a driveability penalty. If existing, off-the-shelf parts are used, the cost impact is close to zero.

It should be noted that some CO_2-reducing measures may result in undesirable tradeoffs against other vehicle characteristics, limiting the validity of direct comparison with 'standard' vehicles. Characteristics that may be impacted include:

- **Noise, vibration and harshness (NVH):** e.g. improved combustion efficiency through tradeoff with combustion noise in diesel engines, reduced vehicle mass through reduction of sound deadening material
- **Driveability:** e.g. reduced engine speeds over the drive cycle through longer gear ratios (potential impact on driveability if low speed torque is critical)
- **Comfort:** e.g. reduced vehicle mass through minimisation of carpeting, seat padding, etc.
- **Handling:** e.g. minimised rolling resistance through use of different tyre design / materials (can result in less desirable tyre grip characteristics)
- **Features:** e.g. reduced vehicle mass through reduction of functionality, such as infotainment equipment, spare wheel, non-essential safety features.

4.5.1 Overall view on pricing vs. estimated costs

The data presented gives a mixed picture of how manufacturers price their vehicles for CO_2 reduction. The price differential for 'eco' models is large in some cases, especially in the B and C segments, perhaps justified in terms of factors such as "green image", lifetime fuel saving and other financial benefits (e.g. reduced vehicle tax and traffic charging incentives). In other cases the price differential is small or zero. Thus the extent to which costs are passed on to customers is not clear from this analysis.

The analysis suggests that manufacturers have different strategies when deciding how to price low CO_2 emitting vehicles. Some of the options that may be considered are:

- Increase the price and generate additional profit
- Increase the price to cover the technology cost but generate no additional profit
- Do not increase price and do not cut base level equipment/features. This is the best option for the consumer
- Do not increase price but cut equipment/features
- Offer the most energy saving model as an additional version to those in the existing portfolio.

The analysis has tried to compare models on the basis of similar trim levels, however offering higher equipment levels (at minimal extra cost) is clearly another mechanism by which manufacturers could attempt to pass on additional costs of CO_2-reducing technology, although there is no evidence that this is a common practice.

In many cases, the estimated additional costs to the manufacturer appear to be much smaller than the additional price charged to the consumer, suggesting additional profit is generated on these models. However, the analysis performed takes no account of engineering costs, which on a per-vehicle basis could be significant for 'eco' variants with relatively small production numbers, and still more significant in the case of more radical technologies such as those featured in the hybrid vehicles considered.

Even if a manufacturer chooses to follow a strategy of parity pricing between 'eco' and 'standard' models, it can be assumed that any additional costs involved will be met by a general increase in prices across the model range as a whole.

4.5.2 Analysis of cost and CO_2 benefits of technologies currently in the marketplace by vehicle segment assessed

Table 40 and Table 41 provide a summary of the cost and CO_2 benefits of technologies currently applied to the vehicles which were reviewed in this report. Table 40 covers diesel vehicles and Table 41 covers gasoline vehicles, both detail additional cost and benefit by vehicle segment.

A dash is shown in the boxes where it is not clear whether the technology is utilised and the box is greyed out where the technology is definitely not implemented in the 'eco' vehicles assessed.

Table 40 Summary of cost and CO_2 benefits for diesel vehicles in the B, C and D segments assessed in this report

Technologies applied to low CO_2 emission DIESEL vehicles assessed in this report	B Segment		C Segment		D Segment	
	On-cost	CO_2 saving	On-cost	CO_2 saving	On-cost	CO_2 saving
Low Rolling Resistance tyres	€30	3%	€35	3%	€40	3%
Aerodynamic improvements	€0	1%	€0	1%	€0	1%
Active aerodynamics			€50	1%	€60	0.8%
Gasoline direct injection						
Automatic stop-start	€175	4%	€200	4%	€225	4%
Regenerative braking (smart alternator)	€40	2%	€40	2%	€40	2%
Electric power steering	€20	1%	€20	1%	€20	1%
Low viscosity engine oil	€8	1%	€10	1%	€12	1%
Mild hybrid						
Full hybrid						
Downsizing	€50	4%	€50	4%	€50	4%
Weight reduction	€128	1.5%	€160	1.5%	€192	1.5%
Transmission improvements	€60	3%	€60	3%	€60	3%
VVT						

4.5.3 Comment on low-CO_2 technologies employed outside B, C and D segments

As explained in the introduction to this task, no additional low-CO_2 technologies were identified for other market segments beyond those already identified for the B, C and D segments. The reason for this may be explained as follows.

Vehicle segments B, C and D offer the greatest potential for influencing a manufacturer's fleet average CO_2 figure, since they account for a very high proportion of total vehicle sales. Thus these segments tend to be the first recipients of new CO_2-reducing technology. In order to offer competitive products, manufacturers can be expected to employ those CO_2-reducing technologies first that give the best trade-off with cost. Technologies that sit further along the cost curve will tend to be employed for a particular model only once the benefits of more cost-effective technologies have already been taken advantage of. The magnitude of CO_2 benefits, at least for the technologies currently available in the market, is reasonably independent of the vehicle segment to which they are applied. Therefore "outlier" technologies can generally be expected to feature on selected models of a manufacturer's product range only in the case of market segments that are both relatively CO_2-sensitive (e.g. large proportion of sales) and relatively price-insensitive. This is rarely the case – for example, the F segment may be considered relatively price-insensitive, however for most manufacturers this segment represents only a small proportion of total sales, thus little incentive exists to develop CO_2-reducing technologies especially for application to this segment.

An exception to this rule is the case of a manufacturer meeting a market demand for products that are seen to be "green", independently of any need to reduce fleet average CO_2. Such a market demand is easiest to imagine in the case of the E segment. Models in this segment are available with several of the technologies identified for the B, C and D segments, despite the fact that sales represent <5% of total passenger car sales. However, it does appear that "green image" market drivers are not currently strong enough for manufacturers to offer any further CO_2-reducing technologies beyond those already available in the B, C and D segments.

Table 41 Summary of cost and CO_2 benefit estimates for gasoline vehicles in the B, C and D segments assessed in this report

Technologies applied to low CO_2 emission GASOLINE vehicles assessed in this report	B Segment		C Segment		D Segment	
	On-cost (€)	CO_2 saving (%)	On-cost (€)	CO_2 saving (%)	On-cost (€)	CO_2 saving (%)
Low Rolling Resistance tyres	€30	3%	€35	3%	-	-
Aerodynamic improvements	-	-	€0	1%	€0	1%
Active aerodynamics			-	-	€60	0.8%
Gasoline direct injection	-	-	€180	5%	€180	5.5%
Automatic stop-start	€175	5%	€200	5%	€225	5%
Regenerative braking (smart alternator)	€40	2%	€40	2%	€40	2%
Electric power steering	-	-	€20	1%	€20	1%
Low viscosity engine oil	€8	1%	-	-	-	-
Mild hybrid			€1,220	15%		
Full hybrid			€3,020	25%		
Downsizing (inc. turbocharging)	-	-	€250	5%	-	-
Weight reduction	-	-	-	-	-	-
Transmission improvements	€60	3%	€60	4%	-	-
VVT	€80	4%	€80	4%	€80	4%

4.6 References

4.6.1 Sources for B Segment vehicle data

Volkswagen Polo BlueMotion

"The new 1.2l TDI® from Volkswagen – Innovation with three cylinders for maximum fuel efficiency" / F Rudolph; J Hadler; H J Engler; A Krause; C Lensch-Franzen, the 31st Vienna Engine Symposium, Apr 2010

Ford Fiesta ECOnetic

http://www.ford.co.uk/Cars/Fiesta/FiestaECOnetic
http://www.carsuk.net/ford-fiesta-econetic-price-specifications-and-data/

Opel Corsa 1.3 CDTi ecoFLEX:

http://media.opel.com/content/media/intl/en/news.detail.brand_opel.html/content/Pages/news/intl/en/2011/OPEL/01_25_opel_corsa_mce

Toyota Yaris

http://www.toyota.co.uk/cgibin/toyota/bv/generic_editorial.jsp?deepLink=YA5_Specification_new&nodiv=TRUE&fullwidth=TRUE&edname=specSheet_YA5&carModel=Yaris&imgName=bv/CarChapter/YA5/Imagery/YA5_spec.jpg&zone=Zone%20YARIS&navRoot=toyota_1024_root

Mitsubishi Colt ClearTec

http://www.mitsubishi-cars.co.uk/colt/

4.6.2 Sources for C Segment vehicle data

Volkswagen Golf BlueMotion

http://www.volkswagen.co.uk/#/new/golf-vi/which-model/engines/overview

Ford Focus ECOnetic

http://www.ford.co.uk/Cars/Focus/FocusECOnetic

Volvo C30 DRIVe

http://www.volvocars.com/uk/all-cars/volvo-c30/details/pages/technical-spec.aspx

Toyota Prius

http://www.toyota.co.uk/bv/leads/pdfFiles/rc46362.pdf

Honda Insight

http://www.honda.co.uk/cars/insight/#fullspecification

4.6.3 Sources for D Segment vehicle data

BMW 320d EfficientDynamics

http://www.bmw.co.uk/bmwuk/pricesandspecifications_technical_specs/0,,1156_181246516__bs-Mw%3D%3D%40bb-TEkwOA%3D%3D%40bm-WjNFRA%3D%3D,00.html?tab=technicalSpec

Audi A4 2.0 TDIe Saloon

http://www.audi.co.uk/new-cars/a4/a4-saloon/saving-you-fuel.html

Mercedes C220 BlueEfficiency

http://www2.mercedesbenz.co.uk/content/unitedkingdom/mpc/mpc_unitedkingdom_website/en/home_mpc/passengercars/home/new_cars/models/c-class/w204/technical_data.html

BMW 318i

http://www.bmw.co.uk/bmwuk/pricesandspecifications_technical_specs/0,,1156_181246516__bs-Mw%3D%3D%40bb-TEkwOA%3D%3D%40bm-WkowMQ%3D%3D,00.html?tab=technicalSpec

Audi A4 Saloon

http://www.audi.co.uk/new-cars/a4/a4-saloon/saving-you-fuel.html

4.6.4 Sources for German vehicle prices

Volkswagen Polo BlueMotion

http://www.volkswagen.de/etc/medialib/vwcms/virtualmaster/de/Models/Der_neue_Polo/media.Par.0033.File.pdf/tup_polo_kw23.pdf

Volkswagen Polo TDI

http://www.volkswagen.de/etc/medialib/vwcms/virtualmaster/de/Models/Der_neue_Polo/media.Par.0033.File.pdf/tup_polo_kw23.pdf

Ford Fiesta ECOnetic

http://www.ford.de/Pkw-Modelle/FordFocus/BroschuerenPreiseDaten

Ford Fiesta DuraTorq 1.6l

http://www.ford.de/Pkw-Modelle/FordFocus/BroschuerenPreiseDaten

Opel Corsa

http://www.opel.de/fahrzeuge/modelle/personenwagen/corsa-5-tuerer/daten/modelle.html

Toyota Yaris

http://www.toyota.de/cars/new_cars/yaris/specs.aspx

Mitsubishi Colt ClearTec

http://www.mitsubishi-motors.de/modelle/colt/preise

Mitsubishi Colt

http://www.mitsubishi-motors.de/modelle/colt/preise

Volkswagen Golf BlueMotion

http://www.volkswagen.de/etc/medialib/vwcms/virtualmaster/de/Models/golf0/golf_6/media.Par.0094.File.pdf/technikupreise_golf.pdf

Volkswagen Golf TDI

http://www.volkswagen.de/etc/medialib/vwcms/virtualmaster/de/Models/golf0/golf_6/media.Par.0094.File.pdf/technikupreise_golf.pdf

Ford Focus ECOnetic

http://www.ford.de/Pkw-Modelle/FordFocus/BroschuerenPreiseDaten

Ford Focus TDCi

http://www.ford.de/Pkw-Modelle/FordFocus/BroschuerenPreiseDaten

Volvo C30 DRIVe

http://www.volvocars.com/de/all-cars/volvo-c30/details/pages/infoundpreisliste.aspx

Volvo C30 D2

http://www.volvocars.com/de/all-cars/volvo-c30/details/pages/infoundpreisliste.aspx

Toyota Prius

http://www.toyota.de/Images/Web-PDF_Prius_PDB_0209_tcm281-463828.pdf

Toyota Auris V-matic (manual)

http://www.toyota.de/Images/081028_Auris_PDB_0208_tcm281-546957.pdf

Honda Insight

http://www.honda.de/content/automobile/modelle_insight_technische_daten.php

Honda Civic 1.4 (manual)

http://www.honda.de/content/automobile/modelle_civic_technische_daten.php

BMW 320d EfficientDynamics

http://www.bmw.de/de/de/newvehicles/3series/sedan/2008/introduction.html

BMW 320d

http://www.bmw.de/de/de/newvehicles/3series/sedan/2008/introduction.html

Audi A4 2.0 TDIe

http://www.audi.de/de/brand/de/neuwagen/a4/a4_limousine/Katalog_und_Preisliste.html

Audi A4 2.0 TDI

http://www.audi.de/de/brand/de/neuwagen/a4/a4_limousine/Katalog_und_Preisliste.html

Mercedes C220 BlueEfficiency

http://www.mercedes-benz.de/content/germany/mpc/mpc_germany_website/de/home_mpc/passengercars/home/new_cars/models/c-class/w204/catalogue_prices.html

BMW 318i

http://www.bmw.de/de/de/newvehicles/3series/sedan/2008/introduction.html

Audi A4 TFSI

http://www.audi.de/de/brand/de/neuwagen/a4/a4_limousine/Katalog_und_Preisliste.html

4.6.5 Other references

"Technology and cost of the MY2007 Toyota Camry HEV final report" (ORNL/TM-2007/132); Olszewski, M; US Department of Energy / Oak Ridge National Laboratory (2007)

Impacts of Electric Vehicles – Deliverable 2 "Assessment of electric vehicle and battery technology" report, ICF, CE Delft, Ecologic, December 2010

5 Model Cycles

5.1 Objective

The objective of work reported in this chapter was to investigate the model cycles of mainstream car models from different manufacturers and different market segments and assess the impacts of their timing on the feasibility of the 95g/km target in 2020.

Activities within this task included:

- Review of factors affecting lead times in vehicle development and upgrades for vehicle platforms and powertrains
- Selection of three manufacturers and vehicle models from each of the B, C and D segments based on annual European sales for detailed analysis
- Analysis of projected vehicle model and vehicle platform cycle introduction dates for the chosen manufacturers and vehicle models provided by IHS Global Insight
- Analysis of projected powertrain cycles for the chosen manufacturers and vehicle models based on manufacturers' announcements of forthcoming powertrain introduction dates, historical data and expert assessment
- Overview of the degree of fit of different manufacturers vehicle model, platform and powertrain cycles with planned EU noxious emissions and CO_2 legislation

Caveats:

- The OEMs, vehicle models and powertrains selected in this task are used as examples to represent the industry as a whole and therefore may not reflect every scenario
- Vehicle and engine cycle introduction dates are considered sensitive commercial information for OEMs, especially regarding future plans, and may not be readily available in the public domain
- Ricardo has used publically available information to create the engine cycle introduction plans

5.2 Factors affecting lead times in vehicle development

Vehicle model / platform and powertrain product development involve a large number of activities with complex interactions. They range from marketing activities to identify customer needs / requirements to engineering activities involving concept development, feasibility studies, technology optimisation, testing and validation (including prototyping), calibration and attribute development, to production planning including supplier selection and plant / equipment installation and continuous improvement.

Each OEM will have a different detailed product development process but all will include steps similar to those described above. In addition many OEMs are moving to utilising Global Product Development Systems (e.g. Ford and General Motors) in order to leverage worldwide resources to help reduce costs and to cut time from the overall product development cycle.

An illustrative example of a high-level technology and vehicle product development process is shown below:

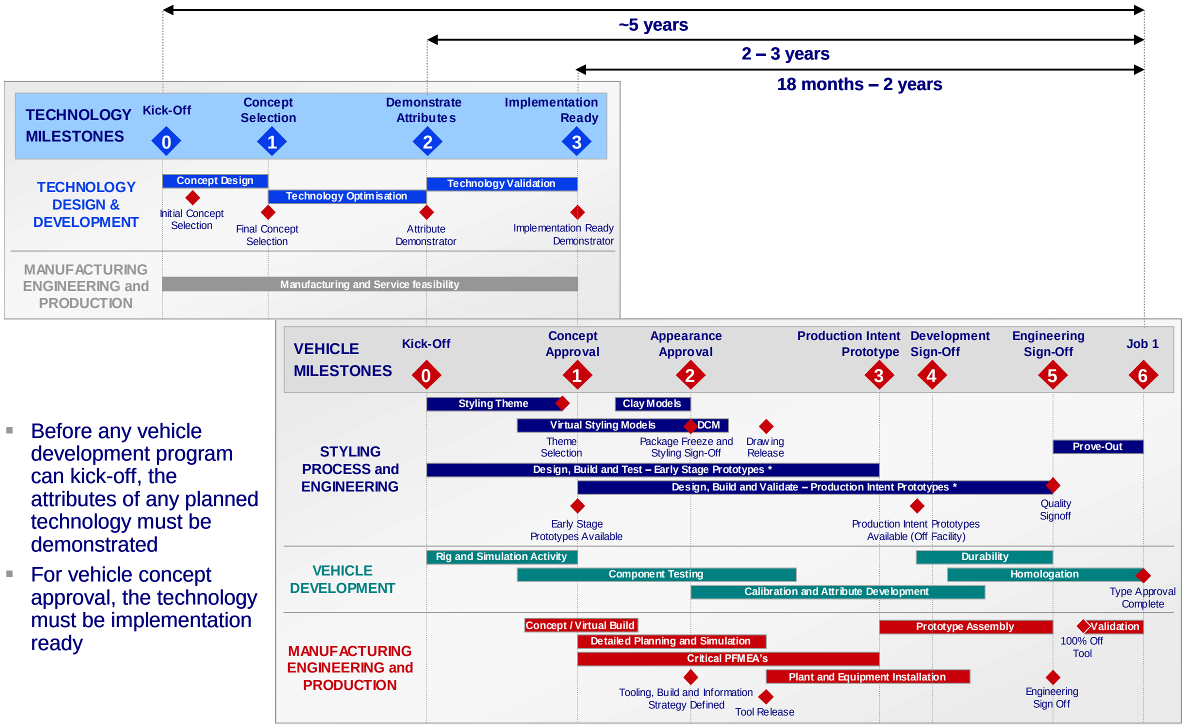


Figure 19 High-level technology and vehicle product development process.

In general;

- To develop a new technology and implement it into a vehicle platform will take circa 5 years
- To implement a new technology which has been demonstrated into a vehicle platform will take circa 2 – 3 years
- To apply an existing technology to a new vehicle application will take circa 18 months – 2 years
- To develop a new engine platform will take circa 3 years

OEM examples;

Peugeot e-HDi technology (new generation stop & start system that combines a reversible starter-alternator and diesel engine which will launch on the Citroen C5 and new C4 and C4 Picasso) had an investment of €300m, a project duration of 36 months and 500 engineers and technicians involved in the project.[17]

There are a number of key factors which affect the lead times in the vehicle / powertrain product development process;

- **Level of change required to vehicle / powertrain**
  The overall product development process to be followed will be fixed but lead-times can vary depending on the level of change required to a vehicle or powertrain, that is, whether it is a new (clean sheet) design or a minor or major change.

  For example; a minor change may be resourcing of a component, a change of transmission ratios, or recalibration of an existing engine for a different vehicle application. A major change may be upgrade of an engine from 2 to 4 valves/cylinder, addition of turbocharging or direct fuel injection, or introduction of a new transmissions type such as DCT.

[17] PSA Press Release "With e-HDi PSA Peugeot Citroen further improves the fuel efficiency and carbon footprint of its diesel engines", 9th June 2010.

It may be possible to remove several levels of prototyping from the development process and reduce the validation (technology in vehicle) time and hence reduce the overall lead-time required.

All OEMs are looking to reduce development times, especially through the use of virtual prototyping. However not all parts of the development cycle can be completed virtually, for example with conformity of components, some hardware phases are still required.

For a new engine development programme there may be up to five levels of prototyping;

Mule: Used for initial attribute and functionality testing, emissions and performance development
1st Prototype: Used to develop functional requirements. Built using non-production suppliers
2nd Prototype: Soft tooled production supplied for functional and durability testing
3rd Prototype: Built using off tool production tooling and production suppliers for further durability testing
4th Prototype: A few weeks from Job 1, using on-process tooling and production suppliers

In addition lead times for prototype components for engines can be up to 12 weeks, particularly large components such as engine blocks and manifolds. So reducing the number of prototype levels can significantly reduce the overall product development lead-time.

It should be noted that reducing the lead-time of a product development process too far, by cutting down on levels of prototyping / product validation (testing) for any given level of change can have an adverse impact on the quality level of a product and potentially cause warranty issues in the field. Although time / cost is saved during the development process this can be more than offset by increased product warranty costs and can damage the reputation of the brand and/or technology in the eyes of the consumer.

- **Collaboration, platform sharing, joint ventures and trading**
  Rather than developing a specific technology in-house OEMs can apply technologies developed by a supplier or other OEM or collaborate with another OEM to develop a technology.

  By using a technology supplied by a third party rather than a 5 year+ programme to develop a new technology and implement it in a vehicle, this could be reduced to an 18 month – 3 year process dependent on the type and maturity of the technology involved. For example, Nissan licensing Toyota's Hybrid Synergy Drive.

  Collaboration between OEMs, jointly developing for example a vehicle platform (e.g. Toyota/PSA cooperation for joint development and production of small cars), engine family (e.g. PSA/Ford joint development of diesel engines) or technology (e.g. Two Mode hybrid system jointly developed by BMW, Daimler and GM) also helps to reduce cost and resource requirements.

OEMs will plan cycles of vehicle and powertrain development which will indicate when a vehicle model will be upgraded / refreshed or move to a new platform and when new engine families will be developed or upgraded, variants added (e.g. a new power variant). An example of a vehicle cycle plan is shown below:

Table 42 A vehicle cycle plan.

OEM A	2009	2010	2011	2012	2013
Model X	New model	Add 3 door variant			Minor face-lift
Model Y			Add cabriolet	New model	
Model Z		Major face-lift			New model

Cycle plans usually span up to 10 years but will be more detailed for the first 5 years in terms of capital investment and resourcing requirements.

The key factors that influence the timing of cycle plans are:

- **Budget**
  Budgets for research & development are dependent on forecast model sales and profits for the vehicle OEMs; these are typically set annually but reviewed during the year according to vehicle sales. Budget availability is the key factor which influences vehicle / powertrain cycle plans. The amount of budget available will determine how many changes to models / powertrains can be planned for a particular year, taking into account the length of the product development process for each change. For example, for a model with a new engine technology to be launched in 2012 development on the new engine needs to have started 5 years earlier in 2007.

- **Resource**
  Availability of resources is also a key factor in influencing vehicle / powertrain cycle plans. However the limitation is not as fixed as with budget availability as there is the possibility of contracting extra resources or using an external consultant when not enough resource is available in-house to deliver the cycle plan.

- **Economic constraints**
  The business case for a particular vehicle model is predicated on an expected sales volume which is sufficient to cover all of the fixed costs involved (development, tooling etc.) and to make a profit. Beyond that sales volume marginal profit will be high as the fixed costs have all been recovered. If the expected sales volume is never reached then the model will make a loss.

Flexibility of the product development process to changes in legislation

For products launching in 2015, development will have started now (2010/2011) or will start in the next 1-2 years depending on the level of change required. The “Business As Usual” product cycle plan will have been carefully planned to ensure there is sufficient budget and resource to deliver. At any one time there will be many product development programmes underway at different levels of completion covering the range of the OEMs vehicle models and engine families.

OEM cycle plans will be firmly detailed in the short term and development on products will already be underway with budget and resources allocated making it difficult to accommodate any changes in legislation such as forward movement of implementation dates or changes to limits/targets in the short term (up to 5 years). It can take up to 5 years to implement a technology into a vehicle model depending on the technology maturity and level of change required. For an OEM to make changes to the cycle plan at this late stage it may involve cancelling or changing product development programmes already underway or accelerating the development of a product. Availability of budget and resources may limit what can be changed.

A “Business As Usual” cycle plan will be designed to keep development costs as low as possible and profits as high as possible. Sometimes there may be a need to accelerate the introduction of a new product into the marketplace in the normal course of business, this could be in response to competitors, legislation or to fulfil a market need. Accelerating product introduction will increase the cost of development, may impact on downstream reliability and therefore increase warranty costs and result in an overall lower profit for the OEM. Whilst accelerating product introduction is possible it is not good for “Business As Usual” due to the increased costs and impact on profitability.

There is a larger degree of flexibility in cycle plans beyond 5 years, as although OEM cycle plans usually span 10 years they are generally not as detailed in terms of budget and resourcing requirements. It will also be easier to amend plans where the product development process has not yet started. Again budget and resource constraints will impact what changes can be made.

5.3 Selection of manufacturers and vehicle models

To select three mainstream models from the B, C and D passenger car segments from three major and unconnected manufacturers an analysis of sales in Europe was conducted.

IHS Global Insight provided data for passenger car sales by OEM brand in Europe for 2009 and projected for 2010. The top five selling OEM brands are shown in the table below:

Table 43 The five selling OEM brands.

OEM Brand	Sales in Europe*	
	2009	2010
Volkswagen	1,892,471	1,782,694
Renault	1,569,534	1,507,802
Ford	1,741,864	1,473,196
Peugeot	1,283,447	1,186,585
Fiat	1,292,283	1,094,694

** All data from IHS Global Insight.*

The top three selling brands of Volkswagen, Renault and Ford were chosen and models in the B, C and D segments of those brands were identified. See tables below:

Table 44 Volkswagen models in the B, C and D segments.

Brand	Model	Segment	Sales in Europe*	
			2009	2010
Volkswagen	Polo	B	294,076	347,262
	Golf	C1	616,513	493,189
	Golf Plus	C1	79,157	82,387
	Passat	D1	203,383	207,503
	Passat CC	D2	29,406	21,013

Table 45 Renault models in the B, C and D segments.

Brand	Model	Segment	Sales in Europe*	
			2009	2010
Renault	Clio	B	392,255	387,500
	Megane	C1	281,255	261,861
	Megane Scenic	MPV-C	141,778	176,220
	Laguna	D1	49,303	49,217
	Laguna Coupe	D1	6,044	6,030

Table 46 Ford models in the B, C and D segments.

Brand	Model	Segment	Sales in Europe*	
			2009	2010
Ford	Fiesta	B	496,843	452,153
	Focus	C1	381,687	351,733
	Focus CC	C1	7,938	3,669
	Focus C-Max	MPV-C	77,917	77,568
	Mondeo	D1	125,760	107,976

** All data from IHS Global Insight*

For the purpose of analysing vehicle model, platform and powertrain introduction cycles the following models, one from the B, C and D segments for each brand were selected:

Table 47 Selected vehicle models for analysing vehicle model, platform and powertrains introduction cycles.

Brand	**Segment**		
	B	**C**	**D**
Volkswagen	Polo	Golf	Passat
Renault	Clio	Megane	Laguna
Ford	Fiesta	Focus	Mondeo

5.4 Vehicle model platform cycles

For the each of the manufacturer models identified above IHS Global Insight supplied projected vehicle model and platform cycle introduction dates.

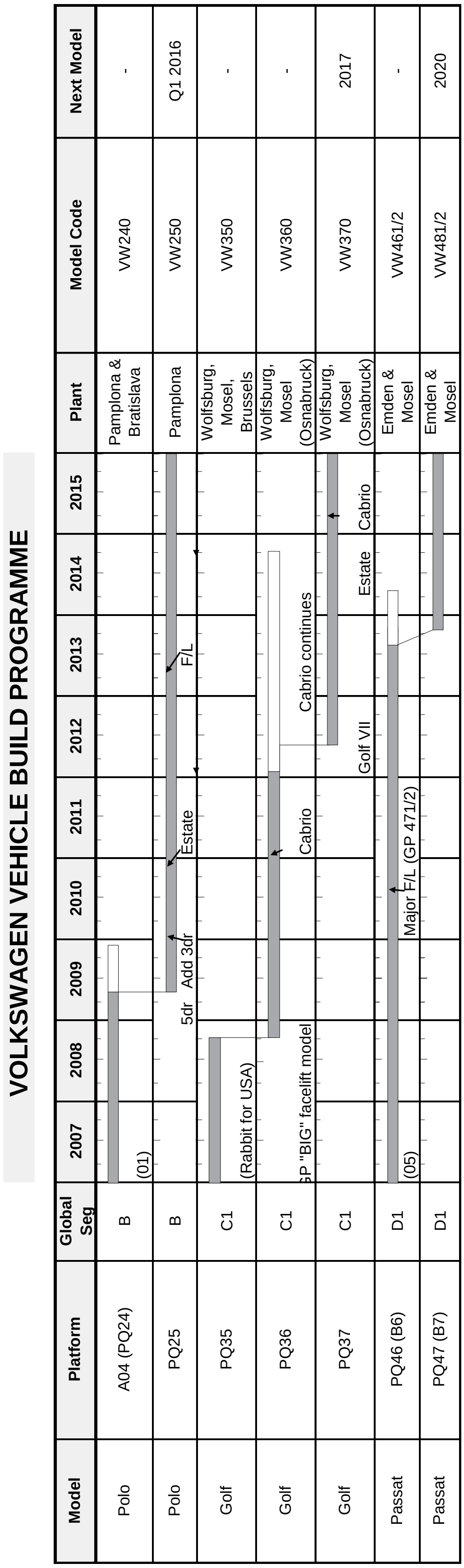
Definitions and abbreviations used in the vehicle model / platform cycles are:

Vehicle Platform: Typically a vehicle platform consists of parts such as chassis, suspension, steering, driveline, brake system etc.

Platform change (NG = Next generation model): A new vehicle platform is designed which means that the architecture as a whole for the model has changed. It also implies that the plant where the model is produced needs to undergo retooling to produce the new platform.

F/L = Facelift: The vehicle model is refreshed by the OEM without changing the vehicle platform. For example a minor facelift may involve changes in features such as lights, bumpers, interior trim and infotainment. A facelift also generally implies that the powertrain also remains unchanged.

Vehicle model platform cycles are shown below for Volkswagen, Renault and Ford:



Source: IHS Global Insight

Figure 20 Volkswagen vehicle build programme.

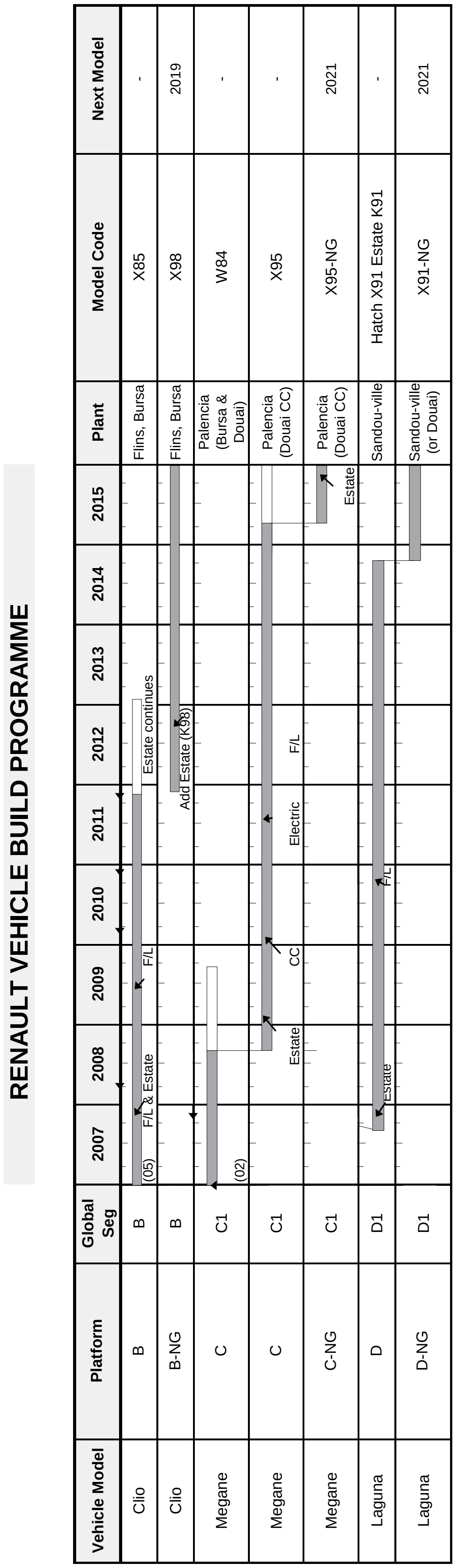


Figure 21 Renault vehicle build programme.

FORD VEHICLE BUILD PROGRAMME

Model	Platform	Global Seg	2007	2008	2009	2010	2011	2012	2013	2014	2015	Plant	Model Code	Next Model
Fiesta	B256	B	(02)									Cologne & Valencia	B256 & B257	-
Fiesta	B2E	B	See Verve Concept					F/L				Cologne & Valencia	B299	-
Fiesta	B2E-NG	B										Cologne & Valencia	B299-NG	2020
Focus	C1	C1	(04)	F/L								Saarlouis & Valencia	C307	-
Focus	C2	C1			5dr first (3dr could be re-positioned as Coupe)				EV	F/L		Saarlouis	C346	2017
Mondeo	CD132	D1	(00)									Genk	CD132	-
Mondeo	CD-EU	D1	Estate			F/L						Genk	CD345	-
Mondeo	CD4	D1										Genk	CD391	2021

Source: IHS Global Insight.

Figure 22 Ford vehicle build programme.

The table below shows the typical time between platform changes and facelifts for each vehicle model derived from the vehicle model / platform cycle charts.

Table 48 Typical time between platform changes and facelifts for each vehicle model.

Segment	Model	Time between platform changes	Time between vehicle facelifts
B	VW Polo	8 yrs	3 – 4 yrs
	Renault Clio	7 – 8 yrs	2 – 3 yrs
	Ford Fiesta	6 yrs	3 yrs
C	VW Golf	4 – 5 yrs	-
	Renault Megane	6 – 7 yrs	4 yrs
	Ford Focus	6 – 7 yrs	4 yrs
D	VW Passat	7 – 8 yrs	5 yrs
	Renault Laguna	7 yrs	3 yrs
	Ford Mondeo	7 yrs	3 yrs

It can be seen that:

- On average vehicle platforms are changed every 6 – 8 years with some exceptions (e.g. VW Golf Mark VI launched in 2008 and the VW Golf Mark VII is due in 2012, just 4 years between platform change)
- Vehicle models are generally refreshed with a face-lift between 2 to 4 years after a platform change
- Vehicle models in the C segment generally have a shorter time between platform changes than those in the B and D segments. The C segment is the biggest selling segment in Europe and most competitive
- Platform changes / facelifts are staggered so that changes to vehicle models are not all made within the same year

5.5 Powertrain introduction cycles

For each chosen manufacturer, Ford, Renault, Volkswagen, several high volume gasoline and diesel engine platforms have been chosen for review to cover engines utilised in each of the vehicle models reviewed in the previous section “Vehicle Model and Platform cycles “

These engine platforms represent a selection of the engines available for each of the OEM vehicle models and by no means represent all of the engine choices available for each model.

In order to allow vehicles and powertrains to be developed in parallel a package envelope for the vehicle will be defined. Vehicles are designed to accommodate whatever engines are available. In order to design the engine, constraints will be defined in terms of packaging targets for the vehicle models into which the engine is expected to go, the required layout (North/South or East/West) and any changes required in line with the strategic direction (e.g. low bonnet lines, under floor engine etc.)

It is unusual for a vehicle and a powertrain to be entirely dependent on each other. Exceptions to this are where there is an architecture level change such as some hybrids, e.g. Toyota Prius and Honda Insight and electric vehicles, e.g. Nissan Leaf and Mitsubishi iMiEV. Then the timeline is dictated by the longest lead item which is typically the vehicle.

The analysis has been conducted at an engine platform level as opposed to looking at each vehicle model and then the engines utilised in each model as the engine platforms are developed to be applied across a range of models. The application of each engine platform to each of the models is noted.

The engine platform cycle plans have been constructed based on manufacturers’ announcements of previous and forthcoming powertrain introduction dates found in press releases, journal articles and technical papers. As the cycle plans are only based on information available in the public domain they may not 100% accurately reflect the future plans of OEMs but give an indication of the timing of upgrades and new engine introductions.

The data used to generate the engine cycle plans is sourced strictly from public domain sources and publications, with some entries based on official OEM statements and some based on unconfirmed reports in the press. The inclusion of an engine/programme does not imply confirmation, by Ricardo, that such engines or programmes exist or are correctly represented.

A number of abbreviations have been used in the following engine cycle plans and are as follows;

CR	=	Common Rail
DI	=	Direct Injection
DI UI	=	Direct Injection, Unit Injector
EOP	=	End Of Production
FSI	=	Volkswagen terminology for their direct injection engines
MPI	=	Multi Point Injection
N/K	=	Not Known
SOHC	=	Single OverHead Cam
SOP	=	Start Of Production
T/C	=	TurboCharged
TCe	=	Turbo Control Efficiency (Renault terminology)
TSI	=	Volkswagen terminology for their forced induction engines (turbocharged)
VVT	=	Variable Valve Timing
?	=	Indicates estimate of information

EXAMPLE VOLKSWAGEN ENGINE BUILD CYCLES

Engine Platform	Fuel	Config	Engine SOP	2007	2008	2009	2010	2011	2012	2013	2014	2015	Engine EOP	Comments	Application in Polo/Golf/ Passat
EA111	Gasoline	1.2L, L3 12v	2001										N/K	FSI ?	Polo
		1.2L, L4	2010				TSI (T/C, DI)						N/K		Polo, Golf, Passat
		1.4L, L4	1996	Add TSI variant (single T/C, DI) - replaces the 1.6L FSI									N/K	FSI (DI) variant introduced in 2000, TSI - Twincharger, DI variant introduced in 2005	Polo, Golf, Passat
		1.6L, L4	1999										N/K	MPI and FSI (DI) variants	Polo
New platform	Gasoline	0.9L, L3?	2011?										N/K	To replace the EA111 engines. Euro 5 on launch. 1.4L also for hybrid application	Polo?
		1.2L, L4?	2011?										N/K		Polo, Golf?
		1.4L, L4?	2011?										N/K		Golf, Passat?
EA 188	Diesel	1.4L, L3		DI-UI									N/K	Replaced by 1.2L, L3 in Europe	Polo
		1.6L, L4		DI-UI									N/K		Polo, Golf, Passat
		2L, L4	2003	DI-UI									N/K		Golf, Passat
EA 189 (based on 2L EA188 architec-ture)		1.2L, L3	2009			CR, Euro 5 - replaces the 1.4L TDi in Europe							N/K		Polo
		1.6L, L4	2009			CR, Euro 5							N/K		Polo, Golf, Passat
		2L, L4	2007	CR, Euro 5									N/K		Golf, Passat

Source: Public domain information including: Volkswagen press releases, journal articles, technical papers.

Figure 23 Example Volkswagen engine build cycles.

Note: The above chart does not represent all of Volkswagen's engine platforms, only a restricted selection for gasoline and diesel. The engine platforms shown are used in many more vehicle applications across Volkswagen, however only application in Polo, Golf and Passat has been identified.

EXAMPLE RENAULT ENGINE BUILD CYCLES

Engine Platform	Fuel	Config	Engine SOP	2007	2008	2009	2010	2011	2012	2013	2014	2015	Engine EOP	Comments	Application in Clio/Megane/ Laguna
K	Gasoline	1.4L, L4	1997						16v variant ends production				2012 (16v)	8v and 16v variants	Clio, Megane
		1.6L, L4	1996										N/K	16v only	Clio, Megane, Laguna
M1/S2	Gasoline	0.9L, L3	2012					Refered to as TCe 90. With DI & T/C. Euro 5 & 6					N/K	Part of downsizing strategy. These engines will replace current naturally aspirated engines in the 1.2 to 1.6L range	Clio?
		1.2L, L4	2012					Refered to as TCe 115. With DI & T/C. Euro 5 & 6					N/K		Clio, Megane?
		1.4L, L4	2009			Refered to as TCe 130. With T/C. Euro 5							N/K	Derived from Renault-Nissan HR engine family to replace current 2.0L NA engine	Megane
		2.0L, L4	2010				NA		Add DI, T/C variant				N/K		-
F	Gasoline	2.0L, L4	1996										N/K	NA and T/C variants,current generation has VVT	Clio, Megane, Laguna
K	Diesel	1.5L, L4	2001						New generation to be launched (Euro 5 / 6)				N/K	Known as 1.5 dCi	Clio, Megane, Laguna
M1/S2	Diesel	1.6L, L4	2011					Will be Euro 6 ready					N/K	Will replace current 1.9 dCi as part of downsizing strategy	Megane, Laguna
		2.0L, L4	2005						New generation to be launched (Euro 5 / 6)				N/K	New M1/S2 platform launched in 2005 with this engine	Megane, Laguna
		3.0L, V6	2009										N/K		Laguna

Source: Public domain information including: Renault press releases, journal articles, technical papers.

Figure 24 Example Renault engine build cycles.

Note: The above chart does not represent all of Renault's engine platforms, only a restricted selection for gasoline and diesel. The engine platforms shown are used in many more vehicle applications across Renault, however only application in Clio, Megane and Laguna has been identified.

EXAMPLE FORD ENGINE BUILD CYCLES

Engine Platform	Fuel	Config	Engine SOP	2007	2008	2009	2010	2011	2012	2013	2014	2015	Engine EOP	Comments	Application in Fiesta/Focus/ Mondeo
DURATEC HE	Gasoline	1.8L, L4	2001										N/K	DI variant in 2003	-
		2.0L, L4	2003				Add DI, T/C, twin VVT variant (known as EcoBoost)						N/K	Ecoboost in Mondeo 2010	Mondeo
SIGMA	Gasoline	1.25L, L4	1996						Anticipate will be preceeded by FOX				2012 / 2013?		Fiesta
		1.4L, L4	1996						Engine may be preceeded by FOX ?				N/K		Fiesta, Focus
		1.6L, L4	1997				Add DI, T/C, twin VVT variant (known as Ecoboost)						N/K	Ecoboost in Focus in 2011	Focus, Mondeo
		1.5L, L4	2014?							Ecoboost:DI, T/C, twin VVT			N/K		Focus, Mondeo?
FOX	Gasoline	1L, L3	2011					NA and T/C variants					N/K	New Euro 5 engine platform	Fiesta ?
PSA DV	Diesel	1.4L, L4	2001			Add 8v, SOHC variant for Euro 5							N/K	PSA joint venture engine	Fiesta
		1.6L, L4	2003			Add 8v, SOHC variant for Euro 5							N/K		Fiesta, Focus

Source: Public domain information including: Ford press releases, journal articles, technical papers.

Figure 25 Example Ford engine build cycles.

Note: The above chart does not represent all of Fords engine platforms, only a restricted selection for gasoline and diesel. The engine platforms shown are used in many more vehicle applications across Ford, however only application in Fiesta, Focus and Mondeo has been identified.
From the engine build cycle charts it can be seen that:

- Engine platforms have a long life span, typically 10 – 15 years. During this time the platform will go through several evolutionary changes
- There is no typical timing pattern for the introduction of new engine platforms (families) as with vehicle platforms
- Engine platforms form the basis for engine families , e.g. 1.2L, 1.4L and 1.6L engines from the same engine platform and there is no typical timing pattern for the introduction of new displacements to an engine family
- For each displacement engine within a family there can then be different variants (e.g. a 1.4L gasoline DI turbocharged version of the base 1.4L naturally aspirated engine, or a different power variant of the base engine). Again there is no typical timing pattern for the introduction of new variants or upgrades to individual engines within a family
- In general, engines have minor upgrades/variants added fairly frequently (although these are not indicated on the engine cycle charts), and major upgrades/variants added less frequently occurring anywhere from 3 to 7 years
- OEMs typically start introducing engines that have been developed/upgraded to meet forthcoming noxious emissions legislation up to 3 years prior to the introduction date

5.6 Fit of vehicle and powertrain cycles with legislation

The following charts combine the selected vehicle model platform and engine cycles for the chosen OEMs with forthcoming legislation dates. This will enable an assessment of the degree of fit of the vehicle model platform and engine cycles with planned noxious emissions and CO_2 legislation to be made.

The legislation reviewed includes:

Noxious emissions

Euro 5: Type Approval 1 September 2010, First Registration 1 September 2011
Euro 6: Type approval 1 September 2014, First Registration 1 September 2015

Fleet average CO_2

130g/km CO_2: Phase-in from 2012 – 2015
95g/km CO_2: 2020

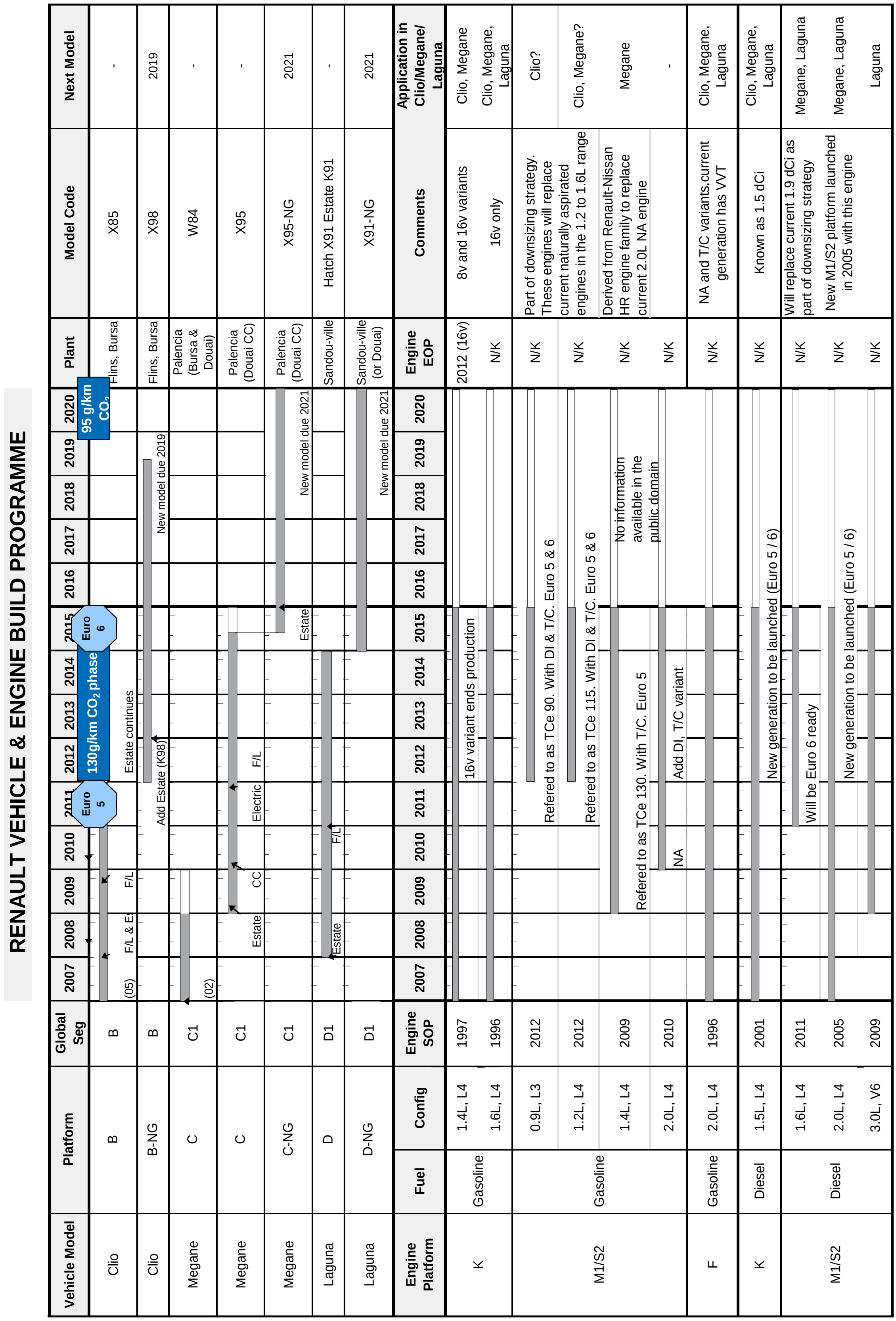
VOLKSWAGEN VEHICLE & ENGINE BUILD PROGRAMME

Model	Platform	Global Seg	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Plant	Model Code	Next Model
Polo	A04 (PQ24)	B	(01)				Euro 5	130g/km CO_2 phase			Euro 6					95 g/km CO_2	Pamplona & Bratislava	VW240	-
Polo	PQ25	B		5dr	Add 3dr		Estate		F/L		New model due 2016						Pamplona	VW250	Q1 2016
Golf	PQ35	C1	(Rabbit for USA)														Wolfsburg, Mosel, Brussels	VW350	-
Golf	PQ36	C1	' facelift model				Cabrio		Cabrio continues								Wolfsburg, Mosel (Osnabruck)	VW360	-
Golf	PQ37	C1						Golf VII		Estate	Cabrio		New model due 2017				Wolfsburg, Mosel (Osnabruck)	VW370	2017
Passat	PQ46 (B6)	D1	(05)			Major F/L (GP 471/2)											Emden & Mosel	VW461/2	-
Passat	PQ47 (B7)	D1												New model due 2020			Emden & Mosel	VW481/2	2020

Engine Platform	Fuel	Config	Engine SOP	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Engine EOP	Comments	Application in Polo/Golf/ Passat
EA111	Gasoline	1.2L, L3 12v	2001															N/K	FSI ?	Polo
		1.2L, L4	2010				TSI (T/C, DI)											N/K		Polo, Golf, Passat
		1.4L, L4	1996	Add TSI variant (single T/C, DI) - replaces the 1.6L FSI										No information available in the public domain				N/K	FSI (DI) variant introduced in 2000, TSI - Twincharger, DI variant introduced in 2005	Polo, Golf, Passat
		1.6L, L4	1999															N/K	MPI and FSI (DI) variants	Polo
New platform	Gasoline	0.9L, L3?	2011?															N/K	To replace the EA111 engines. Euro 5 on launch. 1.4L also for hybrid application	Polo?
		1.2L, L4?	2011?															N/K		Polo, Golf?
		1.4L, L4?	2011?															N/K		Golf, Passat?
EA 188	Diesel	1.4L, L3		DI-UI				Continues production for other markets?										N/K	Replaced by 1.2L, L3 in Europe	Polo
		1.6L, L4		DI-UI														N/K		Polo, Golf, Passat
		2L, L4	2003	DI-UI				Unlikely two 2L engines would continue in parallel?										N/K		Golf, Passat
EA 189 (based on 2L EA188 architec-ture)		1.2L, L3	2009			CR, Euro 5 - replaces the 1.4L TDi in Europe												N/K		Polo
		1.6L, L4	2009			CR, Euro 5												N/K		Polo, Golf, Passat
		2L, L4	2007	CR, Euro 5														N/K		Golf, Passat

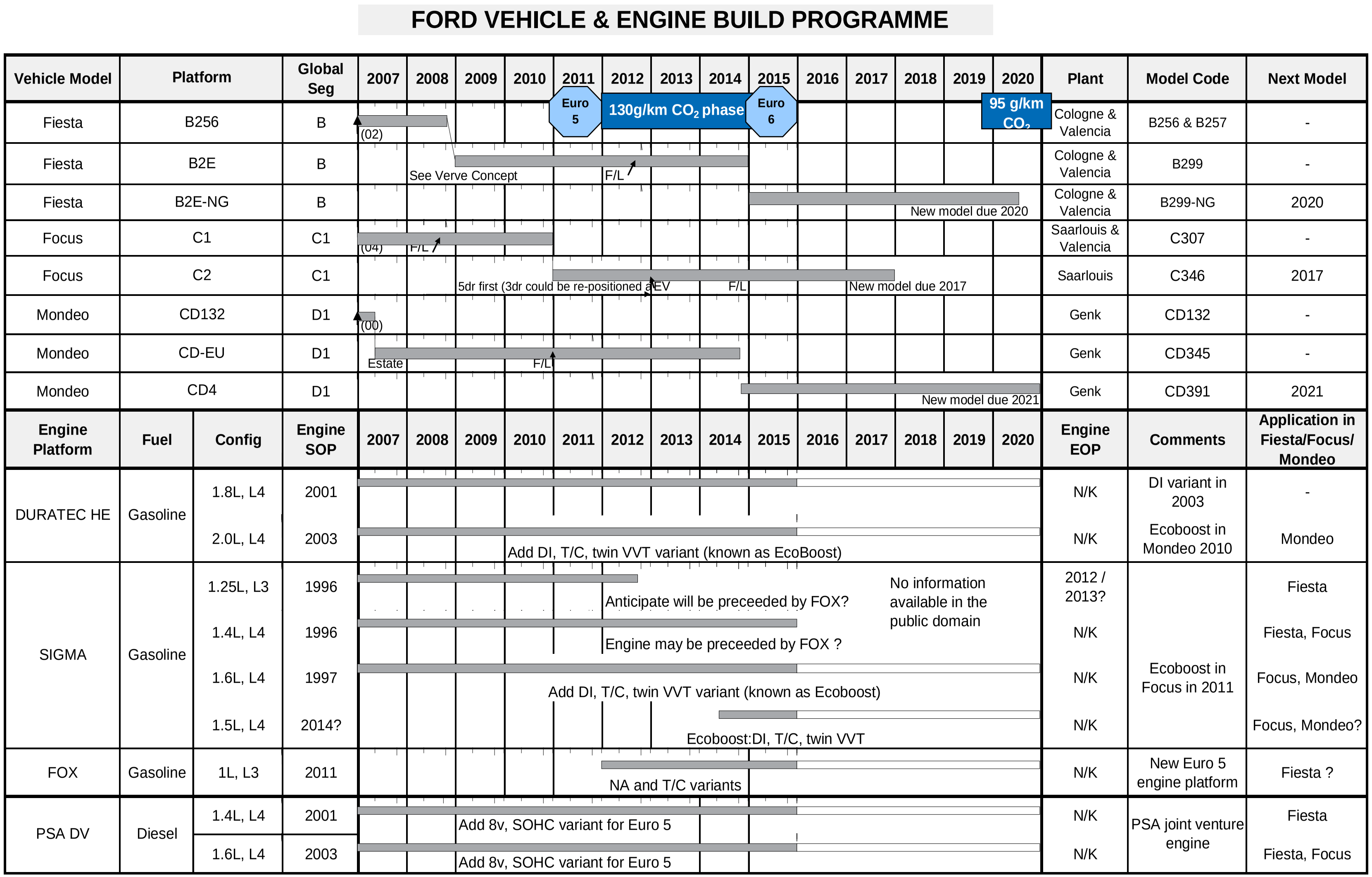
Source: IHS Global Insight, public domain information including: Renault press releases, journal articles, technical papers.

Figure 26 Volkswagen vehicle & engine build programme.



Source: IHS Global Insight, public domain information including: Renault press releases, journal articles, technical papers.

Figure 27 Renault vehicle & engine build programme.



Source: IHS Global Insight, public domain information including: Ford press releases, journal articles, technical papers.

Figure 28 Ford vehicle & engine build programme.

The key observations from a review of the combined cycle plans with the legislation introduction dates are:

- Of the nine vehicle models analysed there is one model with a planned platform change just before the 2012 – 2015 phase-in, five during the 2012 – 2015 phase-in period and three after the phase-in period

- Of the nine vehicle models analysed there are three models with planned platform changes in the 2016/2017 timeframe several years before, three in the 2019/2020 timeframe which is one year prior/on the planned 95g/km CO_2 target date of 2020 and three in 2021, one year after

- There are new engine models / variants planned for launch during the 2012 – 2015 130g/km phase-in period which are part of OEMs downsizing strategies for lower CO_2 (e.g. Renault 0.9L and 1.2L TCe gasoline engines and Ford Fox 1L gasoline engine)

- Engines capable of meeting Euro 5 have been introduced up to 3 years before the legislation introduction date. This is likely to be in order to stagger the development to enable all engine platforms to be upgraded to Euro 5 emissions prior to the introduction date

- There are also indications that OEMs will be launching upgraded engines at Euro 5 emissions levels but capable of meeting Euro 6 in anticipation of the Euro 6 introduction date of 2015

There is a relatively good degree of fit between the engine cycle plans and the planned introduction dates for noxious emissions (Euro 5 and Euro 6) for the OEMs and engine platforms analysed in this study.

There is no distinct pattern/fit between the engine cycle plans and vehicle model platform changes compared to the CO_2 legislation introduction dates but there are some model platform changes and planned introductions of new engines in the 2012 – 2015 timeframe and some planned vehicle platform changes in the 2016 – 2020 timeframe (public domain data not available to comment on engine platform upgrades / introductions in this timeframe) which will contribute to the planned 2020 target of 95g/km for the OEMs, vehicle models and engine platforms analysed in this study.

Five out of the nine models reviewed will have platform changes during the 130g/km CO_2 2012 – 2015 phase-in period and six of the nine models have planned platform changes in the 2016 – 2020 timeframe contributing to the planned 95g/km target in 2020.

5.7 Conclusions

The product development process can vary from 18 months to up to 5 years depending on whether an OEM is applying an existing technology to a new application or developing and implementing a new technology.

The key factors which affect the lead times in the product development process are the level of change required (e.g. clean sheet design vs. major upgrade vs. minor upgrade) and collaboration, platform sharing, joint ventures and trading.

OEMs will plan cycles of vehicle and powertrain development which indicate when vehicle models / engines will be upgraded/refreshed/replaced etc. These plans usually span up to 10 years but will be more detailed for the first 5 years in terms of capital investment and resourcing requirements.

The key factors which affect cycle plans are: budget, resource and economic constraints.

For the OEMs, selected vehicle models and engine platforms analysed in this study:

- On average vehicle models have a platform change every 6 – 8 years and are refreshed with a face-lift between 2-4 years after a platform change

- Engine platforms have a long lifespan, typically 10 – 15 years but during that time will have minor or major upgrades and additional variants added. There is no typical timing pattern for the introduction of new variants or upgrades (it is dependent on the OEM and engine platform) but in general minor upgrades/variants to engine platforms are added fairly frequently (e.g. higher power variant) and major upgrades/variants added less frequently occurring anywhere from 3 to 7 years (e.g. a turbocharged variant of a naturally aspirated gasoline engine)

- Vehicle platform changes / facelifts and engine variants / upgrades are staggered so that changes to all vehicle models or all engine platforms are not all made within the same year

- There is a relatively good degree of fit between the engine cycle plans and the planned introduction dates for noxious emissions (Euro 5 and Euro 6)

- There is no distinct pattern/fit between the engine cycle plans and vehicle model platform changes compared to the CO_2 legislation introduction dates but there are some model platform changes and planned introductions of new engines in the 2012 – 2015 timeframe and some planned vehicle platform changes in the 2016 – 2020 timeframe (public domain data not available to comment on engine platform upgrades / introductions in this timeframe) which will contribute to the planned 2020 target of 95g/km for the OEMs, vehicle models and engine platforms analysed in this study.

The analysis above indicates that manufacturers' development cycles are well timed to meet planned introduction dates of noxious emissions but currently less aligned to the planned 95 g/km CO_2 target in 2020

- OEM cycle plans typically span up to 10 years, which means that detailed plans (in terms of budget and resource requirements) for the next 5 years to 2015 and basic plans up to 2020 are likely to already be in place

- The length of the product development cycle (up to 5 years in some cases) and the fact that OEMs may already have basic vehicle and engine cycle plans in place from 2015 up to 2020, highlights a potential need for 95 g/km CO_2 legislation to be finalised as early as possible and as a minimum 5 years before its implementation date. This will provide certainty for OEMs and enable them sufficient time to consider it in their vehicle and engine cycle plans whilst they are not heavily detailed and the product development processes are not yet underway[18].

[18] Although an actual analysis was not in the scope of this task, it should be noted that an OEM may not have to apply the same level of technology or indeed make changes to all of their vehicle models. OEMs may choose to apply more advanced technology to some models to achieve CO_2 emissions that are significantly below the CO_2 levels required for 130 or 95 g/km (e.g. current eco-models with circa 90 g/km CO_2). These models may be able to provide some compensation for others that can not be updated prior to implementation dates of the CO_2 legislation.

5.8 References

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6 Database consolidation

6.1 Introduction

For the purpose of proving input data to various analyses on the suitability of utility parameters, the definition of limit functions and the costs for meeting the target a 2009 passenger car sales database has been acquired from POLK. Due to budget restraints data were bought only for five large European countries in terms of new vehicle market (France, Germany, Italy, Spain, UK) and two smaller countries (Poland, Romania). Analysis have shown that this sample is sufficiently representative for the characteristics of the EU market as a whole. This chapter describes some of the actions taken to consolidate the POLK data for further use in the study.

6.2 Light passenger cars

Passenger cars are defined within the Type Approval Directive 2007/46/EC as M1, namely “Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver’s seat” [Annex II A1]. The next category of M vehicles, the M2 category, introduces a weight related criteria[19] and therefore M1 vehicles can not weigh more than 5 t (maximum mass). In addition the following vehicles are not considered to be a vehicle of category M1: Multipurpose vehicles if they meet both of the following conditions:

„the number of seating positions, excluding the driver, is not more than six; […] and

$$P - (M + N \times 68) > N \times 68$$

where:

P = technically permissible maximum laden mass in kg,
M = mass in running order in kg,
N = number of seating positions excluding the driver“ [Annex II C.1 Directive 2007/46/EC]

Therefore the database submitted by Polk has been analysed according to this definition in order to check its data consistency and identify erroneous data. As a result of this analysis the database was reduced by 51318 vehicles and 7891 datasets due to inconsistent data.

In detail the following data was excluded from the passenger cars database:

Table 49 Excluded date from the passenger cars database.

Target values/columns	Reason for deletion
All values containing a zero in column “1/2009-12/2009” (number of sales)	No sales were realised for those vehicles in 2009.
manufacturers Aixam, Mega and Microcar	Those manufacturers do not belong to the M1 category but are producing quadricycles[20]
Body group Trucks	This body group does not belong to the vehicle category of M1 but rather to the N-category[21]
Number of seats > 9	≠ M1 Definition (see above)

[19] Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver’s seat, and having a maximum mass not exceeding 5 tonnes [Annex II A 1 Directive 2007/46/EC].
[20] According to DIRECTIVE 2002/24/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 March 2002 relating to the type-approval of two or three-wheel motor vehicles and repealing Council Directive 92/61/EEC resp. Proposal for a EUROPEAN PARLIAMENT AND COUNCIL REGULATION Regulation (EU) No .../2010 of the European Parliament and of the Council on the approval and market surveillance of two- or three-wheel vehicles and quadricycles, COM(2010) 542 final.
[21] Category N: Motor vehicles with at least four wheels designed and constructed for the carriage of goods.Annex II A 2 Directive 2007/46/EC.

Number of seats is 2 or 3 AND the body group is defined as Car utility, Hatchback[22], Off road vehicles, Pick-up, Van, Mono Space.	Except for Pick-ups, all of these cars are designed to carry a larger number of passengers than 2 or 3[23]. If they can only carry such a limited amount of passengers they are rather constructed for carrying goods (N-category) than passengers (M-category). The latter statement does also apply for Pick-ups.

In order to relate the Polk database to another source of data, the respective data of the European Central Database (CDB) for CO_2 monitoring according to Decision 1753/2000/EC was used for further analysis. Following table shows that, although the data differences for some Member States are quite large, the CO_2 values are fairly close on a Member States level and for the sum of the six Member States.

Table 50 Data differences European Central Database (CDB) and Polk database.

	Absolute Differences (CDB minus Polk data)		**Data Differences (%) (CDB=100%)**	
Country	Registrations having CO_2 value	Average CO_2 [g/km]	Registrations having CO_2 value	Average CO_2
France	-3 533	-0.81	-0.16	-0.61
Germany	-11 218	-1.68	-0.30	-1.09
Italy	42 481	-5.36	1.97	-3.93
Poland	-87 521	0.51	-39.88	0.34
Romania	5 294	0.78	4.59	0.49
Spain	-121 848	-3.09	-14.71	-2.18
UK	-32 678	-0.74	-1.68	-0.49
Sum	**-209 023**	**-2.13**	**-1.85**	**-1.47**

Ideally the criteria for multi-purpose vehicles which are not M1 should have applied onto the database and those vehicles should also have been removed. This was not possible due to the tight schedule and the fact that the database was awaited by the whole consortium. Nevertheless the assessment has been done afterwards resulting in 11.272 vehicles which are according to above definition not M1 but still part of the database. The effect of the data is estimated to be low as those vehicles represent only 0.1% of all registrations within the Polk data.

6.3 Light commercial vehicles

Light commercial vehicles are defined within the Type Approval Directive 2007/46/EC as N1, namely “Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes” [Annex II A2]. In addition a vehicle is not considered to be a vehicle of the N-category if it meets both of the following conditions:

(i) the number of seating positions. excluding the driver is not more than 6 and

(ii) $P - (M + N \times 68) \leq N \times 68$“ [Annex II C.3 Directive 2007/46/EC]

In a first step IHS increased the completeness of data for certain parameters. For the following parameters a certain amount of error values and missing values could be identified. Due to the data treatment step of IHS, the number of those error values could be reduced significantly - the percentages in the table below indicate the number of registrations which could be associated with data for the respective parameter after the treatment.

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22 Except Smart ForTwo.

23 Vehicles with less seats like sports cars are part of the body group coupé, convertibles or similar. They are not affected by this data treatment step. Other vehicles being summoned under theses body groups with such a number of seats include numerous Mercedes Vito/Sprinter and VW Crafter. Deleted Monospace are only ~ 40 vehicles and Hatchback ~900. Those are very likely M1, but have the wrong number of seats indicated. Their impact on the overall data set is low.

Table 51 Reduced error values.

Variable	Reduction of error values in %
Fuel cons urban	16.63
Fuel cons extra urban	16.57
Fuel cons combined	11.62
Carbon emission	11.50
Kerbweight	3.24

In a second step the database submitted by Polk has been analysed according to this definition in order to check its data consistency and identify erroneous data. As a result of this analysis the database was reduced by 176.350 vehicles and 6612 datasets due to actual or potential inconsistent data[24].
In detail, the following data was extracted from the passenger cars database:

Table 52 Extracted date from the passenger cars database.

Data change no.	Target values/columns	Reason for deletion
1	All values containing a zero in column "1/2009-12/2009" (number of sales)	No sales were realised for those vehicles in 2009.
2	manufacturers Aixam, Mega, Microcar, John Deere, Porsche, Microcar, BMW, Alfa Romeo, Audi, Infiniti, Jaguar, Daimler, Lancia, Lexus	Those manufacturers do not produce N1 vehicles
3	Number of seats 1,7, 8, 9, 12, 14, 15	Light commercial cars would not have the space to accommodate such a large number of passengers and concur with their primary function to carry goods. Therefore ≠ N1. In addition vehicles having only one seat are uncommon.
4	Maximum mass > 3500kg	≠ N1 Definition (see above)
5	Number of seats is 6 AND the number of doors is 2.	The only N1 vehicles which could have six seats and still have enough room so that their primary use is not compromised are Pick-ups. but they would have four doors and not only two. Therefore these vehicles are unlikely N1.
6	Body type: Bus (Van Derived), City van, Combi Van, M P V Panel Van, Other/Unspec,Van Type, Panel Van Double Cabin, Pick-Up Van, Pick-Up Van Double Cabin, Recreational Van, Rigid Van, Tipper Van, Tractor Van **AND** $P – (M + N \times 68) \leq N \times 68$	≠ N1 Definition (see above)

[24] In total three data assessment have been submitted to TNO for the light commercial vehicles database. One assessment extracted only data which resulted in data change no.1-5, another including also data change no. 6 and the last included all of the above but changed the scope of no. 6 from van body type to all body types. These assessment were don in order to see the effect onto the data which varied with the scope of data.

7 Assessment of footprint as utility parameter

7.1 Analysis of US legislation and relevance to EU context

7.1.1 Analysis of legislation in the United States

The US standards define footprint as a vehicle's wheelbase multiplied by its track width -- in other words, the area enclosed by the points at which the wheels meet the ground. By opting for footprint-based standards NHTSA stated: "By using vehicle footprint in lieu of a weight-based metric, we are facilitating the use of promising lightweight materials that, although perhaps not cost-effective in mass production today, may ultimately achieve wider use in the fleet, become less expensive, and enhance both vehicle safety and fuel economy.[25]"

The main reasoning behind these standards was to provide an inducement to make more efficient vehicles, while by linking the standards to a vehicle attribute it allowed for the US vehicle fleet to remain diverse in terms of vehicle size, body-style and functionality[26]. Under these footprint-based standards, each vehicle manufacturer will have a GHG and CAFE target unique to their fleet, depending on the footprints of the vehicle models produced by that manufacturer. A manufacturer will also have separate footprint-based standards for cars and for light trucks. In general larger vehicles (i.e., vehicles with larger footprints) will be subject to less stringent standards (i.e., higher CO_2 grams/mile standards and lower CAFE standards) than smaller vehicles.

The standard to which the vehicle manufacturer must comply will be based on its final model year production figures. A vehicle manufacturer's calculation of fleet average emissions at the end of the model year will thus be based on the production-weighted average emissions of each model in its fleet. The NHTSA aim was to maximize the range of potential strategies available to automakers in deploying more efficient vehicles, while linking efficiency requirements to characteristics that best reflect the range of vehicle features —passenger capacity, cargo capability, etc.—a vehicle is designed for. The reasoning being that as functional size or "utility" of a vehicle class increases, the emissions or fuel economy requirements decrease, with the ultimate goal to improve vehicle fleet efficiency without compromising the vehicle functionality demanded by the US consumers[27].

"Vehicle weight and 'shadow' (ie pan area) had also been considered as possible functions on which to base the standards, but there were concerns that they could more easily be tailored (ie gamed) with the objective of achieving a less stringent target and they were therefore discounted in favour of footprint. The latter is argued to be more integral to a vehicle's design as it is dictated by the vehicle platform (which is typically used for a multi-year model lifecycle), and cannot therefore easily be altered between model years.

Note that the footprint approach also received support in a March 2004 meta-study by Dynamic Research Inc (DRI)[28] which analysed a number of previous studies into the effects of vehicle weight and size on accident fatality risk. All the studies reviewed used data on crashes for both light trucks and passenger cars. The study concluded that reducing wheelbase and track width (ie footprint) generally increased the number of fatalities, whereas reducing vehicle weight tends to decrease the number of fatalities."[29]

Fergusson et al (2008) also found that although „there are differences between Europe and the US as regards average vehicle size, fleet composition and driving conditions; but to the extent that they are applicable in Europe, these findings on safety would be a significant further argument against a utility parameter that could encourage greater weight rather than footprint. Thus if the EU were to shift at the earliest available date, there would be a uniform basis for establishing CO_2/fuel economy

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25 NHTSA.
26 http://www.hybridcars.com/incentives-laws/cafe-footprint-formula-explained.html
27 NHTSA & http://www.hybridcars.com/incentives-laws/cafe-footprint-formula-explained.html
28 A Review of the Results in the 1997 Kahane, 2002 DRI, 2003 DRI, and 2003 Kahane Reports on the Effects of Passenger Car and Light Truck Weight and Size on Fatality Risk (DRI-TR-04-02), R. M. Van Auken and J. W. Zellner, March 2004.
29 M Fergusson, M., Smokers, Passier, G, Snoeren M., FOOTPRINT AS UTILITY PARAMETER A TECHNICAL ASSESSMENT OF THE POSSIBILITY OF USING FOOTPRINT AS THE UTILITY PARAMETER FOR REGULATING PASSENGER CAR CO_2 EMISSIONS IN THE EU, July 2, 2008, not published.

requirements for models sold on both sides of the Atlantic (in the world's two largest vehicle markets) and similar regulatory pressures on both."

7.1.2 Comparison between US and EU situation

Developments in the United States

The Corporate Average Fuel Economy (CAFE) mandate was first established in 1975 and until April 2010 had changed little. On 1st April 2010 the Environmental Protection Agency (EPA)[30] and National Highway Traffic Safety Administration (NHTSA) finally issued a joint Final Rule to establish a National Program consisting of new standards for light-duty vehicles, which is intended to reduce greenhouse gas emissions and improve fuel economy.
The National Program would be introduced beginning in 2012, with the method for calculating individual manufacturer requirements determined by NHTSA and EPA via a system based on "vehicle footprint", one that basically measures the area within the points where the vehicle's wheels touch the ground. "Under a footprint-based standard, each manufacturer would have a greenhouse gas (GHG) and CAFE standard unique to its fleet, with a separate standard for passenger cars and light-trucks, depending on the footprints of the vehicle models produced by that manufacturer", the EPA and the Department of Transportation (DOT) said in a joint statement. "Generally, manufacturers of larger vehicles (i.e. vehicles with larger footprints) would face less stringent standards (i.e., higher CO_2 grams/mile standards and lower CAFE standards) than manufacturers of smaller vehicles."

Details

- Joint rule between the EPA and NHTSA. EPA is establishing GHG emissions standards and NHTSA is establishing Corporate Average Fuel Economy (CAFE) standards
- EPA: Standards will require vehicles to meet an estimated combined average emissions level of 250 grams/mile (155 grams/km) of CO_2 in model year 2016
- NHTSA: Standards will require manufacturers of those vehicles to meet an estimated combined average fuel economy level of 34.1 mpg in model year 2016
  - Covers passenger cars, light-duty trucks, and medium-duty passenger vehicles built in model years 2012 through 2016.
  - The overall fleet fuel mileage requirement will be an average between both passenger cars and light trucks, and NHTSA is predicting that the 2012 numbers will be 33.3 for cars and 25.4 for trucks in 2012, rising to 37.8 for cars and 28.8 for trucks by 2016.
  - Estimated to result in approximately 960 million metric tons of total carbon dioxide equivalent emissions reductions and approximately 1.8 billion barrels of oil savings over the lifetime of vehicles sold in model years 2012 through 2016.
  - Estimated average cost increase for a model year 2016 vehicle due to the National Program is expected to be less than $1,000
  - NHTSA and EPA's standards are expressed as mathematical functions depending on vehicle footprint
- Determined by multiplying the vehicle's wheelbase by the vehicle's average track width.
  - The standards that must be met by each manufacturer's fleet will be determined by computing the sales-weighted average (harmonic average for CAFE) of the targets applicable to each of the manufacturer's passenger cars and light trucks.

Developments in the European Union

From 2000 to 2009 Commission Decision 1753/2000/EC[31] was in force which established a scheme to monitor the average specific emissions of CO_2 from new passenger cars. The target values for the reduction on the CO_2 emission of passenger cars[32] came from voluntary agreements between the three manufacture association ACEA, JAMA and KAMA. They agreed to reduce their fleet emissions until 2008[33]/2009[34] to an average of 140 gCO_2/km.

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[30] The overall tailpipe emissions of US vehicles are regulated by the NHTSA and the EPA. The EPA set standards for pollutants like NOX, SOX, particulates and carbon dioxide, while NHTSA looks after CAFE fuel-economy regulations. The EPA, however, is the rule enforcer for both sets of regulations and sets fines if vehicle manufacturers fail to meet the target.

[31] DECISION No 1753/2000/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 June 2000 establishing a scheme to monitor the average specific emissions of CO_2 from new passenger cars, Official Journal of the European Communities L 202/1, 10.8.2000.

[32] New M1 vehicles (except special pupose vehicles) being registered in the EU for the first time.

[33] ACEA.

In 2007 the Commission's review of the overall community strategy to reduce CO_2 emissions from passenger cars and light-commercial vehicles „concluded that the voluntary commitments have not succeeded“ and that „the Commission considers necessary to resort to a legislative approach“[35] A result of these findings and considerations was among others the elaboration of Regulation (EC) No 443/2009[36]. This Regulation sets emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles. For light commercial vehicles (N1 category) the Commissions proposal[37] is currently awaiting its first reading in the European Parliament[38] which is considered only to be a formal approval of the an agreement between the European Parliament, the Council and the European Commission[39]. The current corner stones of the N1-proposal agreed by the European Parliament and the Council cover inter alia a reduction target of an average specific CO_2 values of 175 g/km in 2017 and of 147 g/km in 2020[40].

Details of Regulation (EC) 443/2009

In contrary to the US, the EU defines the utility based on the parameter mass in running order[41] by defining "a limit value curve of CO_2 emissions allowed for new vehicles according to the mass of the vehicle. The curve is set in such a way that a fleet average of 130 grams of CO_2 per kilometre is achieved.[42]". Nevertheless data on alternative utility parameters such as footprint (track width times wheelbase) are being collected in order to facilitate longer-term evaluations of the utility-based approach. The Commission will by 2014, review the availability of data for an alternative utility parameter and might submit a proposal to the European Parliament and to the Council to adapt the utility parameter[43]].

Currently mass is used as a utility parameter as it „provides a correlation with present emissions and therefore results in more realistic and competitively neutral targets“ [Preamble 443/2009/ no 12]. In addition mass values are readily available on European level due to the former Decision 1753/2000/EC[44].

According to Annex I of the Regulation the basic formula for the calculation of the specific emissions targets is:

$$CO_2 = 130 + a \times (M - M_0)$$

Where:

M = mass (in running order) of the vehicle in kilograms (kg)
M_0 = 1 372,0 kg
a = 0,0457

"A manufacturer must ensure that by 2012 measured fleet average emissions are below the limit value curve, when all vehicles manufactured and registered in a given year by the manufacturer in question are taken into account. This means that the level of emissions by heavier cars will have to be improved proportionately more than lighter cars compared to today. Manufacturers will still be able to make cars with emissions above the limit value curve provided these are balanced by cars which are below the curve as long as the fleet average remains at 130 grams. Manufacturers'

34 JAMA and KAMA.
35 COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT Results of the review of the Community Strategy to reduce CO_2 emissions from passenger cars and light-commercial vehicles, Brussels, 7.2.2007, COM(2007) 19 final.
36 REGULATION (EC) No 443/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles, Official Journal of the European Union L 140/1 5.6.2009.
37 Reduction of CO_2 emissions from light-duty vehicles: emission performance standards for new light commercial vehicles, Brussels, 28.10.2009, COM(2009) 593 final, 2009/0173 (COD).
38 The legislative observatory (Oeil) as of 21.12.2009.
39 IP/10/1728, Brussels, 15 December 2010, Connie Hedegaard, Commissioner for Climate Action, welcomes agreement to cut emissions from vans.
40 ibidem.
41 Kerbweight plus 75 kg.
42 IP/07/1965, Brussels, 19 December 2007, Commission proposal to limit the CO_2 emissions from cars to help fight climate change, reduce fuel costs and increase European competitiveness.
43 Regulation (EC) 443/2009, Preamble no 12.
44 Regulation (EC) 443/2009, Preamble no 12.

progress will be monitored each year by the Member States on the basis of new car registration data."[45]

"Each calendar year from 2012 onwards for which a manufacturer's average specific emissions of CO_2 exceed its specific emissions target in that year, the Commission will impose an excess emissions premium on the manufacturer or, in the case of a pool, the pool manager. From 2012 until 2018, EUR 5 per newly registered car must be paid for the first gram above the objective. For the second gram of exceedance EUR 15 is due and EUR 25 for the third gram. For emissions of more than 3 grams over the limit, EUR 95 is charged per newly registered vehicle. From 2019, the penalty will be EUR 95 per new car for every gram above the target. The amounts of the excess emissions premium will be considered as revenue for the general budget of the EU."[46]

7.1.3 Program Flexibility

The US program[47] and the EU legislation offer different levels of flexibility via means of credits, which is expected to provide sufficient lead time for manufacturers to make necessary technological improvements and reduce the overall cost of the program, without compromising overall environmental and fuel economy objectives, including:

Flex-fuel/Alternative Fuel Vehicle Credits

- ***US: Flex-fuel and Alternative Fuel Vehicle Credits*** – EPA is allowing Flex Fuel Vehicle or FFV credits in line with limits established under the Energy Independence and Security Act of 2007 during model years 2012 to 2015. After model year 2015, EPA will determine alternative fuel vehicle emission values based on a vehicle's actual emissions while operating on gasoline as well as on the alternative fuel and a demonstration of actual alternative fuel use. FFVs are vehicles that can run both on an alternative fuel and conventional fuel. Most US FFVs are E-85 capable vehicles, which can run on either gasoline or a mixture of up to 85 percent ethanol and 15 percent gasoline. Dedicated alternative fuel vehicles are vehicles that run exclusively on an alternative fuel.

- ***EU: Flex fuels, biofuels and E 85*** – In Regulation (EC) 443/2009 the terms "E85"and "biofuels", as well as "flex-fuel vehicles" and alternative-fuel vehicles" mentioned in Articles 6, 8 and Annex II refer only to vehicles designed to run on a mixture of petrol with 85 % ethanol ("E85")[48]. For those vehicles, Article 6 of Regulation (EC) 443/2009/ specifies that „the specific emissions of CO_2 of each vehicle designed to be capable of running on a mixture of petrol with 85 % ethanol ('E85') […] shall be reduced by 5 % until 31 December 2015 in recognition of the greater technological and emissions reduction capability when running on biofuels." But this "reduction shall apply only where at least 30 % of the filling stations in the Member State in which the vehicle is registered provide this type of alternative fuel complying with the sustainability criteria for biofuels set out in relevant Community legislation." Those sustainability criteria are described in Directive 2009/28/EC which regulates inter alia that „Biofuels[…] shall not be made from raw material obtained from land with high biodiversity value" (Article 17 (3)). Currently it seems that only Sweden will receive this Biofuel discount.

Optional Temporary Lead-time Allowance and Derogations

- ***US: Optional Temporary Lead-time Allowance Alternative Standards*** *(TLAAS)* - Manufacturers with limited product lines that have traditionally paid fines to NHTSA in lieu of meeting CAFE standards may find it especially challenging to comply with the greenhouse gas emission standards. Under the Clean Air Act, manufacturers of light duty motor vehicles cannot pay fines in lieu of complying with motor vehicle emissions standards. However, EPA is finalizing an optional, temporary alternative standards provision, which is less stringent, to provide these manufacturers sufficient lead time to meet the tougher model year 2016 greenhouse gas standards, while preserving consumer choice of vehicles during this time.

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[45] IP/07/1965, Brussels, 19 December 2007, Commission proposal to limit the CO_2 emissions from cars to help fight climate change, reduce fuel costs and increase European competitiveness.
[46] http://www.europarl.europa.eu/oeil/resume.jsp?id=5582632&eventId=1077812&backToCaller=NO&language=en
[47] EPA-420-F-10-014, April 2010.
[48] This is clear since recital 15 ("The use of certain alternative fuels can offer significant CO_2 reductions in well-to-wheel terms. This Regulation therefore incorporates specific provisions aimed at promoting further deployment of certain alternative-fuel vehicles in the Community market") and Article 6 ("Specific emissions target for alternative-fuel vehicles") that refer specifically to E85. Guidance document on the monitoring and reporting of CO_2 emissions from passenger cars as of 25.01.2010 (not publicly available).

- There are two different groups of manufacturers to which this temporary standard applies. Manufacturers that produce between 50,000 and 400,000 model year 2009 vehicles in the U.S. would be allowed to establish a separate averaging fleet comprising on average 25,000 vehicles per year (and no more than 100,000 total vehicles during this four year period). This separate, limited vehicle fleet would be subject to a less stringent greenhouse gas standard of 125 percent of the vehicle's otherwise applicable foot-print target level. The separate fleet could not generate credits for use by the remainder of the manufacturer's fleet. Because of their more limited product lines and higher baseline CO_2 emissions compared with other TLAAS manufacturers, manufacturers producing less than 50,000 model year 2009 vehicles in the U.S. would be allowed to place up to 200,000 vehicles in the TLAAS program between model years 2012-2015 and an additional 50,000 vehicles in model year 2016. The manufacturers would need to demonstrate that they have attempted to purchase credits from other manufacturers in order to comply with the base TLAAS program, but that sufficient credits were not available.
- Manufacturers selling fewer than 5,000 vehicles in the U.S. will be deferred from this rulemaking. These manufacturers have extremely limited vehicle product lines across which to average, have typically paid fines under the CAFE program due to the very high CO_2 emissions of their vehicles, and need additional lead time to bring their vehicles into compliance with the GHG standards. EPA plans to set CO_2 standards for these smallest manufacturers through a separate rulemaking to be completed over the next 18 months. EPA estimates that small volume manufacturers comprise less than 0.1 percent of the total light-duty vehicle sales in the U.S., thus the deferment will have a very small impact on the GHG emission reductions from this rule.
- In model year 2016 (or 2017 for manufacturers below 50,000 vehicle sales), the TLAAS option ends, and all manufacturers, regardless of size, must comply with the same CO_2 standards, while under the CAFE program companies would continue to be allowed to pay civil penalties in lieu of complying with the CAFE standards. However, because companies must meet both the CAFE standards and the EPA CO_2 standards, the national program in effect means that companies will not have the civil penalty option, thereby resulting in more fuel savings and CO_2 reductions than would be the case under the CAFE program alone.

- ***EU: Derogations*** – Regulation (EC) 443/2009 mentions in its preamble 20 that it "is not appropriate to use the same method to determine the emissions reduction targets for large-volume manufacturers as for small-volume manufacturers considered as independent on the basis of the criteria set out in this Regulation. Such small-volume manufacturers should have alternative emissions reduction targets relating to the technological potential of a given manufacturer's vehicles to reduce their specific emissions of CO_2 and consistent with the characteristics of the market segments concerned [...]".

  - An application for derogation from the specific emissions target may be made by a manufacturer which is responsible for fewer than 10 000 new passenger cars registered in the Community per calendar year for a maximum period of five calendar years. For those manufacturers inter alia „a specific emissions target consistent with its reduction potential, including the economic and technological potential to reduce its specific emissions of CO_2 [..]" has to be proposed to the Commission and will, if deemed eligible, be granted [Article 11 (2,3)].

  - An application for a derogation from the specific emissions target calculated in accordance with Annex I may also be made by manufacturers responsible[49], for between 10 000 and 300 000 new passenger cars registered in the Community per calendar year. Those manufacturers should set themselves „a target which is a 25 % reduction on the average specific emissions of CO_2 in 2007 or, where a single application is made in respect of a number of connected undertakings, a 25 % reduction on the average of those undertakings' average specific emissions of CO_2 in 2007" [Article 11(4)b]. This derogation will be granted by the Commission if the criteria for derogation respective paragraph have been met [Article 11 (4)].

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[49] Together with all of its connected undertakings.

Innovative/Advances Technology Credits and Eco-Innovation

- ***US: Advanced Technology Credits*** - EPA is finalizing a temporary incentive program to encourage the early commercialization of advanced greenhouse gas/fuel economy control technologies, such as electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles. In this program, manufacturers who produce advanced technology vehicles will be able to assign a zero gram per mile CO_2 emissions value to the first 200,000 vehicles sold in model years 2012-2016 (for PHEVs, the zero gram per mile value applies only to the percentage of miles driven on grid electricity), or 300,000 vehicles for manufacturers that sell 25,000 vehicles or more in model year 2012. The CO_2 emissions compliance levels for advanced technology vehicles sold beyond these cumulative vehicle production caps will account for the net increase in upstream CO_2 emissions relative to a comparable gasoline vehicle. EPA will reassess the issue of how to address advanced technology vehicle emissions in future rulemakings for MY2017 and beyond, based on the status of their commercialization, upstream GHG control programs, and other factors.

- ***US: Off-Cycle Innovative Technology Credits*** - EPA is finalizing a credit opportunity for new and innovative technologies that reduce vehicle CO_2 emissions, but whose CO_2 reduction benefits are not captured over the 2-cycle test procedure used to determine compliance with the fleet average standards (i.e., “off-cycle”). Eligible innovative technologies include those that are used in one or more current vehicle models, but that are not yet in widespread use in the light-duty fleet. Furthermore, any credits for these off-cycle technologies must be based on real-world greenhouse gas emission reductions not captured on the current 2-cycle tests and verified by test methods that represent average U.S. driving conditions.

- ***EU: Eco-innovation -*** Upon application by a supplier or a manufacturer, CO_2 savings achieved through the use of innovative technologies will be considered. The total contribution of those technologies to reducing the specific emissions target of a manufacturer may be up to 7 g CO_2/km. The Commission will finalise guidelines describing the Eco-innovations systematic by February 2011 so that they will be adopted by the Commission in Summer 2011 [Lindvall 2010][50].

Early Credits and Super-credits

- ***US – Early Credits*** - EPA is finalizing a program to allow manufacturers to generate early credits in model years 2009-2011. Credits may be generated through early additional fleet average CO_2 reductions, early A/C system improvements, early advanced technology vehicle credits, and early off-cycle credits. As with other credits, early credits are subject to a five year carry-forward limit based on the model year in which they are generated. Manufacturers may transfer early credits between vehicle categories (e.g., between the car and truck fleet). With the exception of model year 2009 early program credits, a manufacturer may trade other early credits to other manufacturers without limits. CAFE credits earned in model years prior to model year 2011 will still be available to manufacturers for use in the CAFE program in accordance with applicable regulations.

- ***EU- Super-credits –*** Regulation (EC) 443/2009 foresees the application of super credits also to allow manufacturers to generate early credits but only being based on the CO_2 emission of vehicles. In detail those passenger vehicles with specific emissions of CO_2 of less than 50 g CO_2/km are being counted more than once. In 2012 and 2010 they shall be counted as 3.5 cars, in 2014 as 2.5 cars, in 2015 as 1.5 cars. After that they will be only counted as one car.

Phase-in

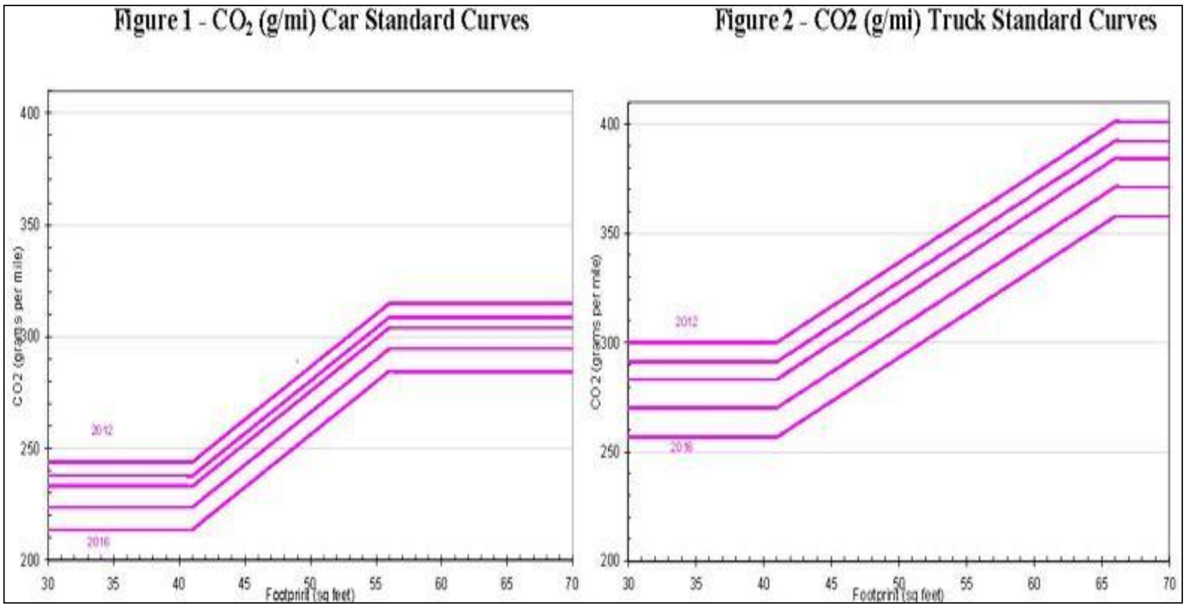
- ***EU -*** The specific emissions targets must be met by all manufacturers from 2012 onwards. Although between 2010 and 2015 the manufacturer’s average specific emissions of CO_2 are being based on certain percentage of their fleet (65 % in 2012, 75 % in 2013 and 80 % in 2014). From 2015 onwards the average specific emissions will be based on the whole fleet.

[50] Presentation of S. Lindvall, DG Climate Action in WG 4, 3.12.2010.

7.1.4 Average Required Fuel Economy and Projected Fleet-Wide Emissions

United States

The figure below illustrates the passenger car CAFE standard curves for model years 2012 through 2016, as well as the light truck standard curves for model years 2012-2016. As illustrated below, each parameter changes on an annual basis, resulting in the yearly increases in stringency.



Source: National Highway Traffic Safety Administration 40 CFR Parts 85, 86, and 600; 49 CFR Parts 531, 533, 536, et al. Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule.

Figure 29 CAFE Standard Curves.

The US standards, as set by NTHSA, will require vehicle manufacturers to meet an estimated combined average fuel economy level of 34.1 mpg by model year 2016, or 6.9 L/100km in a European equivalent as illustrated in the table below.

Table 53 Average required fuel economy (L/100km under Final CAFÉ standards.

	2011-base	2012	2013	2014	2015	2016
Passenger Cars	7,84	7,13	6,92	6,92	6,53	6,36
Light Trucks	9,8	9,41	9,05	8.84	8,55	8,17
Combined Cars & Trucks	8,71	8,11	7.71	7.52	7.22	6.9

These standards cover both passenger cars and light-duty trucks built in model years 2012 through 2016. The overall fleet fuel mileage requirement will be an average between both passenger cars and light trucks, and NHTSA is forecasting that the 2012 numbers will be 33.3 mpg (or 7.13 l/km) for cars and 25.4 mpg (or 9.41 l/km) for trucks in 2012, rising to 37.8 mpg (6.36 l/km) for cars and 28.8 mpg (8.17 l/km) for trucks by 2016.
The US fleet-wide emissions standards, as set by the EPA, will require vehicles to meet an estimated combined average emissions level of 250 grams/mile of CO_2 in model year 2016, or an equivalent of 155 g/km of CO_2, as illustrated in the table below.

Table 54 Projected Fleet-Wide Emissions Compliance Levels under the Footprint-Based CO_2 Standards (g/km) [51].

	2012	2013	2014	2015	2016
Passenger Cars	163	159	153	147	140
Light Trucks	215	209	202	194	185
Combined Cars & Trucks	183	178	171	163	155

The average required fuel economy and emissions standards for the US are estimated to result in approximately 960 million metric tons of total carbon dioxide equivalent emissions reductions and an approximate 1.8 billion barrels of oil savings over the lifetime of vehicles sold in model years 2012 through 2016.

How the major automotive manufactures compare to these standards is illustrated by Figure 30 and Figure 31, which review the so-called distance to target in terms of MPG fuel economy requirements between 2009 and the 2016 targets for the major vehicle brands operating in the US market.

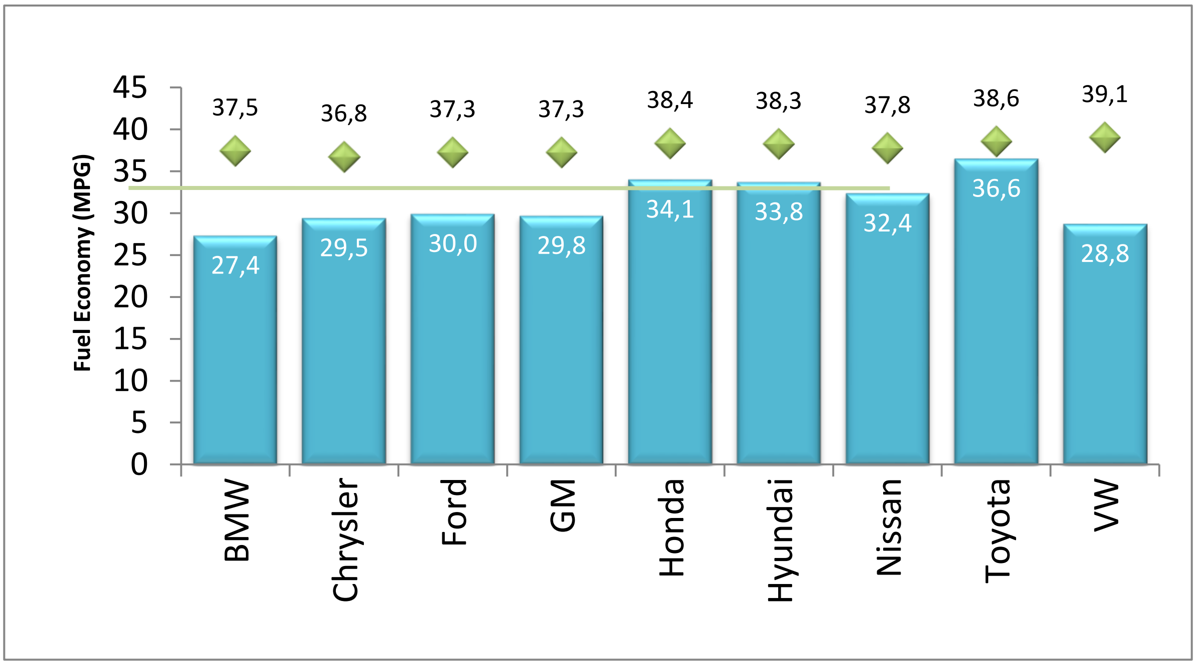


Figure 30 Passenger Car 2009 MPG performance compared to target[52].

[51] EPA standards.
[52] IHS Global Insight.

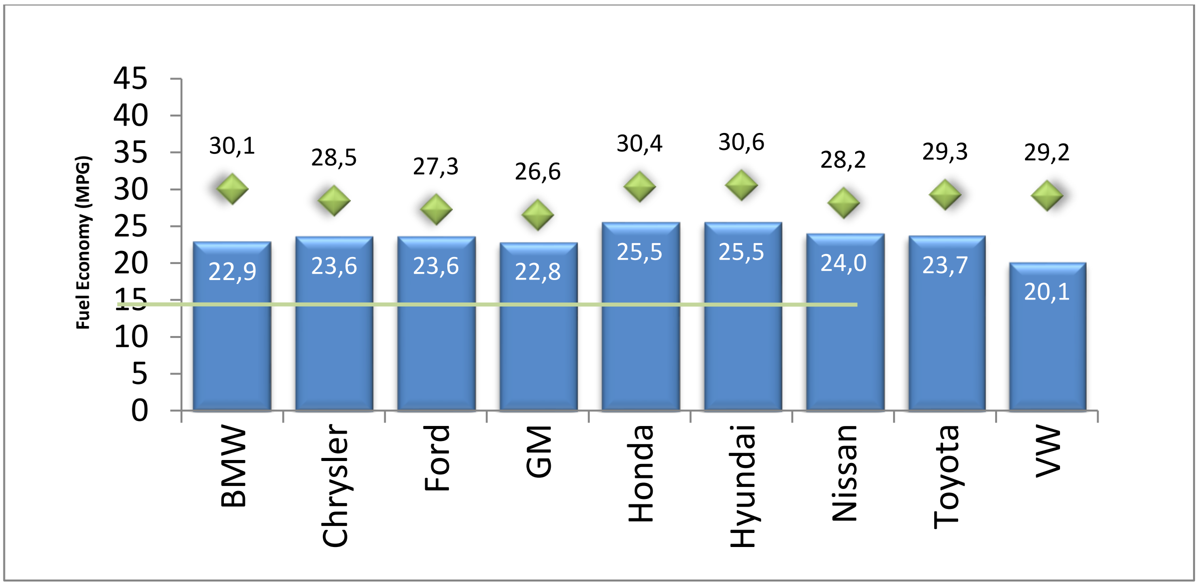


Figure 31 Light Truck 2009 MPG performance compared to target[53].

While clearly indicating that much work remains to be done by the majority of vehicle manufacturers, the illustrations also show that each OEM has individual targets based upon their vehicle size mix and sales volumes. For the passenger car fleet the current average stands at 38.0mpg compared to 28.3mpg for the light truck fleet. Overall average increases of 4.3% per year will be required to meet the 2016 standards.

The impact upon different vehicle types, as illustrated by the figure below, suggests that full-size cars (equivalent to European D/E segment vehicles) and midsize crossovers appear to get hit the hardest by these new standards, requiring efficiency improvements of 42.6% and 33.0% respectively. In contrast the popular full-size pickups are comparably less affected with efficiency improvements of around 23.5%.

Model Year 2016 CO2 and Fuel Economy Targets for Various Model Year 2008 Vehicle Types

Vehicle Type	Example Models	Example Model Footprint (sq. ft.)	EPA CO2 Emissions Target (g/mi)	NHTSA Fuel Economy Target (mpg)	Typical Segment Increase Needed
Example Passenger Cars					
Compact car	Honda Fit	40	214	41.4	**18.3%**
Midsize car	Ford Fusion	46	237	37.3	**28.6%**
Full-size car	Chrysler 300	53	270	32.8	**42.6%**
Example Light-duty Trucks					
Small SUV	4WD Ford Escape	44	269	32.8	**31.2%**
Midsize crossoverr	Nissan Murano	49	289	30.6	**33.0%**
Minivan	Toyota Sienna	55	313	28.2	**22.6%**
Large pickup truck	Chevy Silverado	67	358	24.7	**23.5%**

Source: EPA.

Figure 32 Examples of Targets for various vehicle types.

[53] IHS Global Insight.

European Union

For M1 the average CO_2 value for EU 27[54] is 145 g/km for reporting year 2009. For N1 vehicles the respective CO_2 monitoring is not yet in place and therefore the current CO_2 value of the N1 fleet is not known exactly. Studies suggest that it was 203 g/km in 2007[55]. The reduction targets those vehicles categories have to face are shown in following table.

Table 55 Reduction targets of passenger cars (M1) and light commercial vehicles (N1)-Wide Emissions Compliance Levels under the Footprint-Based CO_2 Standards (g/km)[56].

	2012	2017	2020
Passenger Cars	130	-	95
Light Commercial vehicles	-	175	147

The EU targets are more ambitious than the US targets, taking into account the strong emission reduction realised within the EU in comparison with the US. Comparing the years 1995 to 2008, the CO_2 emissions of new passengers cars in EU 15[57] decreased by 18% (186 g/km[58] to 153 g/km[59]) while the reduction in CO_2 emissions of new light duty vehicles in the US was only 4% (236 g/km to 227 g/km[60])

On a manufacturer level the necessary reduction in CO_2 emission per km are shown below (as of 2006).

54 All fuels, all manufacturers.
55 Brussels, 28.10.2009, SEC(2009) 1454, COMMISSION STAFF WORKING DOCUMENT, IMPACT ASSESSMENT, Accompanying document to the Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL Setting emission performance standards for new light commercial vehicles as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles.
56 EPA standards.
57 Petrol and diesel cars , all manufacturers.
58 Source: COM(2009)713 final, REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL Monitoring the CO_2 emissions from new passenger cars in the EU: data for the year 2008.
59 COM(2006) 463 final, COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT Implementing the Community Strategy to Reduce CO_2 Emissions from Cars: Sixth annual Communication on the effectiveness of the strategy.
60 Source http://www.epa.gov/otaq/cert/mpg/fetrends/420r10023-main-rpt-tables.xls, Unit converted from g/mi to g/km.

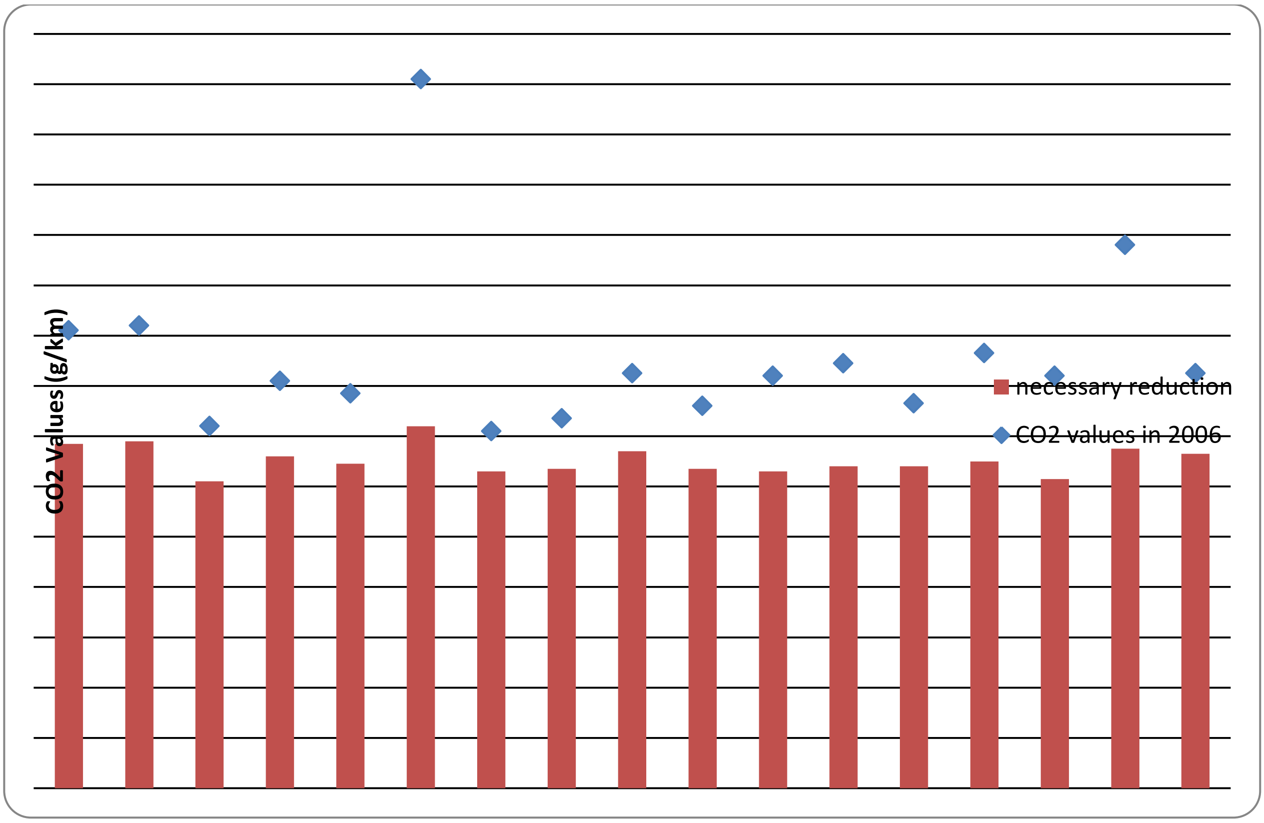


Figure 33 Passenger Car 2006 CO_2 values compared to target[61].

Like in the US above figure shows that each OEM will receive individual targets based upon their vehicle size mix and sales volumes.

7.2 Detailed analysis of the 2009 EU sales database in relation to footprint

7.2.1 Methodology

The calculation in this section was based from a sample of around 53,000 technical observations of passenger cars, which covered 7 European countries and accounted for more than 89% of total car sales in 2009.

The footprint parameter was calculated as follows:

Footprint = wheelbase × average track width in m^2.

Average track width = average of front and rear wheel track width

The least squares method was used to calculated the footprint utility curve for a simple linear regression y = ax+ b where the dependant variable, y, is CO_2 emission and x, the footprint; a, the slope of regression lines and b, the constant. This regression was weighted by the level of sales by model in 2009.

The value of the a and b parameter for the sales weighted regression and target slopes for the footprint based limit function for respectively targets of 130 g/km and 95 g/km are presented in Table 56.

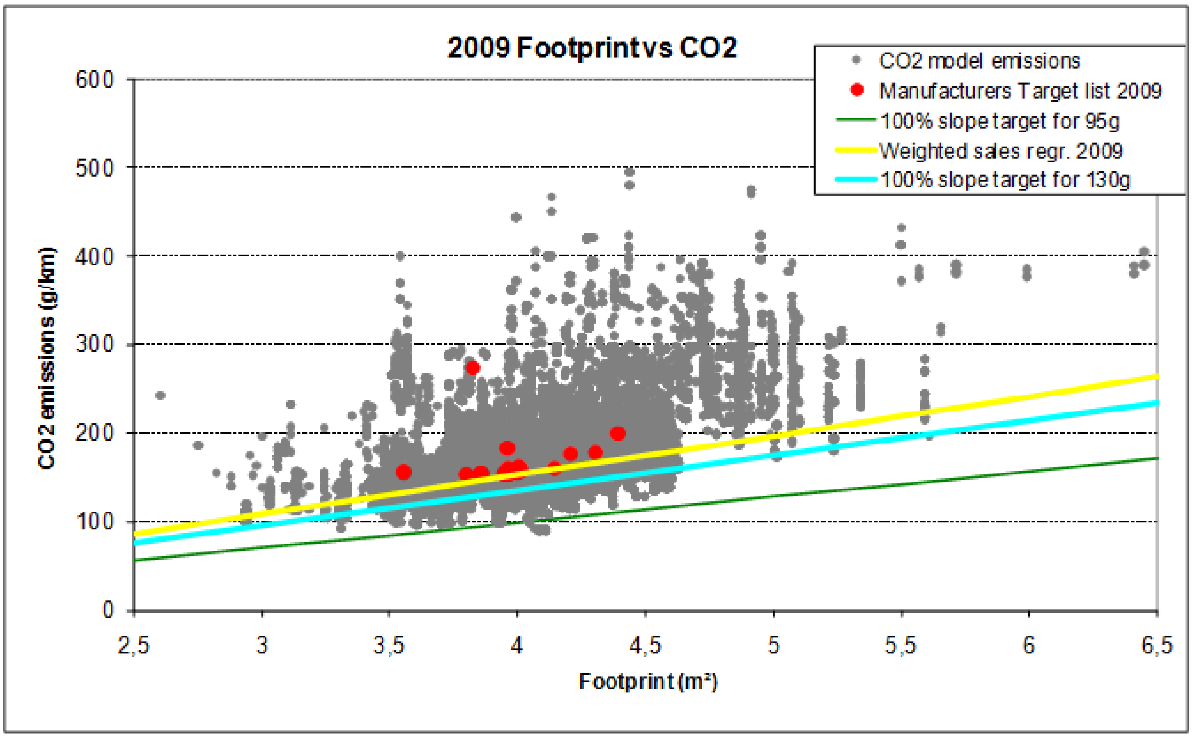
[61] Based on data from: MEMO/07/597, Brussels, 19 December 2007, Questions and answers on the proposed regulation to reduce CO_2 emissions from cars. The used mass value for the limit value curve differs for this calculation from the one of Regulation (EC) 443/2009. Therefore the indicated values can only be taken as indications for necessary reduction targets.

Table 56 a and b values for 2009 sales weighted fit and values of limit curve function.

Sample analysis	**a**	**b**
Sales-weighted fit based on 2009 database	44.365	-24.6
	CO_2	**Footprint**
Weighted average value of sample	**146**	**3,85**
Limit curve function	**a**	**b**
100% slope target for 130g/km	39,422	-21,9
100% slope target for 95g/km	28,808	-16,0

Source: IHS.

7.2.2 Footprint vs CO_2 emission



Source: IHS Global Insight

Figure 34 Manufacturer Average Footprint and CO_2 from 2009.

Figure 34 shows the scatter of CO_2 emissions against all 2009 sales models' footprint and the 2009 average emissions for main manufacturer groups of connected undertakings. Compared to the 2006 analysis, the scatter moves down to a more concentrated area between 3.5 to 4.5 m² footprint and around 100 CO_2 g/km to 250 CO_2 g/km.

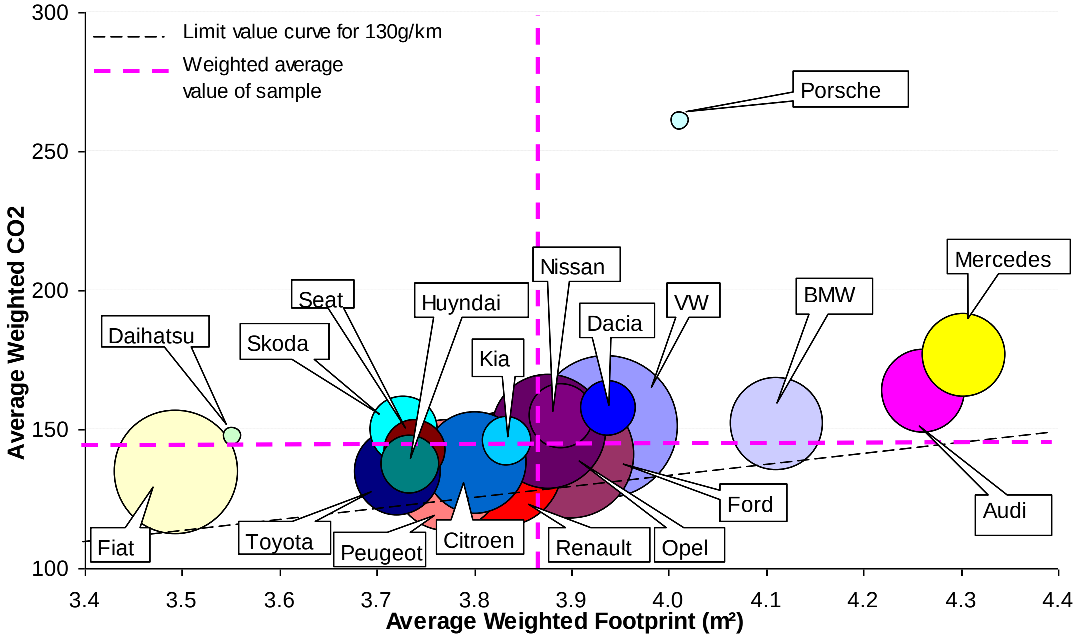
Except for a few companies with highest average CO_2 emissions (Porsche, Mercedes and Nissan), the company averages are spread over the 2009 sales weighted line due to the fact that the most available models have lower CO_2 emissions. Fiat and Daihatsu show the smallest footprint, as illustrated in Table 57. The figures in Annex F provide a detailed graphical overview per manufacturer group.

Compared to Figure 4 in the IEEP/CE/TNO 2008 study, which was based on a 2006 database with approximated footprint data, the sales weighted regression line based on the 2009 database is much closer to the limit function with 100% slope for the 130 g/km target, illustrating the improvement in CO_2 emissions achieved between 2006 and 2009.

Table 57 Sales-weighted average CO_2 and Footprint by Manufacturer, ordered by decreasing sales.

Manufacturer	Average CO_2 g/km	Average Footprint
VW	150.8	3.9
FORD	140.6	3.9
FIAT	134.1	3.5
RENAULT	135.6	3.8
OPEL	148.8	3.9
PEUGEOT	133.4	3.8
CITROEN	137.5	3.8
BMW	151.9	4.1
TOYOTA	134.0	3.7
AUDI	163.3	4.3
MERCEDES	176.3	4.3
SKODA	149.4	3.7
NISSAN	154.5	3.9
SEAT	141.9	3.7
HYUNDAI	137.3	3.7
DACIA	157.3	3.9
KIA	145.2	3.8
PORSCHE	260.9	4.0
DAIHATSU	147.3	3.6

Source: IHS Global Insight.

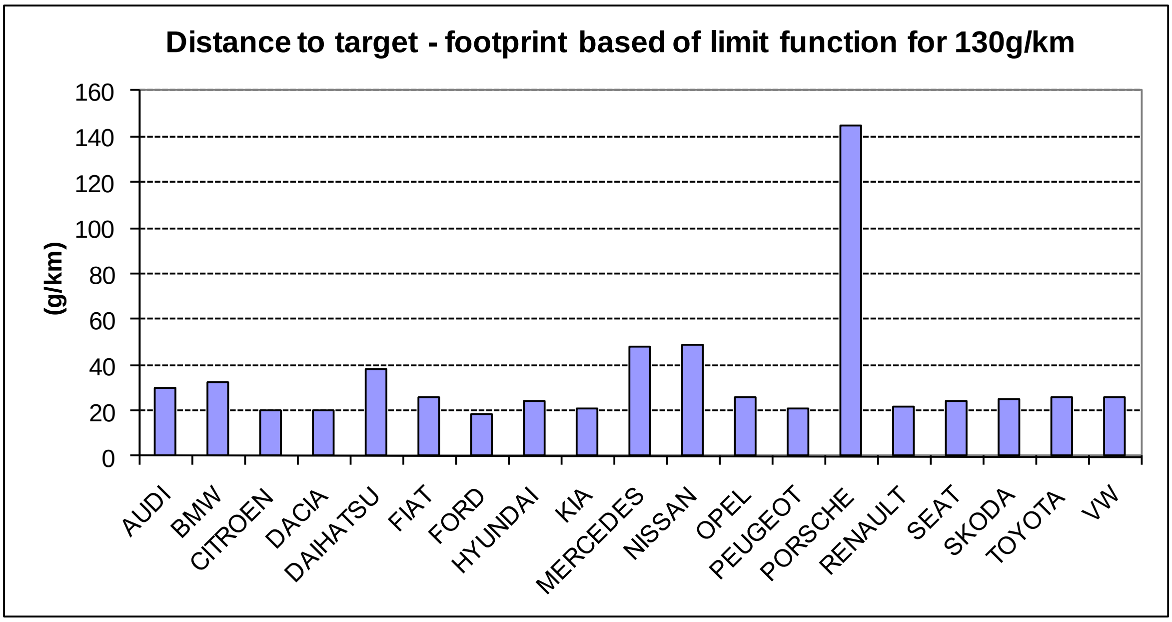


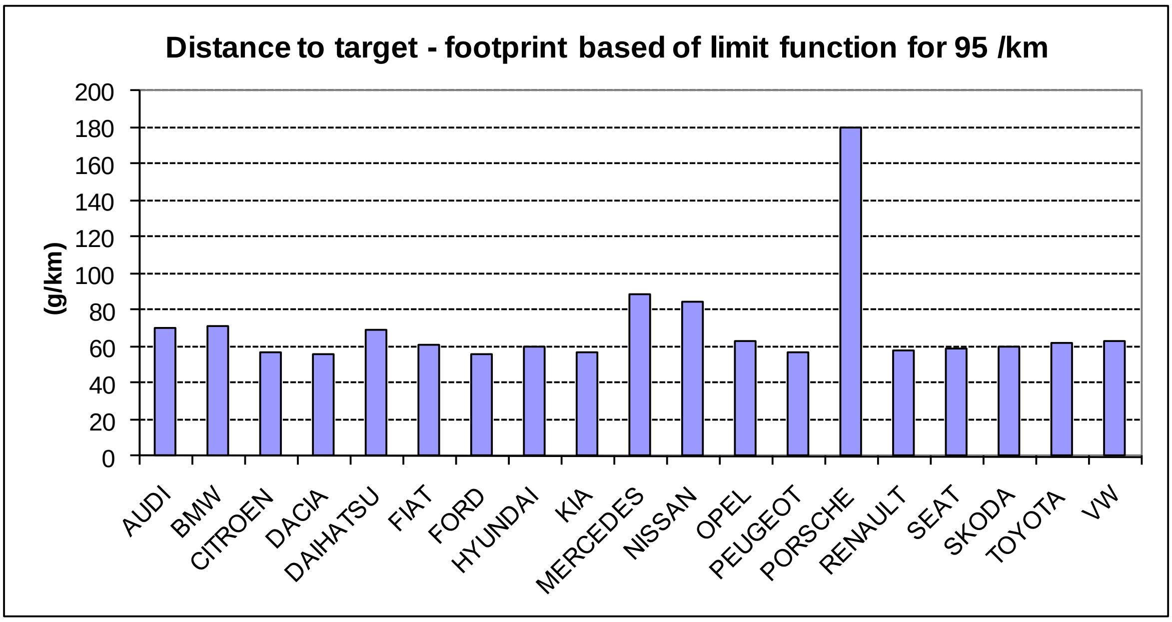
Source: IHS Global Insight.

Figure 35 Sales-weighted average CO_2 emissions per manufacturer as function of Footprint; bubbles size indicates 2009 total sales.

Figure 35 shows the sales-weighted CO_2 emissions position of manufacturers compared to the average footprint of their models. The major manufactures are extremely concentrated around 3.7 to 4.0 m² footprint and some of those with high-end model ranges such as Audi, Mercedes or Porsche, are still far from the limit curve function. BMW and Fiat lie outside of the central concentration in terms of footprint and just above the CO_2 limit curve function, the latter because of the quite low average footprint. Only eight manufacturers tend to be under the weighted CO_2 average of this sample which is equal to 145 g/km.

Thus, as Figure 36 illustrates, the efforts required for most manufacturers to reach the target are still significant. More than 68% of manufacturers in the sample show a difference of more than 20 g/km of CO_2 emissions to the target in average in 2009, but only 37% a difference of more than 25 g/km.

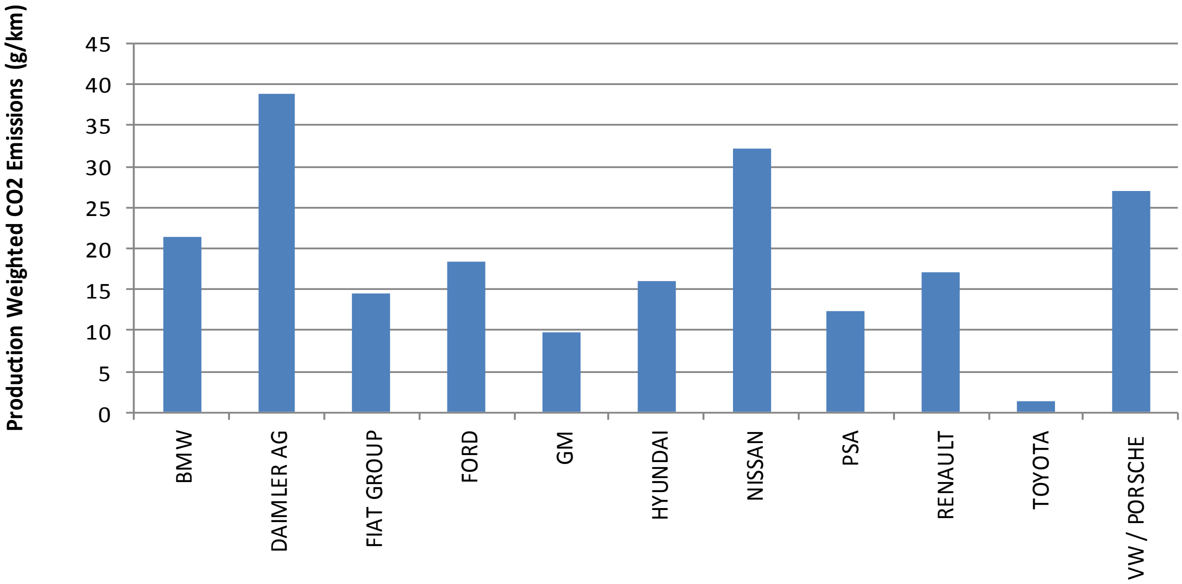




Source: IHS Global Insight.

Figure 36 Distance to target compared to Footprint-based target of 130 g/km and 95 g/km.

In order to better appreciate the relevance of the distance to target challenge ahead, Figure 37 provides insight into the approximate distance to target based on vehicle mass. However, due to data availability limitations, Figure 37 is restricted to a European production weighted outlook by selected manufacturing groups, instead of a sales weighted approach. Nevertheless the comparison does show that while the premium vehicle manufacturers overall face a relatively similar challenge as under the footprint based approach, for the large volume vehicle manufacturers the challenge ahead under the footprint based approach does seem more significant. Caution does have to be taken into account, since for several vehicle manufacturers, imports of overseas manufactured vehicles are not taken into account in this comparison, causing some distortion.



Source: IHS Global Insight – note: production based data

Figure 37 Approximate distance to target compared to mass-based target of 130 g/km.

7.3 Longer term evolution of vehicle characteristics in response to use of footprint as utility parameter

7.3.1 Autonomous trends

During the last few decades, the European automotive industry has seen continuous changes in terms of vehicle requirements and characteristics. Many of these were driven by legislation and/or market forces such as increased safety and comfort requirements. Possibly influenced by this, a trend towards increased vehicle comfort and size has been observed since at least the early nineties and was reflected in practically every vehicle segment, as illustrated by Figure 38[62]. Note: this figure is based upon Western European production data, but it provides a good indication of the overall European market trend.

[62] IHS Global Insight.

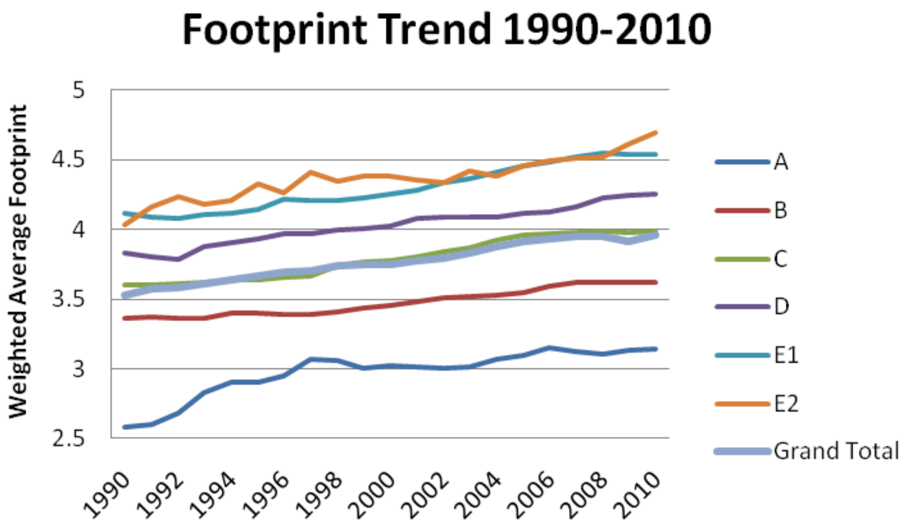


Figure 38 Footprint Trend.

This figure illustrates that the average weighted footprint has increased by about 0.4m over the two decade period of 1990-2010, and increased in every single vehicle segment – see also Figure 39[63]. However, the figure also shows the tendency that the earlier identified increase started to level out from around 2005 and is not expected to continue its growth trajectory for a variety of reasons. Among these reasons are the increasing vehicle running costs. In fact, due to vehicle efficiency improvements in the last few years, fuel running costs may have stabilised, but higher fuel prices of recent times prevented an overall reduction while ownership costs such as insurance/parking/taxation have only shown signs of increase.

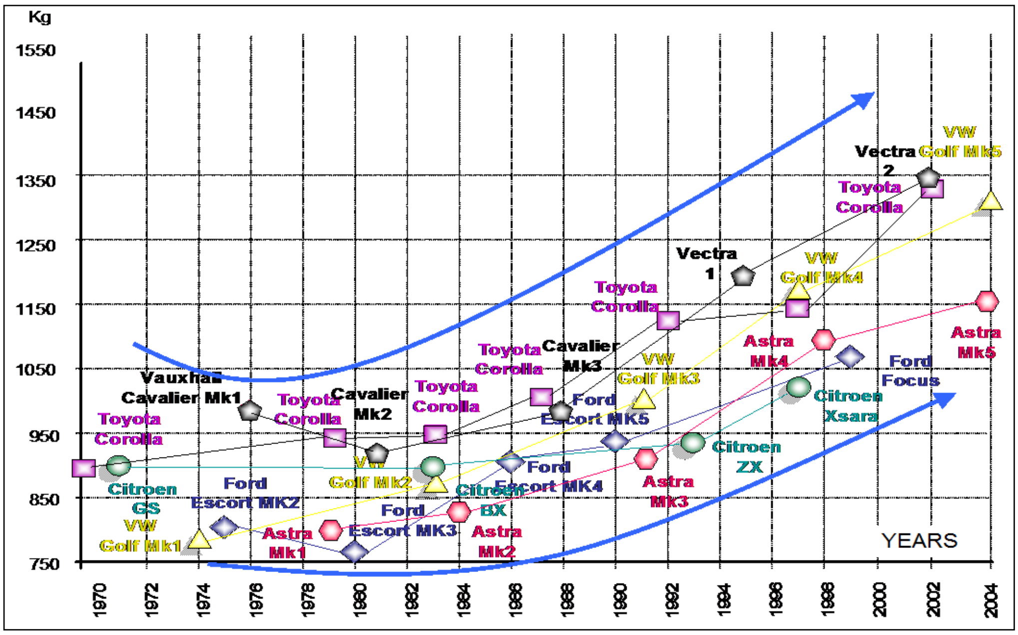
On the other hand, the increased incompatibility between larger vehicle sizes and lack of physical space in parking garages and crowded city centres is illustrated by Figure 39. Currently new garages and parking spaces are no longer able to accommodate many vehicle sizes properly, as parking space legislation has not been updated for almost 3 decades[64]. Even small sized vehicles have grown significantly – e.g. the current generation Volkswagen Polo is now the same size as the original 1974 Volkswagen Golf. This has led automotive component/technology suppliers to develop measuring technology that can be fitted to vehicles to check if the road ahead is wide enough to allow the vehicle to pass (mainly aimed at SUV vehicles for inner-city driving).

Figure 39 Increase in Vehicle Width of VW Golf 1974-2010.

When looking at vehicle weight developments over the last decades (see Figure 40), a similar observation can be made. However it has to be mentioned that given the recent legislative pressure concerning CO_2 targets, many manufacturers have started to review vehicle dimension/weight

[63] MDR Mitteldeutscher Rundfunk (18/05/10).
[64] MDR Mitteldeutscher Rundfunk (18/05/10).

growth. It should still be noted that it typically takes several years before these revisions become apparent in new vehicles due to long design and development stages inherent to the automotive industry.



Source: Thatcham.

Figure 40 Weight increase trend for C-segment vehicles.

Given that the automotive industry is increasingly a truly global business with stringent economic/financial interests at heart, it is becoming too unattractive for a vehicle manufacturer to allocate a variety of resources towards vehicle ranges aimed at regional divergence, beyond small play with the vehicle overhangs (which are required to satisfy the different bumper impact standards around the world). It is also noted that vehicle width is extremely hard to change on an existing vehicle platform, while also proving to be very costly. Therefore it is deemed unlikely that regional divergence in terms of product dimensions will proliferate further.

Effectively it has become too unattractive for a vehicle manufacturer to design and develop vehicle platforms for a specific geographical region only, especially in an era of anticipated future regulatory harmonization (like future emission standards). Hence this could prove to be a further deterrent against vehicle manufacturers gaming with footprint in order to satisfy just the European requirements.

7.3.2 Possibilities for and effect of gaming with footprint

If footprint is to be used as a utility parameter in legislation, it should be relatively difficult to game with. Gaming in this respect means the alteration of a vehicle's footprint in order to achieve a higher CO_2 target without actually improving the fuel efficiency of said vehicle. In this section, the potential for gaming with footprint will be assessed.

The footprint of a vehicle can be increased in two ways; either by increasing the wheelbase or the track width. Both will be assessed separately.

Increasing wheelbase

The wheelbase of a vehicle can basically be increased by increasing the overall length of the vehicle whilst keeping the same front and rear overhang. A number of high-end luxury cars are currently available in a "long wheelbase" version. Examples of these vehicles are the Audi A8, Mercedes S-class and the BMW 7-series. In effect, such vehicles have had an additional section fitted "in between" the original front and rear sections. The characteristics of these example vehicles are shown in Table 58.

Table 58 Extended wheelbase vehicle examples.

	Audi A8 4.2 TFSI *normal / long*	Mercedes S350 BLUEefficiency *normal / long*	BMW 740i *normal / long*
Overall length [mm]	5137 / 5267 (+130)	5096 / 5226 (+130)	5072 / 5212 (+140)
Wheelbase [mm]	2992 / 3122 (+130)	3035 / 3165 (+130)	3070 / 3210 (+140)
Kerbweight [kg]	1835 / 1885	1810 / 1875	1835 / 1870
Footprint [m^2]	4,91 / 5,12	4,87 / 5,07	5,01 / 5,24
Average trackwidth [mm]	1640 / 1640	1603 / 1603	1631 / 1631
CO_2 emission [g/km]	219 / 224	177 / 179	232 / 235
EU5+7 registrations 2009 [-][65]	- / -[66]	7629 / 2674	7817 / 2324
Mass increase [%]	2,7	3,6	1,9
Footprint increase [%]	4,3	4,1	4,6
CO_2 increase [%]	2,3	1,1	1,3
CO_2 increase per footprint increase [%/%]	0,85	0,27	0,41

From this, we can see that increasing the wheelbase of a vehicle by some 4,3% (the average wheelbase increase of the three example vehicles) increases the CO_2 emissions by some 1,6% on average. The relative increase in CO_2 per percent increase of the wheelbase is thus around 1.6/4.3/=0.37 [%/%].

These “long wheelbase” versions are built alongside their standard length counterparts and the engineering changes made to them are relatively minor compared to the option of increasing wheelbase without increasing the overall length of the vehicle. All of these vehicles have an increased footprint compared to their non-stretched counterparts. The additional wheelbase is used to increase the rear legroom in all cases.

Previous work on estimating the mass and CO_2 increase caused by “stretching” cars [TNO 2008] also concluded that a wheelbase increase of some 10% leads to a mass increase of 4 to 5% and thus (using the $\Delta CO_2/CO_2$ = 0.65 $\Delta m/m$ relationships as used in [TNO 2006]) a CO_2 increase of around 3%. This is closely comparable with the 0.37 %/% conclusion from the exercise above. The Audi A8 does show a larger than expected CO_2 increase. Based on just the mass increase (which with +2.7% corresponds well with the other examples), a CO_2 increase of 0.65*2.7=1.8% or just below 4 grams was expected. The true CO_2 increase is 5 grams, which means the difference could easily be explained by rounding differences in the CO_2 emissions.

Concluding, for gaming with footprint a 10% increase in wheelbase is expected to lead to a 3 to 4% increase in CO_2. For the average footprint from Table 56 and 95/g/km as target value this relation translates into an absolute slope value (CO_2 vs footprint) of 7.4 to 9.9. As these values are much higher than the 100% slope for the 95 g/km target (around 29) This means that for most slope values for the 2020 target based on footprint gaming with wheelbase will bring vehicles significantly closer to the target line. This effect is actually stronger than for mass.

From this, it can be concluded that the slope of the footprint-based limit function should not exceed 20 to 30% if one wants to avoid gaming by increasing the length of the vehicle.

Increasing the wheelbase at constant overall length is much more involved. This severely influences packaging and body design and effectively, an entire redesign of the vehicle is needed. One should remember though, that this does not require the development of a completely new vehicle platform, as platform technology can cater for vehicles with differing wheelbases (and track widths). Previous work indicates that increasing the wheelbase within a fixed overall length does not cause an increase in CO_2 emissions. [TNO 2008].

[65] This includes all engine and trim levels for the different models, not just the engine and trim level as specified at the top of the table.
[66] The new model Audi A8 was introduced very near the end of 2009.

The scope of increasing footprint at constant length is limited to moving the wheels to the outer corners. By doing so, the wheelbase could at most be equal to the overall length of the vehicle minus the average diameter of the wheels. To estimate the potential of increasing wheelbase at constant vehicle length, the 2009 sales database has been used to check what the ratio between length and wheelbase currently is.

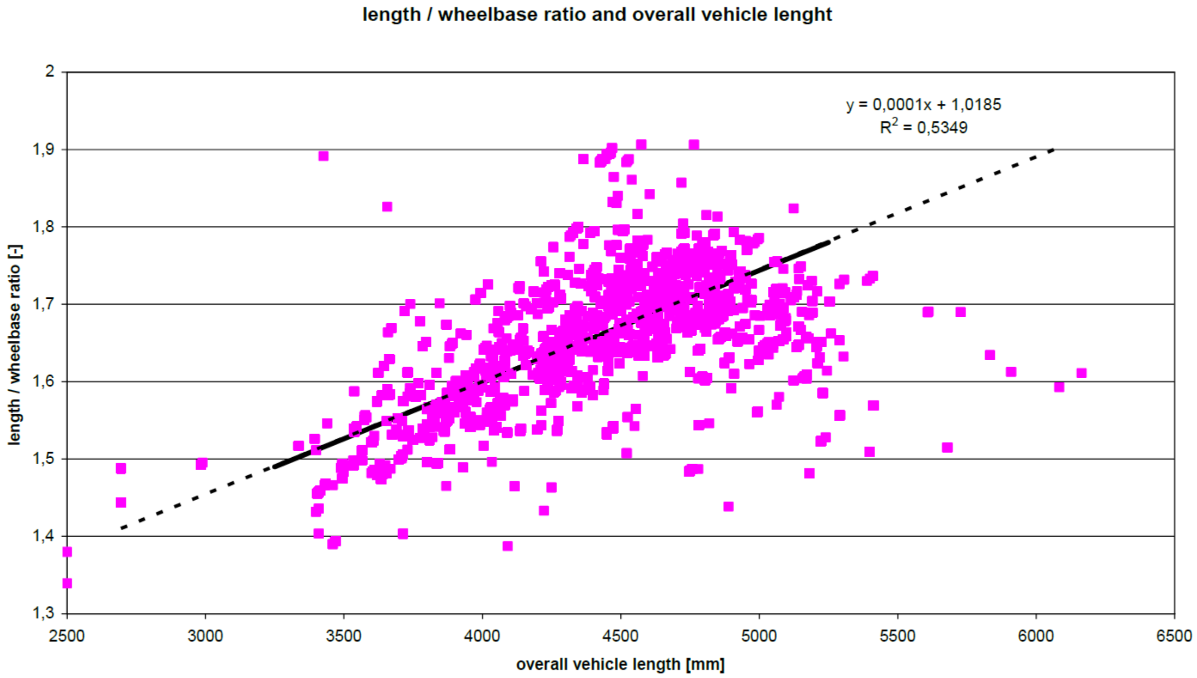


Figure 41 Length / wheelbase ratio versus the overall vehicle length from the 2009 sales database

From this, we can conclude that on average, longer vehicles have a higher length to wheelbase ratio. At the lower end of the scale, the Smart ForTwo (length 2500mm, wheelbase 1867) has a length/wheelbase ratio of 1,33. Given the layout of the Smart ForTwo (see Figure 42), this can be interpreted as the lowest attainable ratio[67].

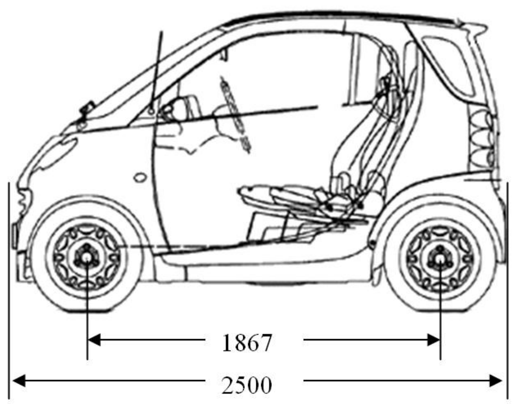


Figure 42 Smart fortwo side view showing overall length and wheelbase.

The bulk of the shorter vehicles starts to appear at a ratio of around 1,55, which could be regarded as a realistic lower limit. The 2009 sales weighted average footprint was 3,79 m^2. If all vehicles were

[67] Although in theory lower ratios could be possible by decreasing wheel size, this decreases the available space for braking components as well as negatively influence the ride and handling characteristics, which is not a viable proposition. The influence on ride and handling can be minimized by engineering, but at a certain point, it is imply not viable anymore to significantly decrease the wheel size further. The example vehicle is fitted with 15" wheels, which is already at the lower bound of the currently fitted wheel sizes.

to have a length to wheelbase ratio of 1,55 (whilst keeping their length constant), this would increase to 3,97m^2, an increase of some 5%.

A number of typical vehicles with a length/wheelbase ratio of 1,55 are shown in Table 59 for reference.

Table 59 Example vehicles with a length/wheelbase ratio of 1,55.

Make	*Model*	*Length [mm]*	*Wheelbase [mm]*
Mitsubishi	Colt	3875	2500
Fiat	Panda	3574	2305
VW	Fox	3825	2465
Dacia	Sandero	4020	2590
Suzuki	Swift	3695	2380
Toyota	Yaris	3820	2460
Mini	New Mini	3958	2547
VW	Transporter T5	5290	3400
Lada	Kalina	3850	2470

Increasing track width

Track width can only be increased if the width of the vehicle is also increased. This leads to an increase in frontal area and thus to an increase in CO_2 emissions through higher air-drag. However, previous work [TNO 2008] has investigated this issue and concluded that at limit function slopes below 60% (relative to a 100% line for 2015 as defined in that study), increasing the track width leads to an increase in CO_2 emissions that is great enough not to decrease the distance to target. As the 2020 limit functions used in this study (based on a 2009 database) are expected to be flatter than the 100 % line from [TNO 2008] the % for which gaming with track width is discouraged is expected to be higher.

8 Assessment of alternative transport utility parameters

8.1 Introduction and option identification

The objective work reported in this chapter was to assess the suitability/feasibility of using utility parameters that more directly reflect the transport utility of a vehicle, rather than mass and footprint.

8.1.1 Identification of options

The process to identify possible vehicle parameters that potentially better reflect the true transport utility of a vehicle started off with the more obvious candidates for consideration such as number of seats and luggage space or "payload". Combinations of these or combinations of these with the alternative parameters mass, pan area of or footprint were also considered. Of course the suitable parameters will need to be available within the database used, while the available database could potentially also allow multi-dimensional utility parameters.

The inception report originally suggested the following nine database parameters to be assessed:

1. Wheelbase (mm)
2. Front track (mm)
3. Rear track (mm)
4. Total authorised weight (kg)
5. Weight without load (kg)
6. Reference mass
7. Number of seats
8. Overall height (mm)
9. Trunk space / loading space (litre)

Following the assessment phase regarding the utility parameters it was decided that wheelbase (mm) was a suitable requirement as it allows for the distinction between vehicle categories. However the front track (mm) and rear track (mm) parameters were deemed not relevant parameters, since a composite of these parameters is the footprint (as already utilized in task 2.2). Concerning the weight/mass related parameters, it was decided that it was redundant to feature kerb weight, payload and gross vehicle weight, as two of these parameters would be sufficient. Consequently the two selected suitable weight/mass references decided upon were payload and mass in running order. The latter was chosen as it sticks to the definition of mass as it is in the current regulation. The relevance of utilising solely the number of seats was also put into question, due to the gaming potential this could create, while the trunk space/volume alone was also not deemed relevant for similar reasons, as it would only really make sense for commercial vehicles such as vans. Hence it was decided to additionally utilise a composite taking into account the number of seats (by translating a seat into a certain volume) added to the trunk volume. Finally vehicle height (mm) on its own was deemed unsuitable and was decided to be replaced by a composite of footprint and vehicle height as a proxy for vehicle interior volume. Given the availability of the above discussed parameters and data it was also decided to introduce a few multi-dimensional utility parameters.

Overall the utility parameters decided upon for further assessment were:

1. Wheelbase (mm)
*2. Footprint * height (as a proxy for interior volume)*
3. Mass in running order (kg)
4. Payload (kg)
5. A composite of the number of seats expressed in volume + trunk volume
5a. Number of seats (quantity + trunk volume)
6. Price
7. A composite of 4 and 5
8. A composite of footprint (task 2.1) and 3
9. A composite of 7 and 8

It could not be answered by the data provider how the information on the number of seats should be read in relation with the information of the trunk volume. It is assumed that the minimum trunk volume[68] has been indicated as the number or seats appears normal and not significantly reduced.

For some of the parameters additional calculations had to be performed.

Following parameters were combined by scaling/normalising them:

- Number of seats (quantity) + trunk volume (Parameter 5a)
- Footprint and mass in running order (Parameter 8)
- Payload and number of seats + trunk volume and sum of footprint and Mass in running order (Parameter 9)

Footprint and height (Parameter 2)
Footprint was calculated using the track width times wheelbase. In case of two different track widths the average value was taken into account

Mass in running order (Parameter 3)

Regulation (EC) 443/2009 refers to the mass in running order which is defined in section 2.6 of Annex I to Directive 2007/46/EC and includes the driver and a defined amount of liquids and fuel.

The information given for the mass of the vehicles within the Polk database differs from country to country, brand to brand and model to model[69]. According to Polk there is no comprehensive definition of the column “kerbweight” [70]. Due to this it is most likely that a mixture of different masses have been taken into account. Due to this following method was applied in order to receive a mass which get as close as possible to the mass in running order. Assuming that the correct definition of kerb weight is mass of the vehicle in running order excluding the weight of the driver, then reference mass would be kerb weight + 100 kg. For cases where manufacturers already included 75 kg for the driver in their kerb weight value, reference mass would be kerb weight + 25 kg.

Since it is not known how many of the data sets use one or the other definition a value in between was chosen. Therefore 60kg was added to every entry in the column “kerb weight” forming a new column named mass in running order.

Number of seats (volume) + trunk volume (Parameter 5)

Instead of using the number of seats, a standard volume for a seat has been defined and the maximal interior volume of passenger was calculated.

Price (Parameter 6)

The Polk database comprised three currencies other than the Euro (British Pound, Polish zloty, Romanian leu). These currencies were converted by using the Euro reference exchange rates published by the European Central Bank[71].

8.2 Assessment of options

8.2.1 Assessment of necessary data availability

The feasibility to use other vehicle parameters than mass or footprint for the monitoring mechanism according to Regulation 443/2009/EC depends on a number of issues. Primarily these parameters must be addressed by European legislation which is already in force or will have to be in force when needed. Secondly the possibilities to access these parameters within the type approval and registration process at Member States level are crucial.

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68 When all theoretically foldable/removable seat can still be occupied by passengers.
69 Email by Polk, 03.11.2010.
70 It is presumed that the 90% fuel and liquids for the mass in running order and the 100kg to be used.
71 http://www.bundesbank.de/statistik/statistik_zeitreihen.en.php?func=list&open=devisen&tr=www_s332_b01012_1

In order to assess whether the vehicle parameters can be included in the Monitoring Mechanism in a robust way the availability of above parameters within Directive 2007/46/EC and Council Directive 1999/37/EC have been analysed as they are the base documents for the monitoring besides Regulation 443/2009/EC. Although the CO_2 monitoring has to be based upon the CoC it is for numerous Member States helpful if the respective parameter has to be mandatory recorded on the European registration documents for vehicles. The availability of mandatory recording due to this Directive could be an asset when the type approval directive does not require information on a parameter. As following table shows this is not the case and therefore the only the availability of the parameters present on the CoC is being analysed.

Table 60 Assessment of Directive 2007/46/EC and Council Directive 1999/37/EC.

Parameter	Directive 2007/46/EC (CoC for M1)	Council Directive 1999/37/EC
Wheelbase	+	(+)[72]
Axle track	+	-
Height	+	-
Mass in running order	+	+[73]
Payload	(+)[74]	(+)[75]
Number of seats	+	+
Trunk volume	-	-
Price	-	-

Wheelbase, axle track and mass in running order already have to be reported according to Regulation (EC) 443/2009 and are also available within the type approval Directive respectively the CoC which is the basis for the reporting. The use of wheelbase and axle track for an alternative utility parameter would therefore reduce the effort within the Member States. The parameters height and the number of seats are also available through the CoC and payload can be easily deduced from the mass in running order and the maximum mass. Only trunk volume and the price of a vehicle are not available within the CoC for M1[76].
While it is thinkable that the technical parameter of trunk volume could be made part of the CoC in the future, this would most likely require thorough changes within all Member States. The same is true to the parameter price which has in addition the difficulty that it changes very quickly in dependence from economic developments and is also subjective, which makes it difficult to operationalise for a monitoring scheme.

Based on this assessment the following parameters seem reasonable candidates for a utility parameter

- Wheelbase
- Axle track
- Height
- Mass in running order
- Payload
- Number of seats

8.2.2 Statistical assessment

Within this task the relationship between the respective utility parameter and the CO_2 value is being assessed.
For the calculation of the respective average only those rows have been taken into account which comprised the desired information. The example featured below could for example not be used for the calculations of parameters involving the mass related parameters as the information about the mass in running order (resp. kerbweight) and the payload is missing. For all other parameters the

[72] Optional for the MS.
[73] Mass of the vehicle in service with bodywork, and with coupling device in the case of a towing vehicle in service from any category other than M 1.
[74] Computable as the mass of the vehicle in running order and the technically permissible maximum laden mass are present in the CoC.
[75] Possibly computable if the mass of the vehicle in running order is present in the registration documents.
[76] And also not required within the type approval documentation of an M1 vehcile.

information is available and was be used. Due to this the number of vehicles upon the calculation is based changes for each parameter.

Table 61 Example of an incomplete data set.

No	Carbon emission	Height	Mass in running order	Number of seats	Payload	Wheelbase	Ø Price 1/2009-12/2009	No of registrations	Track width front	Track width rear	Trunk-Volume	Price (Euro)
26	109	1465	-1	4	-1	2340	11650	476	1415	1405	712	11650

The following table shows that the parameter mass has a closest relationship with the CO_2 value, closely followed by footprint & mass in running order (normalised) and price. The graphical equivalence for the significance of the regressions for all parameters can be found in the Excel file submitted to the Commission.

Table 62 Relationship of the chosen parameter with the CO_2 value.

Parameter no.	**linear regression (y= carbon emission)**	**registrations**	**R² (registration weighted)**
	y=ax+b		
3	x = mass in running order	10137144	0,497
8	x = normalised footprint + mass in running order	9983603	0,462
6	x = Price (Euro)	10922232	0,447
2	x = footprint * height	10519775	0,382
1	x = wheelbase	10887735	0,305
9	x= normalised (payload+number of seats+trunk volume+mass+footprint)		0,259
4	x = payload	9641401	0,141
7	x = normalised sum of payload and number of seats (quantity) +trunk volume	9253732	0,123
5	x= normalised number of seats (quantity) + trunk volume	10453958	0,094
5a	x= number of seats (volume) + trunk volume	10453958	0,059

Whether R^2 is a decisive criterion for assessing alternative utility parameters depends on the definition of utility. In practice numerous and also very individual criteria define the utility of a vehicle for a consumer. In practice also socio-economic criteria are taken into account in order to define the potential or actual utility of a vehicle to its future or current owner. Such criteria are for example:

- the reputation of a vehicle or a manufacturer,
- the design of a vehicle,
- the lifestyle of the consumer,
- parking possibilities at the place of residence/working place,
- the effectiveness of the public transport at the place of residence.
- the attitude towards individual and public transport and travelling in general etc.

These criteria are hard or impossible to incorporate into a utility function and the European type approval directive currently defines the function/utility of a car based on its (theoretical) usage pattern which is reflected by their technical design. They are either designed or constructed for the carriage of passenger or for the carriage of goods. In real life every vehicle is constructed to transport both just with different emphasis. One could argue that with regard to utility and CO_2 value that a vehicle has a high utility if it transports numerous passengers and goods at the same time while having a low CO_2 value and leaving out other utilities like the speed, comfort, safety of transportation or the ones mentioned above. When defining utility only based maximum transporting capacity (of passengers and luggage) and having the lowest possible CO_2 values then the relationship between the different parameters expressed by R^2 is of lower importance. Such an approach might nevertheless thwart the explicit wish of the EU to incorporate the “diversity of European automobile manufacturers and avoid any unjustified distortion of competition between them”[77]. Ultimately this is a political decision which can not be taken here.

[77] Regulation (EC) 443/2009 preamble no. 10.

If R^2 should be the decisive criteria the sequence of the most suitable parameters is being dictated by the table above. Taking into account the analysis in sections 8.2.2 and 7.3.2, the following top three parameters remain as reasonable candidates for a utility parameter:

- Mass in running order
- Footprint and mass in running order
- Footprint and Height

8.2.3 Impact onto selected manufacturers

In order to assess the impact of the different parameters, they have been applied upon following manufacturers.

Table 63 Selected manufacturers.

Manufacturer	**incl. makes/models**
VW	
Ford	
Fiat	Lancia, Alfa Romeo
Renault	
Opel	
Peugeot	
Citroen	
BMW	Mini
Mercedes	Smart
Toyota	Lexus
Audi	
Skoda	
Nissan	
SEAT	
Hyundai	
KIA	
DACIA	
DAIHATSU	
Vauxhall	
Daewoo	Chevrolets having as model group: GM: Captiva/Equinox/Vue Gr., GM: Lacetti/Excelle/Nubira Gr., GM: Magnus/Leganza Gr., GM: Matiz/Spark Gr., GM: Rezzo/Tacuma Gr.
GMC	Chevrolets having as model group GM: Alero/G6 Gr., GM: Chevrolet Corvette Gr., GM: Chevrolet HHR Gr., GM: Cobalt/G4/Sunfire Gr., GM: Geo Prizm/Nova Gr., GM: Impala/La Crosse/Lumina Gr, GM: Trailblazer/Colorado/Envoy, GM: Venture/Trans Sport Gr., GM: Yukon/Blazer Group, GM: G3/Aveo Gr
PORSCHE	

The criteria for selecting those manufacturers were discussed among TNO, Ökopol and the Commission.

The current distribution of the manufacturer based on their average CO_2 emission, average value per parameter and their number of registration has been calculated for each of the above manufacturer and for each of the parameters.

- The graphical equivalence and all related calculations of the current distribution can be found in the Excel file submitted to the Commission. The respective graphs for the parameters selected in section 8.2.2 are shown below.

Mass in running order

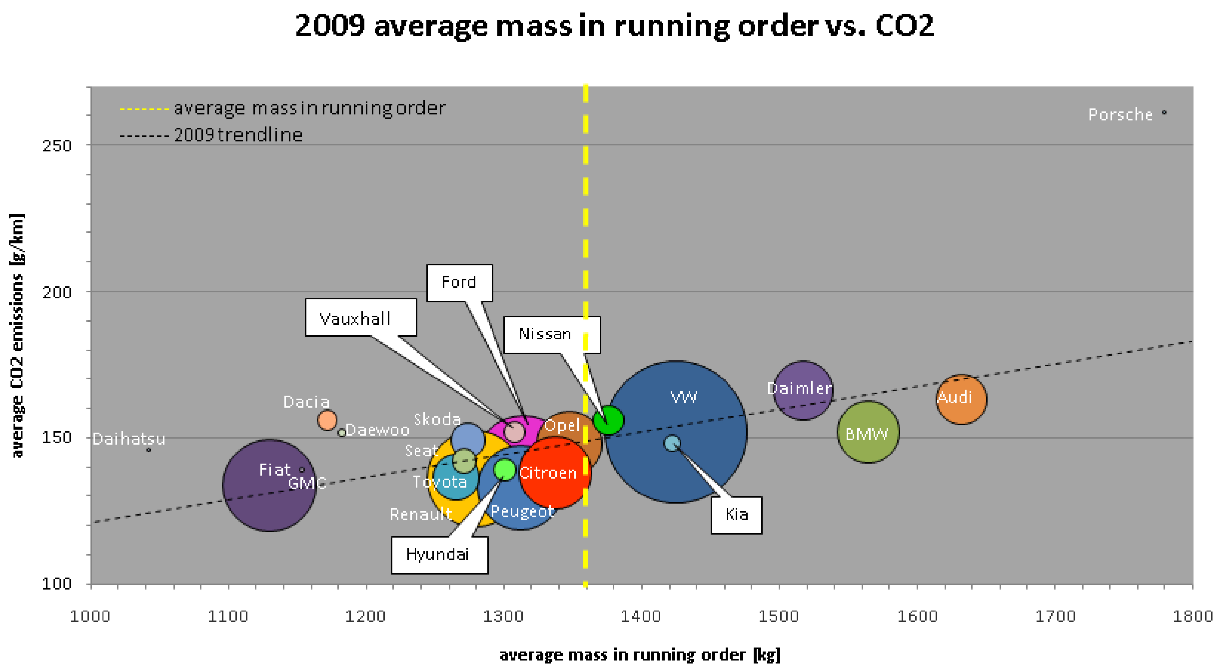

Figure 43 Relationship of the chosen parameter with the CO_2 value.

Footprint and Height

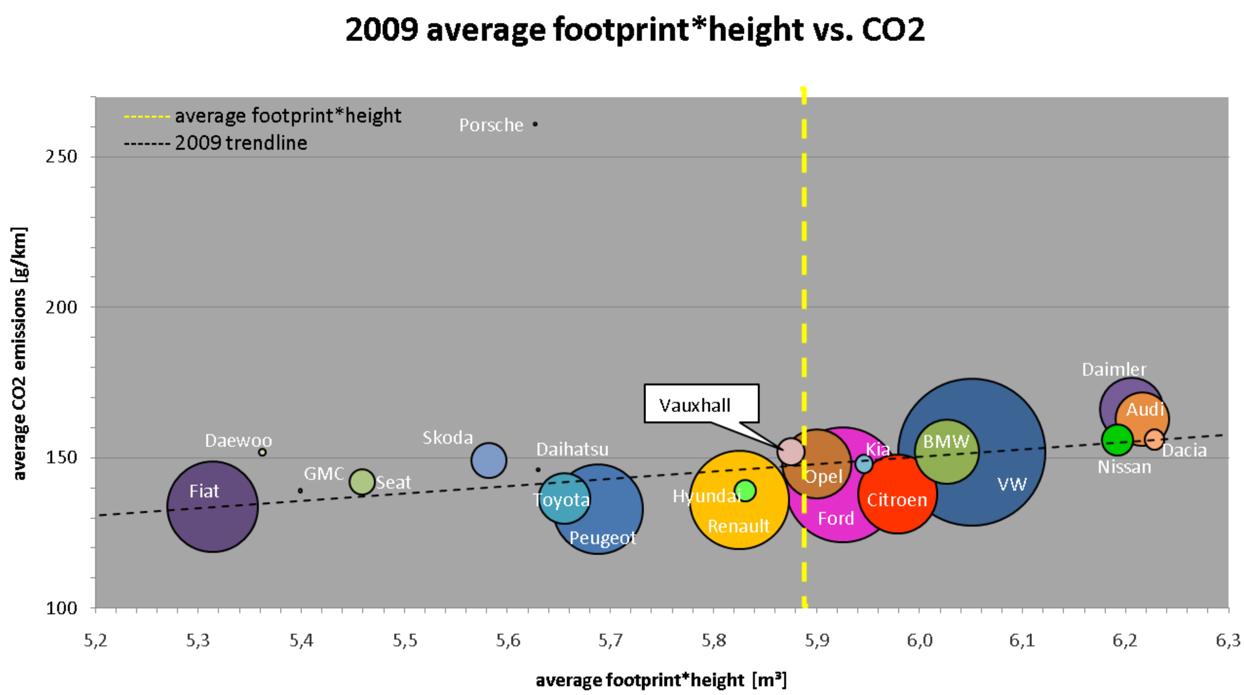

Figure 44 Relationship of the chosen parameter with the CO_2 value.

Footprint and mass in running order

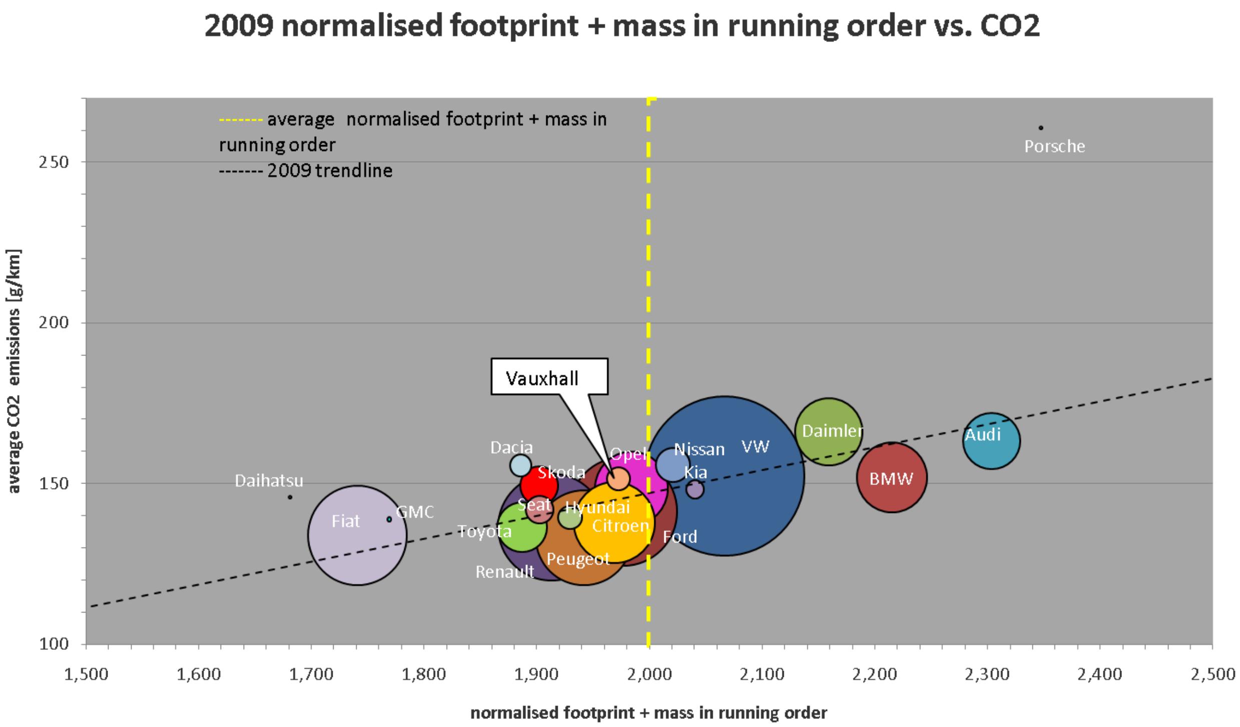

Figure 45 Relationship of the chosen parameter with the CO_2 value.

8.3 Selection of manufacturers - criteria

This section explains how the OEMs were selected for the analysis of the utility parameter. This was necessary in order to reduce the effort as ~ 180 manufacturers market their vehicles within the European Union while vehicles from only 16 companies/manufacturers are responsible for 98% of all registrations within the EU [Ökopol 2007][78]
The criteria for selecting those manufacturers where discussed among TNO, Ökopol and the Commission and are being shown below:

Criterion 1: Total number of registrations in the Polk database

With this criterion the top 12 manufacturers where chosen, namely:

- VW
- Ford
- Fiat
- Renault
- Peugeot
- Citroen
- Opel
- Toyota
- Mercedes
- Audi
- BMW
- Skoda

Criterion 2: Manufacturers owned/associated with manufacturers chosen by criterion 1:

- Seat
- Vauxhall
- Dacia
- Chevrolet
- Porsche
- Daihatsu

The “manufacturer” Chevrolet is in fact not a manufacturer but a make of General Motors and GM Daewoo. The only possible distinction in order to assign the right proportion of makes being

[78] Ökopol 2007, Schilling S., Gruhlke, A, Sander, K., Service contract on the implementation of Decision 1753/2000/EC Reporting Period 2006 Final Report December 2007.

produced by GM Daewoo resp. General Motors is a distinction by model name. But even this assignment can be flawed as it is not always clear which models are being produced by which manufacturer. For the time being following assignment has been chosen:

GMC: GM: Alero/G6 Gr., GM: Chevrolet Corvette Gr., GM: Chevrolet HHR Gr., GM: Cobalt/G4/Sunfire Gr., GM: Geo Prizm/Nova Gr., GM: Impala/La Crosse/Lumina Gr, GM: Trailblazer/Colorado/Envoy, GM: Venture/Trans Sport Gr., GM: Yukon/Blazer Group, GM: G3/Aveo Gr[79]

GM Daewoo: GM: Captiva/Equinox/Vue Gr., GM: Lacetti/Excelle/Nubira Gr., GM: Magnus/Leganza Gr., GM: Matiz/Spark Gr., GM: Rezzo/Tacuma Gr.

Criterion 3: Makes of manufacturers chosen by criterion 1

Some of the names used for the respective row “manufacturers” within the Polk database are not manufacturers according the type approval legislation but rather makes. Therefore these makes had also to be counted towards the manufacturers chosen under criterion 1.

- Mini
- Lancia
- Alfa Romeo
- Smart
- Lexus

8.4 Converting seat into occupied volume

In section 8.2.2 the advantage and disadvantages of defining the utility based on the maximum transporting capacity are discussed. The following section discusses available definitions for seats and provides a possibility to calculate the transporting capacity of a vehicle by converting the amount of seats available within a car into a volume. This is done in order to add the volume of the trunk and to get an approximation of the maximum transporting capacity of vehicles (of passengers and luggage) since M1 vehicles can have up to nine seating positions and also a large variety of trunk volumes.

8.4.1 Type approval Directive[80]

Currently seat resp. seating positions are being defined in the Type approval Directive 2007/46/EC as

- ‘seating position’ shall be regarded as existing if the vehicle is provided with ‘accessible’ seat anchorages;
- ‘accessible’ shall mean those anchorages, which can be used“ (Annex II C.1 i, page 83, Type approval directive)
- The number of seats is indicated in the CoC in Annex IX, Part 1, entry 42.1 of the Type approval Directive
- Annex II is currently being revised and it is likely that the definition of seat or seating position will be changed in the course of this revision.

8.4.2 Dimensions of a seating position

8.4.3 Hybrid III dummy

The Hybrid III dummy is used for the simulation of the behavior and potential injuries of a human in a passenger car involved into a car accident. Their dimensions are therefore standardized and reflect among others the body dimensions of the

- average car driver differentiated by gender,
- passenger differentiated also by age

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[79] Due to information received later it is quite likely that this model belongs to GM Daewoo instead of General Motors. The data has not been updated accordingly.

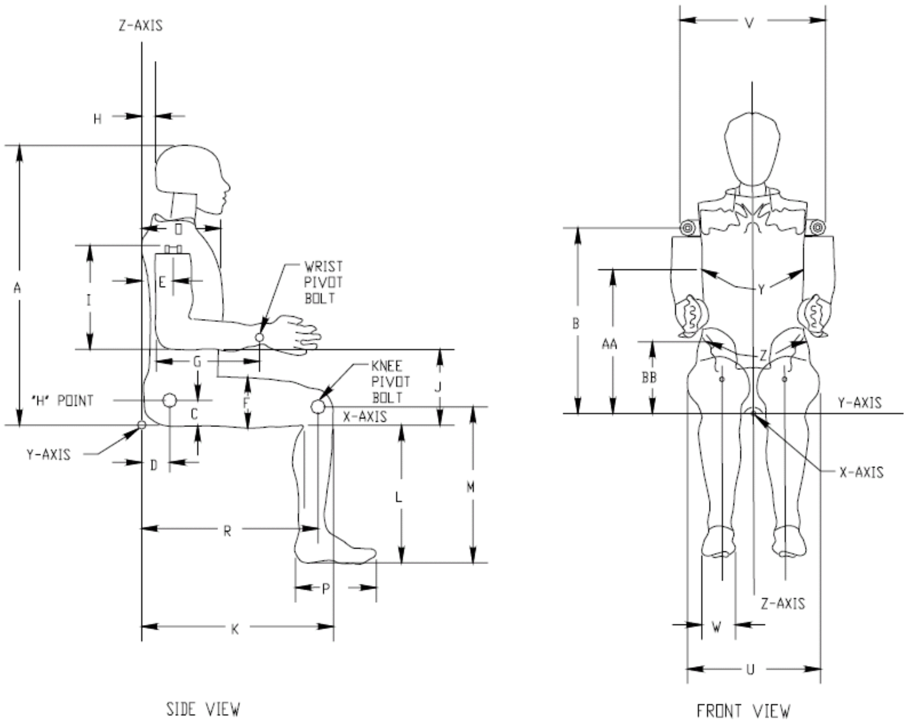
[80] DIRECTIVE 2007/46/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive) (Text with EEA relevance) (OJ L 263, 9.10.2007, p. 1).

The Hybrid III dummy 50th male is mentioned in the frontal impact regulation (ECE R94) and also in the EuroNCAP[81] test procedures. Due to this the use of this is legally required in order to be able to market a car in the European Union[82].

According to the German Federal Highway Research Institute's (BAST[83]) 2010 all body dimension of the Hybrid III Dummy series stem from the 1970s and are therefore outdated. Due to this the car industry uses different data which is not publicly available.
Due to the fact that the 50th percentile adult male Hybrid III Dummy is already too small in order to represent the average adult male European and because task 2.3 requires to know the volume of a standard seat and not of the body for which it is reserved, the 95th percentile adult male Hybrid III Dummy is being taken as a basis for calculating the seating space per seat/seating position for the front seats. The Hybrid III 95th male and the Hybrid III 5th female dummy are research dummies which not legally requested to be used by European legislation.

The 95th percentile adult male is taller than 95% of the expected male car drivers and has the following dimensions.

81 European New Car Assessment Programme assessing the safety of vehicles.
82 In addition the EuroSID dummy (50th male) is mentioned in the side impact regulation (ECE R95) as well as in the EuroNCAP testprocedures [TNO pers. Comm. November 2011].
83 Bundesanstalt für Straßenwesen.



SYMBOL	EXTERNAL DIMENSIONS	SPEC. in.	TOL. in.
A	Total Sitting Height	36.20	0.6
B	Shoulder Pivot Height	21.10	0.6
C	Hip Pivot Height (Set up dimension)	4.00	0.3
D	Hip Pivot from Backline (Set up dimension)	6.10	0.2
E	Shoulder Pivot from Backline without Jacket	3.60	0.2
F	Thigh Clearance at the highest point of the thigh flesh	6.60	0.3
G	Back of Elbow to Wrist Pivot	12.20	0.3
H	Head Back From Backline (set up dimension)	3.50	0.1
I	Top of the shoulder yoke to elbow length	14.30	0.4
J	Elbow Rest Height	8.40	0.4
K	Backline to knee length	25.50	0.5
L	Bottom of seating surface to bottom of foot	18.50	0.5
M	Knee Pivot Height	21.00	0.5
O	Chest Depth without Jacket	9.70	0.3
P	Foot Length	10.40	0.3
R	Backline to knee pivot length	22.80	0.5
U	Hip Breadth at H Point	15.90	0.4
V	Shoulder Breadth	18.70	0.4
W	Foot Breadth	3.90	0.3

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Figure 46 Caption from the User Manual Hybrid III.

In order to define a volume of a seat only its height, width and breadth is necessary. Those dimensions are taken into account as follows:

Table 64 Seat dimensions according to 95th male.

95 th Male					
			in inch		in cm/cm²
		Dimensions	Tolerance	Sum	
Height of lower body dimensions					
L	Bottom of seating surface to bottom of foot	18,5	0,5	19	48,26
F	Thigh clearance at the highest point of the thigh flesh	6,6	0,3	6,9	
L + F				25,9	65,786
Width of lower body dimensions					
K	Backline to knee length	25,5	0,5	26	66,04
Volume of the lower seat & body dimensions (incl. seat pad and anchorages)					
(L+F)*K*V				12861,94	210769,434
Height of upper body dimensions					
A	Total sitting height	36,2	0,6	36,8	
F	Thigh clearance at the highest point of the thigh flesh	6,6	0,3	6,9	
A-F	Thigh to top of the head			29,9	75,946
Width of upper body dimensions					
H	Head back from Backline	3,5	0,1	3,6	
G	Back from elbow to wrist	12,2	0,3	12,5	
st (own estimate)	Seatback thickness				10
H + G				16,1	40,894
H + G + st					50,894
Breadth for upper and lower body dimensions					
V	Shoulder breadth	18,7	0,4	19,1	48,514
Volume of the upper body dimensions				9194,549	187516,105
(A-F)*(H+G+st)*V					
Volume of full body/resp. seat				**in inch³**	**in cm³**
[(L+J)*K*V]+[(A-F)*(H+G+st)*V]				22.056	398.286

In order to take into account that the dimension in the back seats are somewhat more limited in most passenger cars, the maximal available seat within a given car where populated with different dummies. The volume calculation of the 50th percentile male and 5th percentile female has been made according to the example calculation of the 95th percentile male Hybrid III dummy.

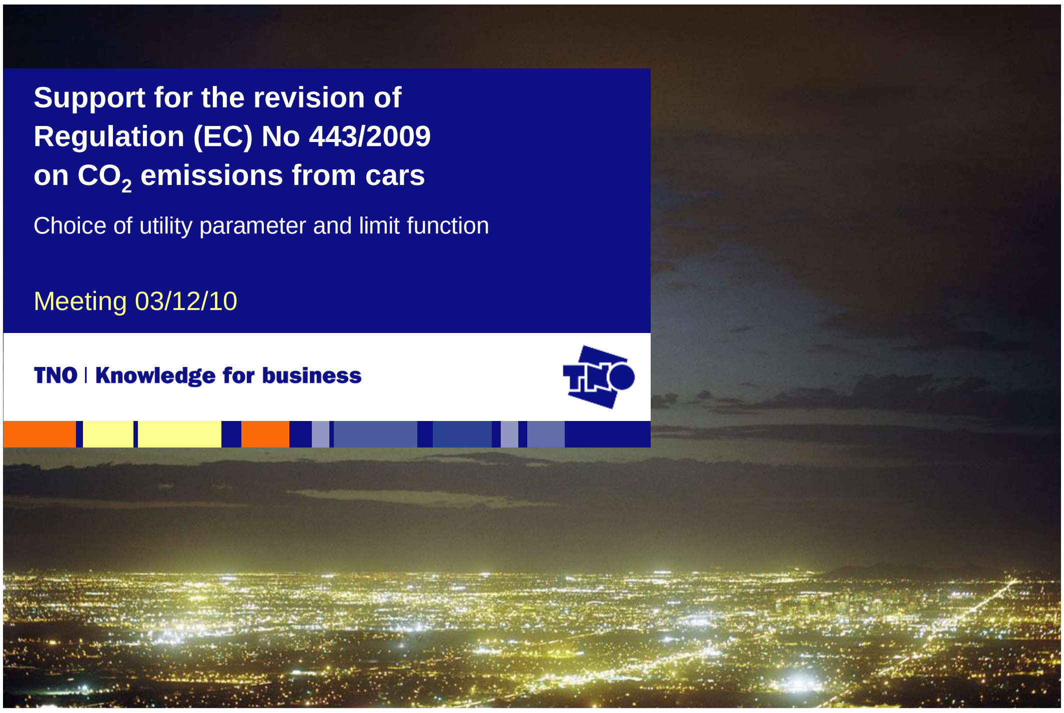
Table 65 Volume calculation for 95th and 50th male and 5th percentile female.

Number of seats	**Number of Dummies**			**Volume calculation**
	95th percentile male	50th percentile male	5th percentile female	**cm³**
2	2	0	0	796.571
4	2	2	0	1.407.545
5	2	2	1	1.608.670
6	2	2	2	1.809.795
7	2	2	3	2.010.920
8	2	3	3	2.316.408
9	3	3	3	2.714.693

9 Preliminary evaluation of modalities for reaching the 95 gCO_2/km target

This subtask was replaced with a meeting with the Commission on 3/12/2010 during which possibilities for modalities were discussed. The corresponding presentation “Choice of utility parameter and limit function” can be found below in sections 9.1 and 9.2.

9.1 Evaluation of utility parameters – presentation 03/12/2010



Goal of this meeting

- Present results of analysis on utility parameters
  - Correlation of different utility parameters with CO_2
  - "Bubble graphs" with relative positions of OEMs
  - Qualitative evaluation, incl.:
    - measurability
    - scope for gaming
    - perverse incentives
    - promotor / inhibitor of lower CO_2 emissions
- Discuss options for limit curve shape
  - Without / with "floor" and/or "ceiling"?
  - Linear or non-linear?

Utility parameters considered

- reference mass
- pan area
- footprint
- wheelbase
- footprint x height
- combination of # of seats and trunk space
- payload
- price

3

Reference mass

(mass in running order = kerb weight + 60 kg)

\+ Easily / objectively measured
\+ Accepted by industry
  - continuation of present system
  - (part) of industry seems in favour of using mass also for 95 g/km

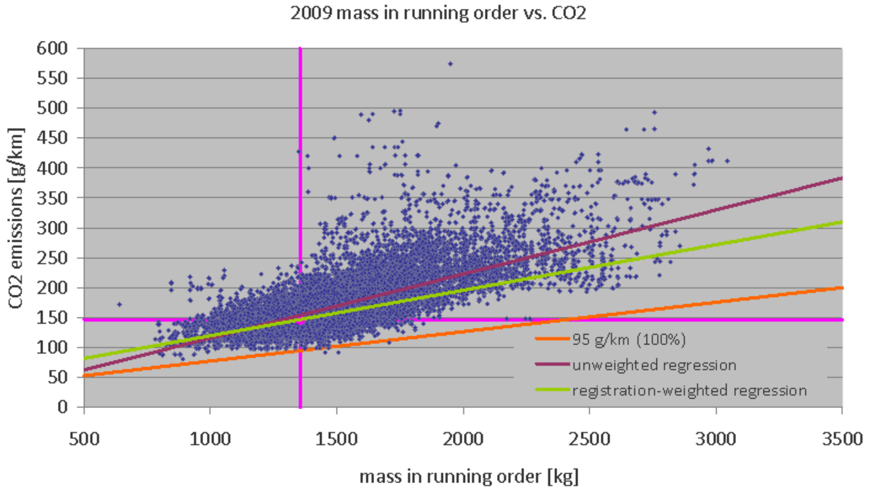
\+ Good correlation with CO_2
o …
\- Not a measure of utility
\- Possibilities for gaming depend on slope of limit function
  - 60% slope for 95 g/km target may lead to difficulty in meeting target for manufacturers of large cars (larger share of total reduction potential used)

\- Easy options for gaming: “Brick in the boot”
\- Makes weight reduction as CO_2 reduction measure less attractive
  - unless limit function is continually updated on basis of changing average mass
  - but effect of applying weight reduction measures may be masked by autonomous mass increase…

4

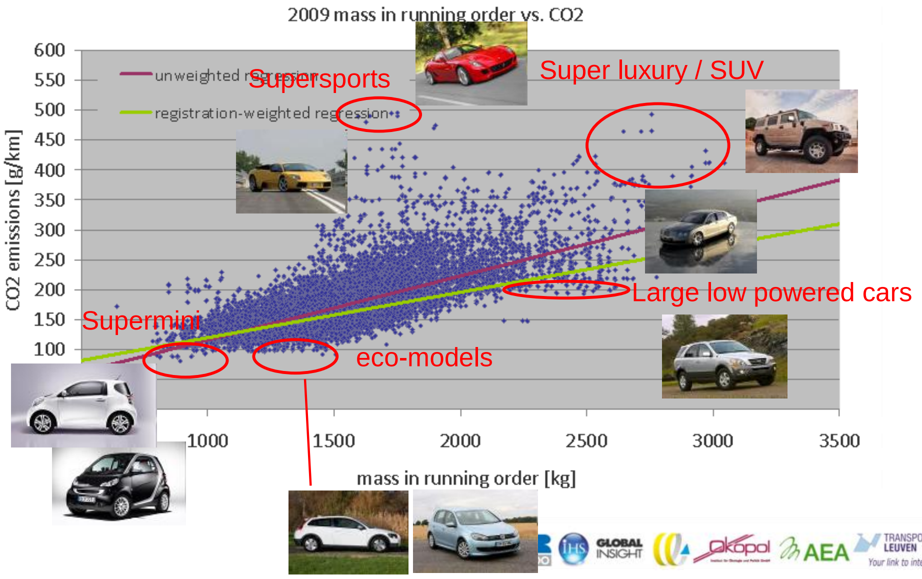
Reference mass
(mass in running order = kerb weight + 60 kg)

$R^2 = 0.497$

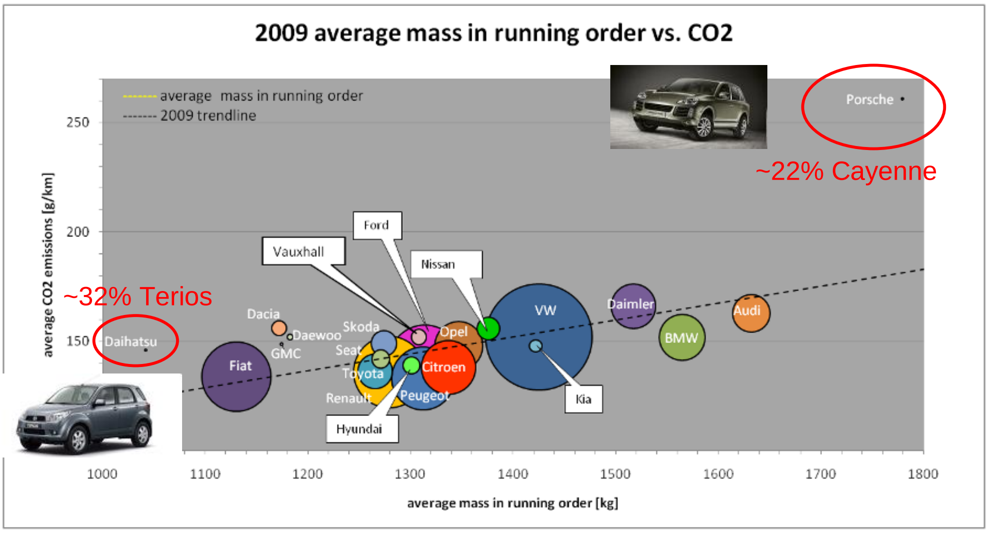


Reference mass
(mass in running order = kerb weight + 60 kg)

$R^2 = 0.497$



Reference mass
(mass in running order = kerb weight + 60 kg)



Pan area

+ Easily / objectively measured
  - may require some rules on dealing with protrusions (mirrors, etc.)
+ Somewhat better measure of true utility than mass
+ Good correlation with CO_2
o …
- Gaming is relatively easy without affecting structural design of vehicle and without consequences for mass and vehicle CO_2 emissions

8

Footprint
(wheelbase x track width)

+ Easily / objectively measured
+ Better proxy for utility than mass
  - See # of seats + trunk volume: true utility may not provide a solid basis for CO_2 differentation
+ Used in US legislation
+ Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions
  - Footprint is not necessarily better than weight with respect to avoiding all possibilities of perverse incentives, but possibilities of cheap gaming options are much reduced.
  - Possible impact of changing footprint on CO_2 is weaker than for mass so does not provide better threshold against gaming or perverse incentives than mass.
  - But the scale of the perverse incentives appears much less as utility can only be increased by effectively increasing the size of the vehicle, with all the cost and complexity that that entails, and resulting in what is essentially a different vehicle.
  - Also, incremental increases in footprint result in proportionately smaller increases in CO_2 emissions than increases in weight, so the adverse environmental impact is less.
+ Good correlation with CO_2

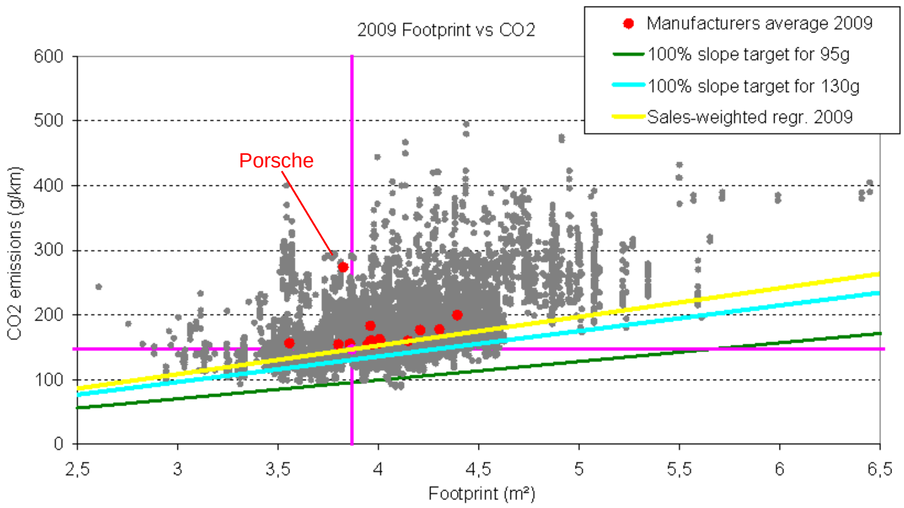
o …

- Relatively tough on compact / high cars (e.g. MPVs)
- May promote tendency towards larger cars
  - This can be compensated by adjusting limit function for growth in average footprint.

9

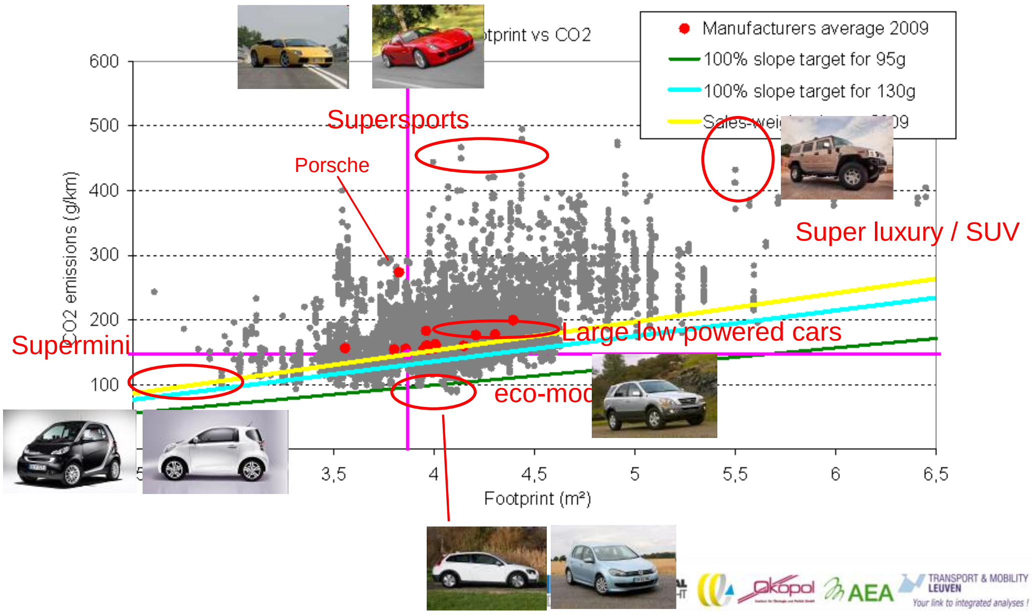
Footprint
(wheelbase x track width)

$R^2 = 0.320$

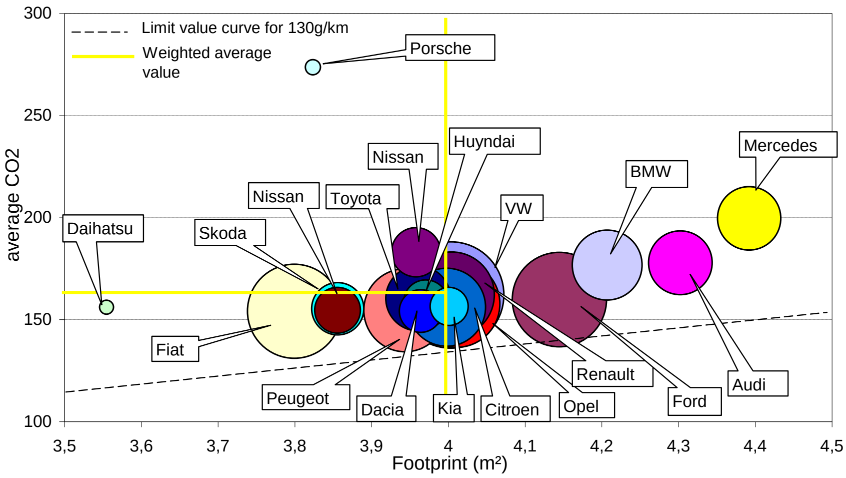


Footprint
(wheelbase x track width)

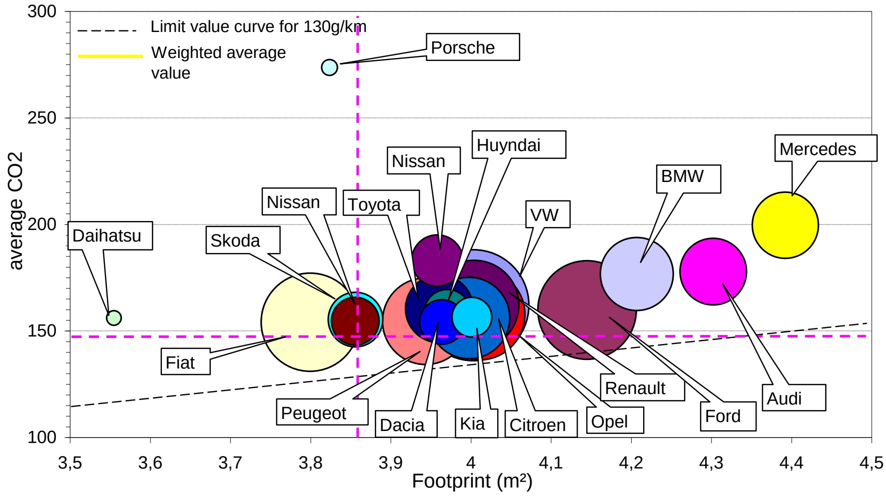
$R^2 = 0.320$



Footprint
(wheelbase x track width)



Footprint
(wheelbase x track width)



Wheelbase

- \+ Easily / objectively measured
- \+ Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions
- \+ Good correlation with CO_2
- o …
- \- Always a less good proxy for utility than footprint

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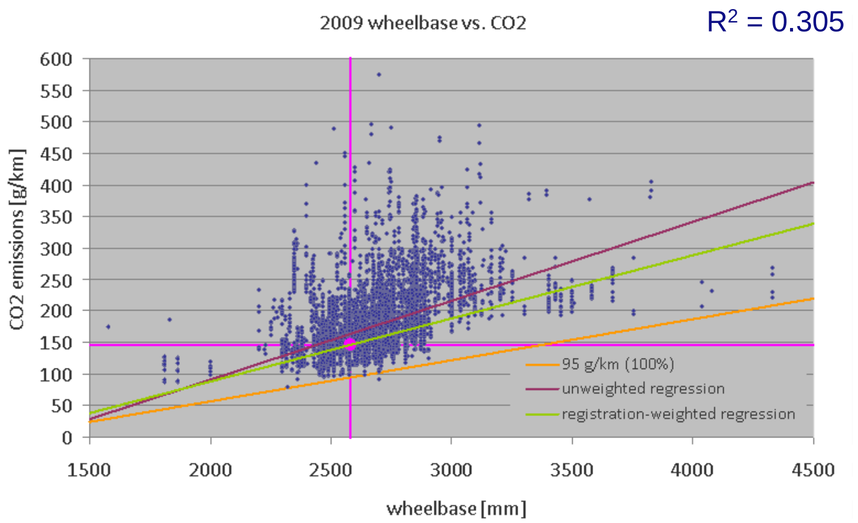
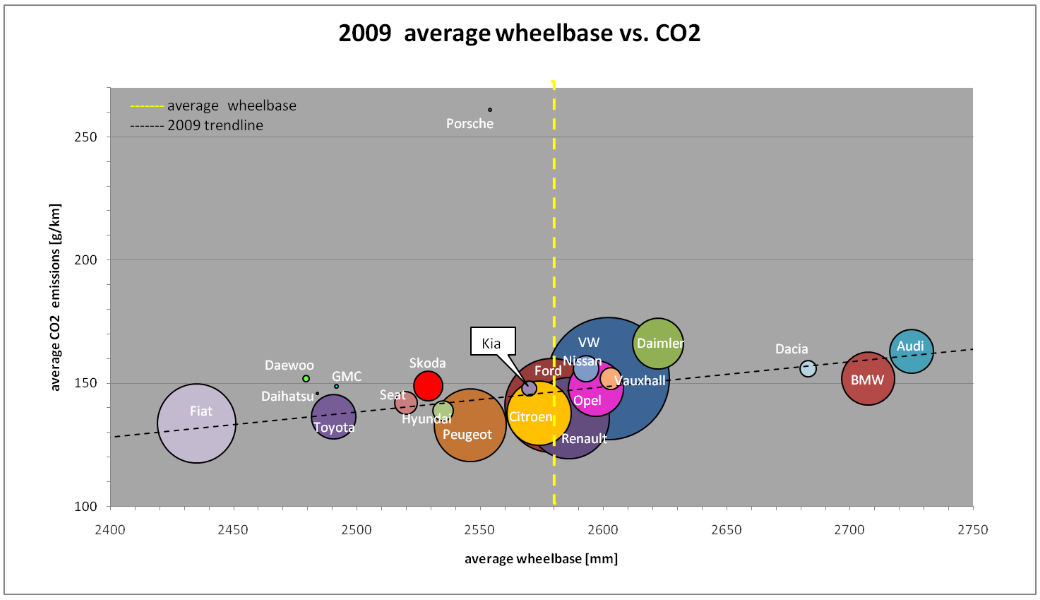
Wheelbase



Wheelbase

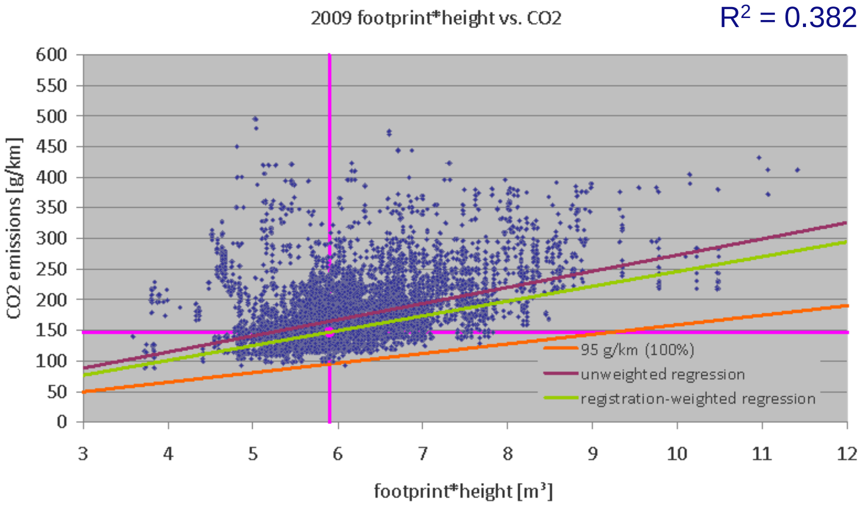


Footprint x height

- \+ Easily / objectively measured
  - provided definition is height is unambiguous
- \+ Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions
- \+ Good correlation with CO_2
- o …
- \- May promote tendency towards higher cars
  - bad for aerodynamics, but impact on NEDC is limited
  - this can be compensated by adjusting limit function for growth in average footprint

Footprint x height

$R^2 = 0.382$

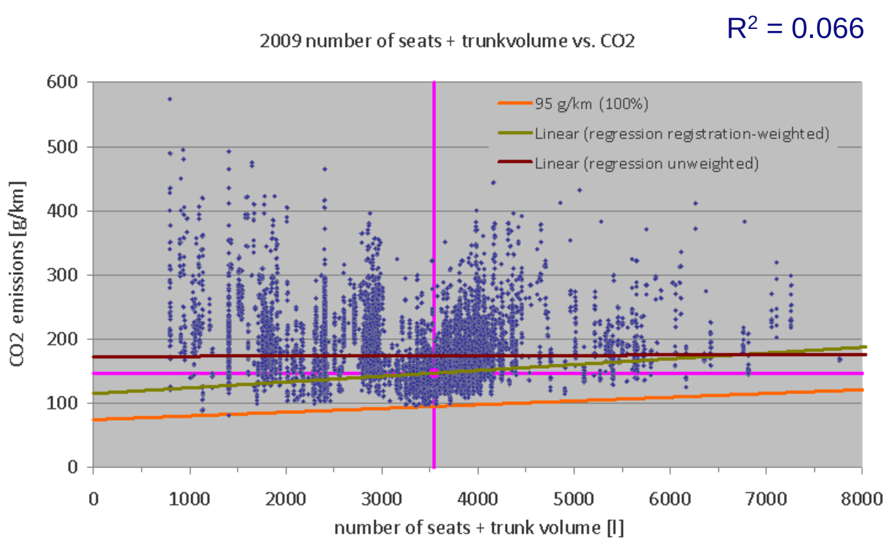


# of seats (expressed in volume) + trunk volume

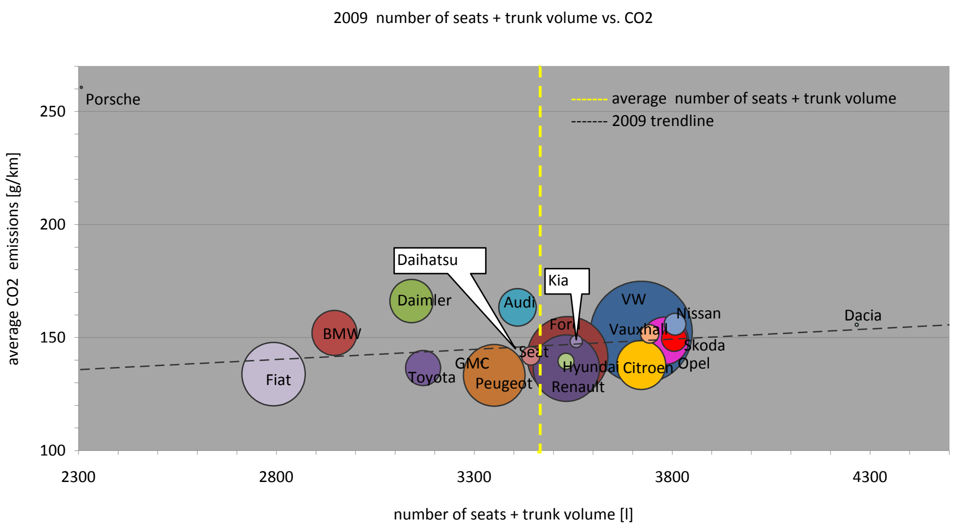
+ Very true utility parameter
+ This combined parameter could also be used for vans
o Possibilities for gaming depend on accuracy of assumed volume per seat
  - Whether or not increasing # of seats leads to more relaxed target depends on dimensions of car / seats compared to “average” car for which default value is defined
- Very poor correlation with CO_2
  - Increasing utility has limited impact on CO_2
  - Limit function based on fit leads to extremely stringent reduction goals for sports cars
- Based on assumption for default volume per seat that can be disputed

? Does expressing seats in volume solve the problem of defining what a seat is and possible problems with small seats, foldable or removable seats?

# of seats (expressed in volume) + trunk volume

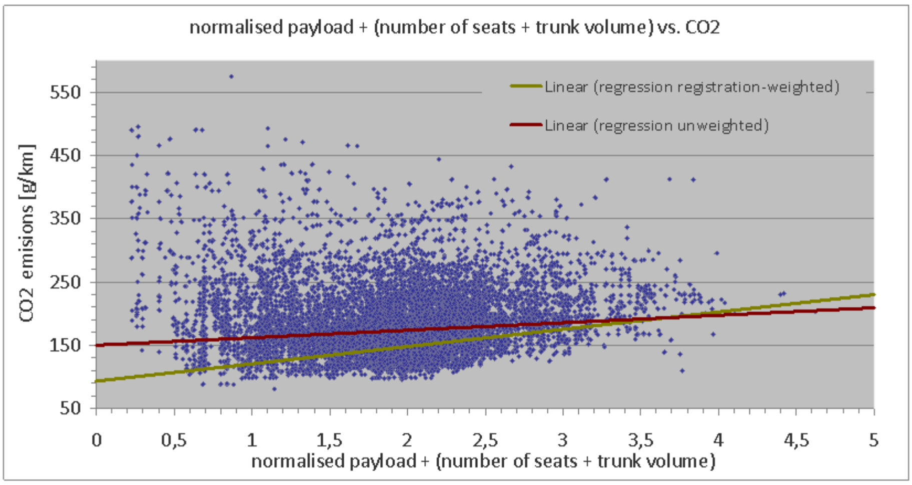


of seats (expressed in volume) + trunk volume



Normalised (payload + (# of seats + trunk volume))

$R^2 = 0.120$



Payload

+ More true utility parameter, although more for vans than for passenger cars
o …
- For vehicles with GVW < 3500 kg payload is not a measurable parameter, but a manufacturer-declared value
- For vehicles with GVW = 3500 kg payload is difference between max GVW and reference mass, so correlation with true transport function is limited
- Weak correlation with CO_2
  - Whatever correlation there is, seems leveraged by small number of vehicle models with high payload values

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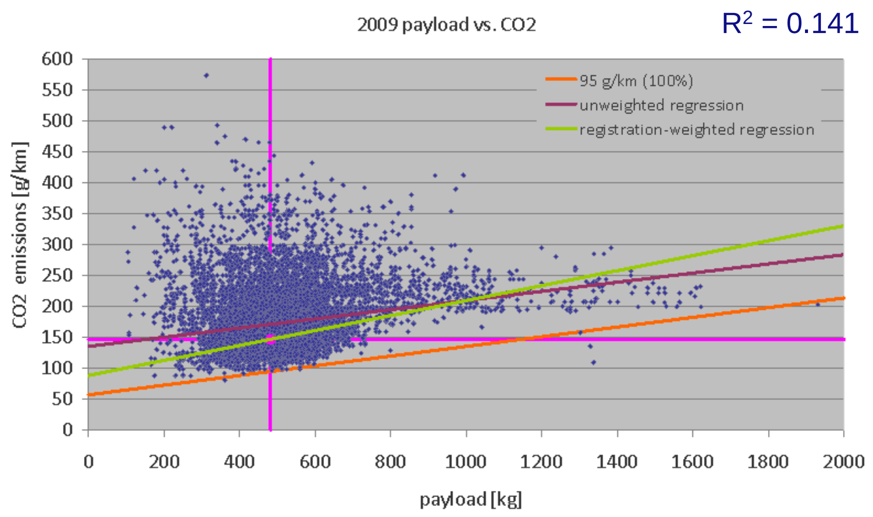
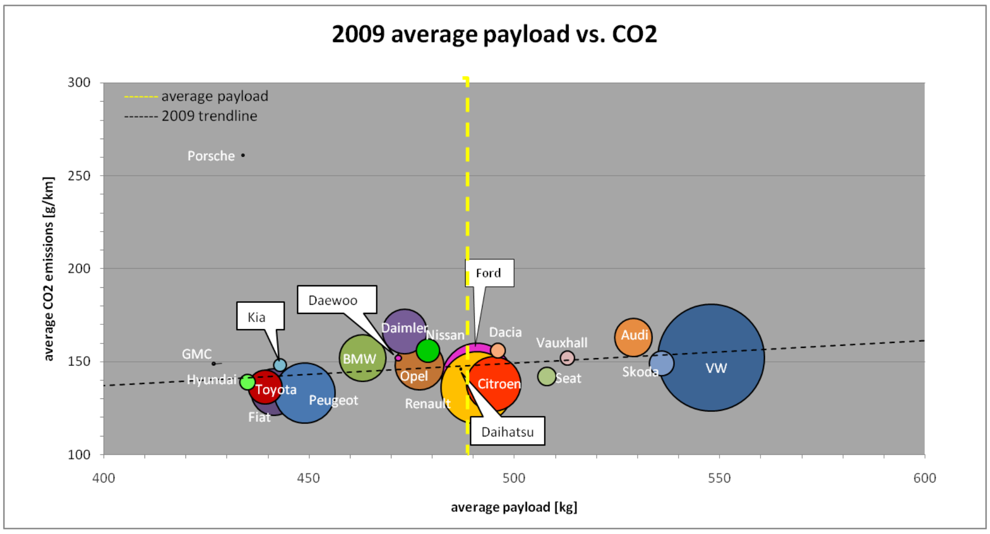
Payload



Payload



Price

+ Good correlation with CO_2
  - but largely due to strong leverage of limited number of very expensive cars

o …

- Not a measure of functional utility
- Very uneven distribution of vehicles around <U>
- Price is not a vehicle attribute that can be objectively measured or verified
  - Both retail price and base price excl. taxes differ per country
- Gives credit to performance (kW/ton ratio)
  - More performing variants of the same model are always more expensive
- Promotes gaming by adding expensive options to standard fitting of car / base model

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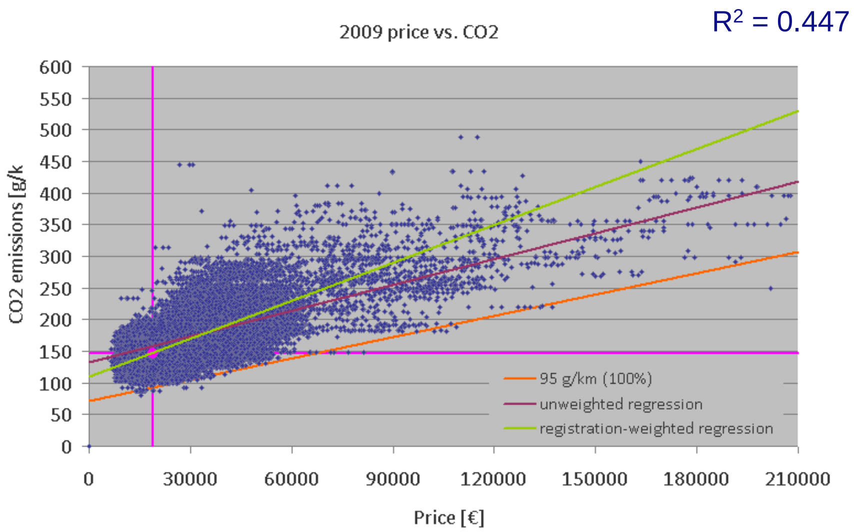
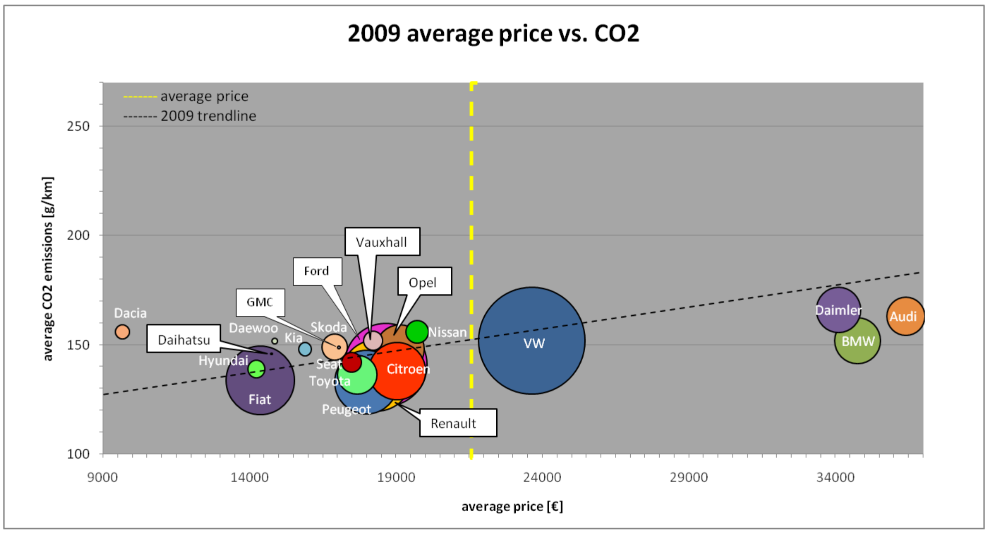
Price



R^2 = 0.447
2009 price vs. CO2
CO2 emissions [g/k
Price [€]
600
550
500
450
400
350
300
250
200
150
100
50
0
0
30000
60000
90000
120000
150000
180000
210000
95 g/km (100%)
unweighted regression
registration-weighted regression

Price



2009 average price vs. CO2
average price
2009 trendline
average CO2 emissions [g/km]
average price [€]
250
200
150
100
9000
14000
19000
24000
29000
34000
Dacia
Daihatsu
GMC
Daewoo
Kia
Skoda
Ford
Vauxhall
Opel
Nissan
Hyundai
Fiat
Seat
Toyota
Peugeot
Citroen
Renault
VW
Daimler
Audi
BMW

Short list of most attractive utility parameter candidates

- reference mass
  - continuation of existing scheme
  - main drawback: disincentive for applying weight reduction
- footprint
  - similar to US legislation
- footprint x height
  - proxy for interior volume
  - determinant of what makes a car big and heavy

9.2 Evaluation of options for limit functions – presentation 03/12/2010

Possible motivations for “floor” in limit function

- Flattening of cloud of (U, CO_2) points at low U
  - reference mass: strong flattening of lower envelope of data points
    - due to fact that manufacturers have already applied CO_2-reducing technologies but have no incentive to go below 100 g/km for ecomodels
  - pan area: ???
  - footprint: strong flattening of lower envelope of data points
    - same reason as for reference mass
  - wheelbase: flattening of lower envelope + some points with very low wheelbase value at CO_2 level of lower envelope
  - footprint * height: : flattening of lower envelope + some points with very low wheelbase value at CO_2 level of lower envelope
  - payload: no / unclear
  - price: no flattening visible
- lowest CO_2 value technically attainable for small cars
  - This argument was used in US legislation.
  - This is not a limiting factor in EU situation. Lowest attainable value for average small car is much lower than 100% limit function for all cars in database.
- avoid undesired impact on safety from vehicle downsizing
  - This argument was used in US legislation for the case of footprint.
- political choice to limit the CO_2 reduction requirements for small cars

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Possible motivations for “ceiling” in limit function

- flattening of cloud of (U, CO_2) points at high U
  - reference mass: a hint of flattening mainly in lower envelope of data points
  - pan area: ???
  - footprint: some flattening
  - wheelbase: maybe, but values suggest that these are extended vehicles (limo’s)…
  - footprint * height: no
  - payload: no
  - price: somewhat
- political choice to
  - limit the maximum CO_2 emissions for which large vehicles get credited
  - reduce required reduction effort for medium and small cars
- compensation of impact of floor for small vehicles on limit function for medium size cars

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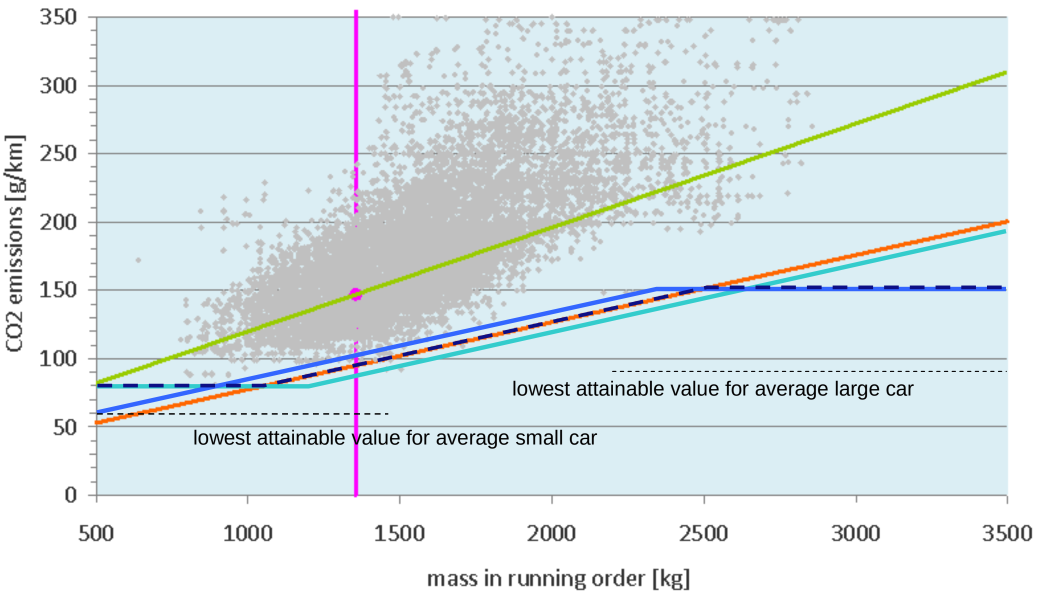
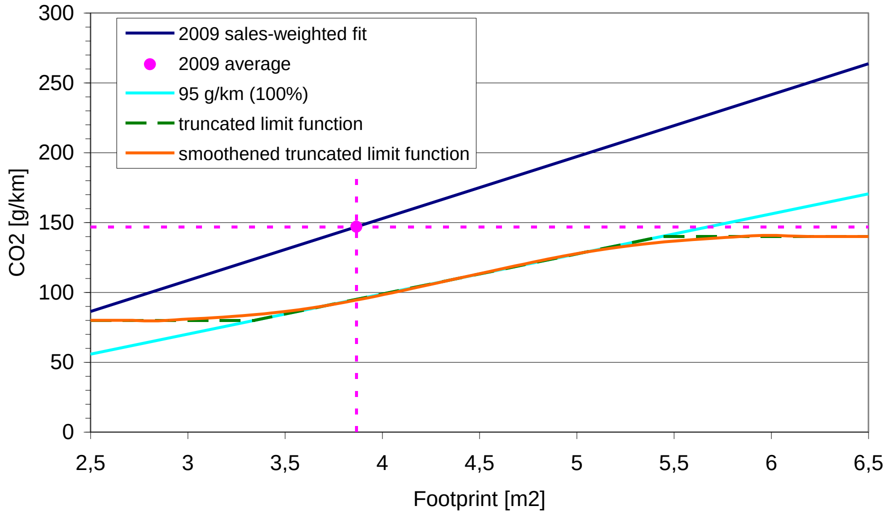
Floor & ceiling



Truncated linear or non-linear function?

- Arguments for moving from non-linear (“constrained logistic”) to truncated linear function in US legislation seem to be based on invalid arguments regarding:
  - overly steep middle part
  - overly fuel economy targets stringent for small footprint vehicles
  - greater incentive for manufacturers to upsize vehicles in order to reduce their compliance obligation

Linear segments or smoothened function?



Slope of limit function

- Slope < 100% can be used to reduce incentive for gaming
  - Need for that depends on utility parameter
- For the 130 g/km the 60% slope was also motivated by opinion that:
  - legislation should be tougher for large cars than for small ones
  - large cars have more “unnecessary” performance and features so that the scope for CO2 emission reduction is higher than just the potential of technical measures
- A < 100% slope can not be justified for 95 g/km anymore
  - 95 g/km target brings vehicles closer to end of cost curve
  - under 130 g/km already large cars will get closer to end of cost curve than small ones
- Need for lower slope is reduced by possibility to adjust target if average utility shifts between now and 2020

10 Average additional vehicle costs per manufacturer for manufacturer-based modalities

10.1 Introduction

In this chapter the possible modalities for a legislative approach to reduce CO_2 emissions from cars to an average level of 95 g/km in 2020 are analysed and discussed on the basis of a comparison of costs per vehicle and per manufacturer for meeting the target.

Since a study with a very similar methodology was performed by TNO in 2007 for a target of 130 g/km in 2012, the applied methodology is only described concisely. A more detailed explanation can be found in [Smokers, 2007]. Differences in methodology compared to [Smokers 2007] are mentioned explicitly.

10.2 Setting out the policy options

10.2.1 Generating the 'long list' of regulatory options

As identified in [Smokers 2007] the main elements or modalities for defining a CO_2 regulation for passenger cars are:

- Obligated or responsible entity;
- Target focus;
- Target type;
- Instrument/sanction;
- Choice of a utility parameter.

In close consultation with the Commission services the following options for defining the above-mentioned elements of have been selected as main candidates for the to modalities are to that define the 95 g/km for 2020. This report assessed the costs for compliance associated with these options and different variants of especially the target type and choice of utility parameter:

- ***Obligated or Responsible Entity:*** This refers to the legal entities to be placed under the primary obligation to take action to reduce passenger car CO_2 emissions, and to be responsible for ensuring that this takes place. In line with previous studies, e.g. [Smokers 2007], and with the legislation in place for the 130 g/km target in 2015 (Regulation (EC) No 443/2009), manufacturer groups are defined as obligated entities.

- ***Target Focus***: Again similar to previous studies and the existing legislation, the average CO_2 emission of the total EU sales of manufacturer groups is used as target focus.

- ***Target Type:*** The global target was already laid down in Regulation (EC) No 443/2009– a Community average of 95 g/km by 2020. For the implementation of this target at the level of individual manufacturer groups three types of utility-based limit functions have been considered:
  - linear sloped line targets;
  - linear sloped line targets with horizontal cut-offs at the upper or the lower end and
  - non-linear curves which approach horizontal cut-offs.

  Within all three variants, different slopes (and where possible cut-off levels) were analysed. Line targets including a slope, where a target varies according to some measure of a vehicle's 'utility', were deemed desirable as they allow some flexibility to give a larger allowance of CO_2 emissions to vehicles that offer greater utility than others. The choice of a utility function is, however, another issue – discussed below.

- ***Instruments and sanctions:*** The main sanction type considered is an excess premium of penalty per g/km of the manufacturer-specific target that has been exceeded.
  NOTE: In the cost assessment presented in this report such sanctions have not been taken into account.

- ***Utility Parameter:*** In order to determine an appropriate utility parameter, the following criteria were used: good/acceptable measure of a vehicle's 'utility'; preference for a continuously-variable function; availability of required data; understandable; minimising perverse effects; and not excluding technical options. Based on these criteria two main options were shortlisted, namely empty vehicle weight (or reference mass) in kg and footprint (vehicle track width x wheel base) in m^2. This latter option was not assessed in [Smokers 2007] and its suitability was therefore individually studied [TNO 2011] and found to be better than for instance pan area, which was studied in [Smokers 2007]. Both options (vehicle weight and footprint) were deemed to show a reasonably close correlation to CO_2 emissions. Weight has the obvious advantage of consistency with the present legislation for 2015, but may be less appropriate in the longer term as it reduces the potential of weight reduction as an option for contributing towards meeting the target.

10.3 Quantitative analysis of cost impacts

10.3.1 Introduction

Using an updated version of the model developed for [TNO 2006] and [TNO 2007], a wide range of regulatory options for implementing the 95 g/km legislation for passenger cars have been quantitatively assessed with respect to average additional costs per car for meeting the target and especially the distribution of required CO_2 reduction efforts and associated costs per vehicle over the various manufacturers / manufacturer groups selling cars in Europe and over the six market segments discerned in the model (small, medium and large vehicles running on petrol or diesel).

Assessed options

The following options of basic regulatory options have been modelled, on the basis described above:

- utility based limit function
  - applied to the sales weighted average in 2020 per manufacturer group
    - For each model sold by the manufacturer group the CO_2 emission limit is calculated based on the vehicle's utility value (see explanation further on). The target per manufacturer is then calculated as a sales-weighted average of the limit values per model.

As stated above, the suitability of three types of limit functions were tested (Annex H). This analysis showed that for reasonable levels for the floors and ceilings of non-linear limit functions do not have significant impacts. Since the non-linear curves ought to be based on the linear curves with cut-off, the same conclusions were drawn for the continuous limit functions with floors and ceilings. Conclusively, these types of limit functions proved to be interesting theoretical concepts, but they were not taken into account in the remainder of this study.

Application of a certain measure to the sales weighted average CO_2 emissions per manufacturer implies that manufacturers are allowed to perform internal averaging, i.e. the excess emission of one vehicle that emits more that the value allowed by the limit can be compensated by other vehicles that emit less than allowed if the limit were applied at the vehicle level. The model calculates the distribution of reductions per segment that yields the lowest overall costs for meeting the sales averaged target, in terms of additional manufacturer costs. This solution is characterised by equal marginal costs in all segments. Within each segment also internal averaging is included implicitly as all vehicles in the segment undergo CO_2 reduction up to the same level of marginal costs.

Baseline scenarios

In this report the costs for meeting the 2020 target are expressed relative to two different references:

- **A 2009 reference situation**: Costs in this case are the costs of additional technology applied between 2009 and 2020 for moving from the 2009 average to the 95 g/km target in 2020 (or the manufacturer specific target associated with the limit function defined for 2020).
- **A baseline scenario** in which it is assumed that the 130 g/km is maintained between 2015 and 2020. Additional costs for meeting 95 g/km are defined relative to the costs assessed for meeting 130 g/km in 2020 (on the basis of the utility-based limit function defined in Regulation (EC) No 443/2009) using the 2020 cost curves. Note: the costs calculated according to this baseline scenario are different from the costs calculated in previous studies for the 130 g/km target in 2015, since new cost curves were developed for this study (task 1.1.8).

In the remainder of this report, the second reference is handled before the first reference, since these outcomes represent the discrepancy between ‘business as usual’, i.e. a target of 130 g/km, and the target that was laid down for 2020, i.e. 95 g/km.

The petrol-diesel share in the new vehicle sales in 2020 is assumed equal to that in 2009, because according to [JD Power 2008] the diesel shares in Western and Eastern Europe will respectively be about 55% and 35% in 2015 and the current share is already close at approximately 45%.

Scenarios for autonomous mass increase (AMI)

As agreed upon with the European Commission, it is assumed in the current study that there will be no autonomous mass increase (AMI) between 2009 and 2020. This means that the costs for meeting the target do not have to be corrected for the costs of applying technology to compensate for increased CO_2 emissions resulting from increased vehicle mass between 2009 and 2020.

Baseline data for 2009

For 2009 the model contains data on vehicle sales, CO_2 emissions, weight and footprint per segment per manufacturer (group) that have been derived from a sales database purchased from Polk Marketing Systems. This EU5+2 database contains the above mentioned information for the five biggest European economies (France, Germany, Italy, Spain and the UK) and Romania and Hungary. In an additional task within the ‘Framework Contract No ENV.C.3./FRA/2009/0043’, the aquired EU5+2 database was compared to an EU27 database. From the comparison was deduced that using the EU 5+2 database would lead to very comparable results for almost all manufacturers with respect to the average mass, CO_2 emission and the resulting distance to target under the current legislation [TNO 2010].

Manufacturer groups, used for the assessment, have been based on the situation per January 1st, 2011. For each manufacturer group the 2009 sales of all brands belonging to that group are included in the sales averaged values of utility and CO_2 per segment.

A comparison between manufacturers with respect to average weight, average footprint, average CO_2 emissions and sales can be found in [TNO 2011].

Utility-based limit functions

Linear utility-based limit functions are expressed as: CO_2 limit = a U + b, with U the utility parameter. The slope a and y-axis intercept b can be varied provided that the following relation is fulfilled:

$$95 \text{ g/km} = a <U>_{2020} + b,$$

with $<U>_{2020}$ the average utility value of all new vehicles sold in Europe in 2020.

Variants with different slopes are defined relative to a “100% slope” base limit function. This “100% slope” limit function is constructed by firstly introducing a sales-weighted least squares fit through the CO_2 emission values of all 2009 vehicle models plotted as function of their respective utility values (Annex G). Hereafter this line is lowered to meet the average of 95 g/km in such a way that the relative reduction is equal for all utility values. This way the “100% slope” base limit function is defined as the limit function for which the burden of CO_2 reduction between 2009 and 2020 is evenly distributed over the range of utility values. Relative to this reference alternatively sloped limit functions can be defined. The labelling of these slopes is based on a percentage of the 100% slope.

The range of slope values used for the calculations presented in this chapter is indicated in Table 66.

Table 66 Utility based limit functions.

utility-based limit function (aU + b)	mass			footprint		
		a	*b*		*a*	*b*
least squares fit 2011		0.0762	43.9		45.3	-27.9
slope 60%	*60%*	0.0296	55.1	*60%*	17.6	27.2
slope 70%	*70%*	0.0346	48.4	*70%*	20.6	15.8
slope 80%	*80%*	0.0395	41.8	*80%*	23.5	4.5
slope 90%	*90%*	0.0444	35.1	*90%*	26.4	-6.8
slope 100%	*100%*	0.0494	28.5	*100%*	29.4	-18.1
slope 110%	*110%*	0.0543	21.8	*110%*	32.3	-29.4
slope 120%	*120%*	0.0592	15.2	*120%*	35.2	-40.7
slope 130%	*130%*	0.0642	8.5	*130%*	38.2	-52.0
slope 140%	*140%*	0.0691	1.9	*140%*	41.1	-63.3

Presentation of results

Besides in absolute manufacturer costs related to achieving the 2020 target, the cost impacts are also expressed as the relative retail price increase per vehicle for both situations. The relative retail price increase is calculated by multiplying the additional manufacturer costs by a factor of 1.44, according to [Smokers 2006], and dividing that by the average retail price calculated from the database.

Caveats

- Results for individual manufacturer groups as presented here, should not be interpreted as predictions of the costs in 2020 for that manufacturer group but should rather be seen as an estimate of the costs for a manufacturer group with characteristics (in terms of sales distributions and CO_2 emissions per vehicle per segment) similar to that manufacturer group.
- All results per segment are calculated under the assumption that manufacturers apply direct and full cost pass through of the costs for CO_2 reduction measures to the retail price of the vehicles in which these measures are applied. In reality manufacturers obviously have the freedom to distribute the overall costs for meeting the 2020 target in a different way over the model spectrum that is offered, or to absorb all or part of the cost rather than passing it through to the purchaser.

10.3.2 Results for mass as utility parameter

Results expressed as cost impacts relative to a baseline in which 130 g/km is maintained between 2015 and 2020

Figure 47 shows the absolute manufacturer cost increases at the level of manufacturer groups, resulting from applying a mass-based CO_2 limit function with different slope values. These costs are relative to the situation in which the current 130 g/km legislation is maintained between 2015 and 2020. The distribution of absolute manufacturer cost increases over market segments is presented in Figure 48. The relative retail price increases per manufacturer group and the distribution over the segments are respectively shown in Figure 49 and Figure 50.

NOTE: Certain manufacturers are not able to meet their target given the available reduction potential defined by the cost curves. These manufacturers are indicated with grey bars in the figures below. Moreover they are listed in Table 67 (for mass as utility parameter) and Table 68 (for footprint).

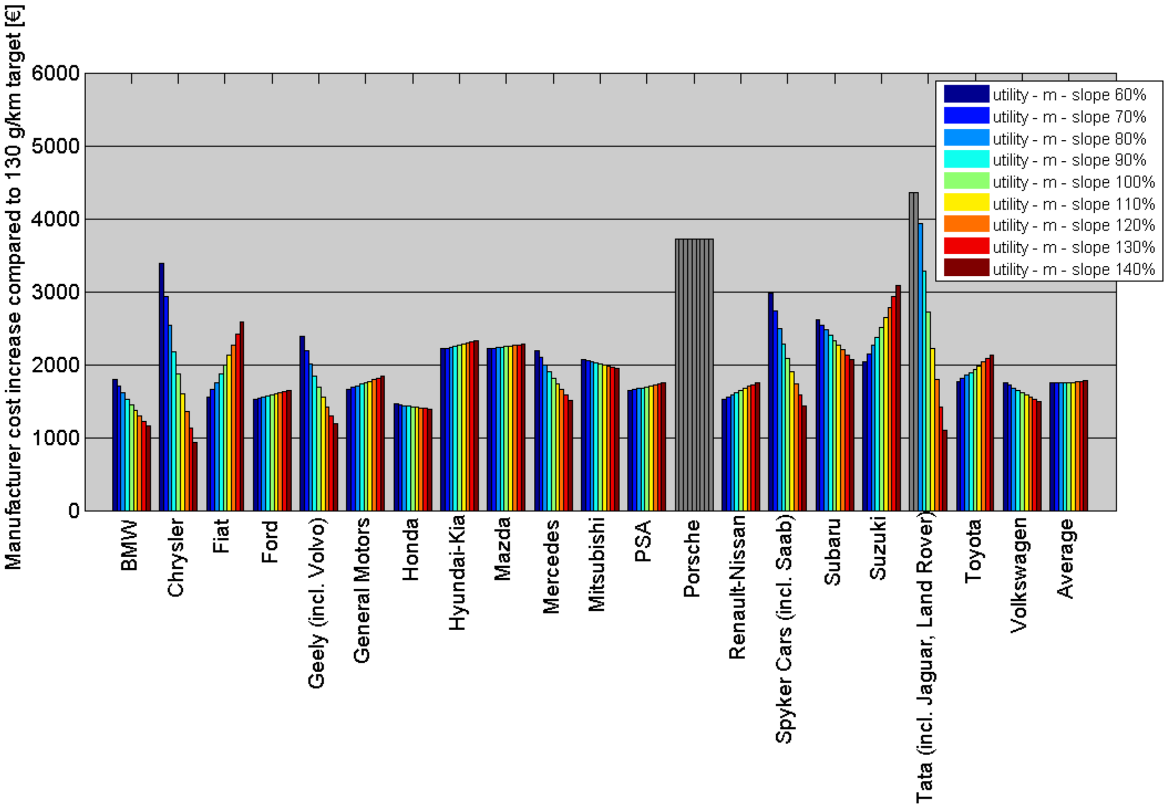


Figure 47 Absolute manufacturer cost increase per manufacturer for utility-based limits applied per manufacturer for U = mass, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

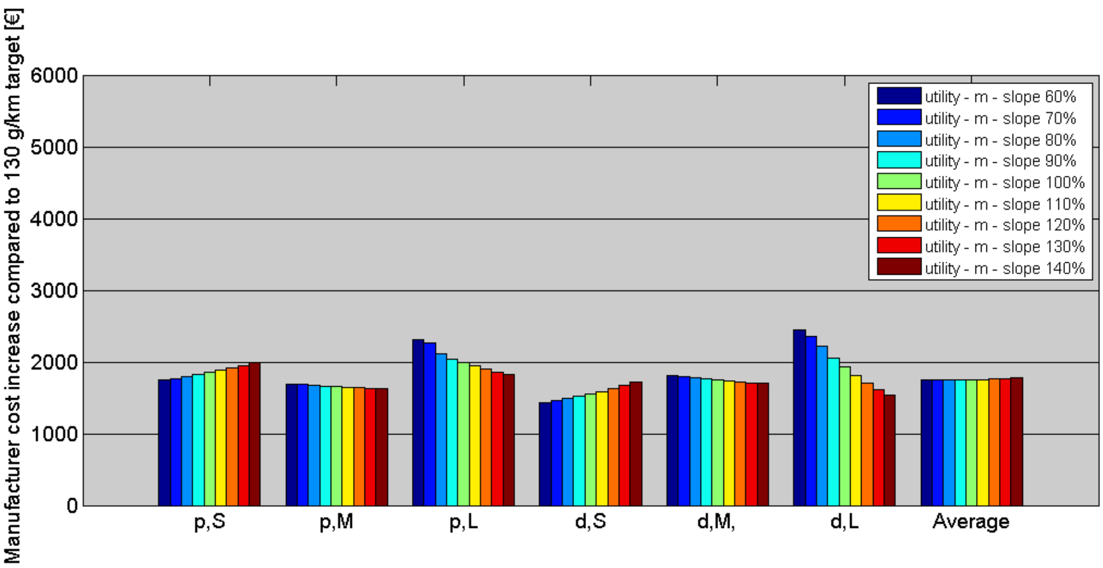


Figure 48 Absolute manufacturer cost increase relative to 2009 per segment for utility-based limits applied per manufacturer for U = mass, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.

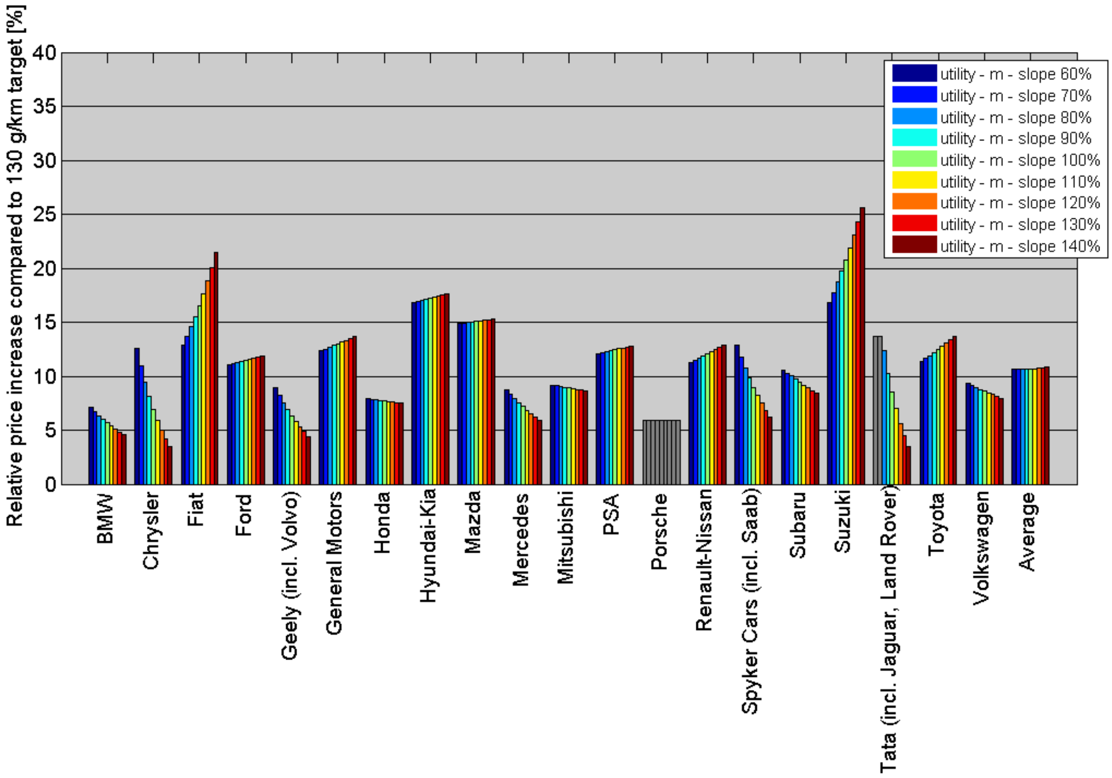


Figure 49 Relative price increase per manufacturer for utility-based limits applied per manufacturer for U = mass, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

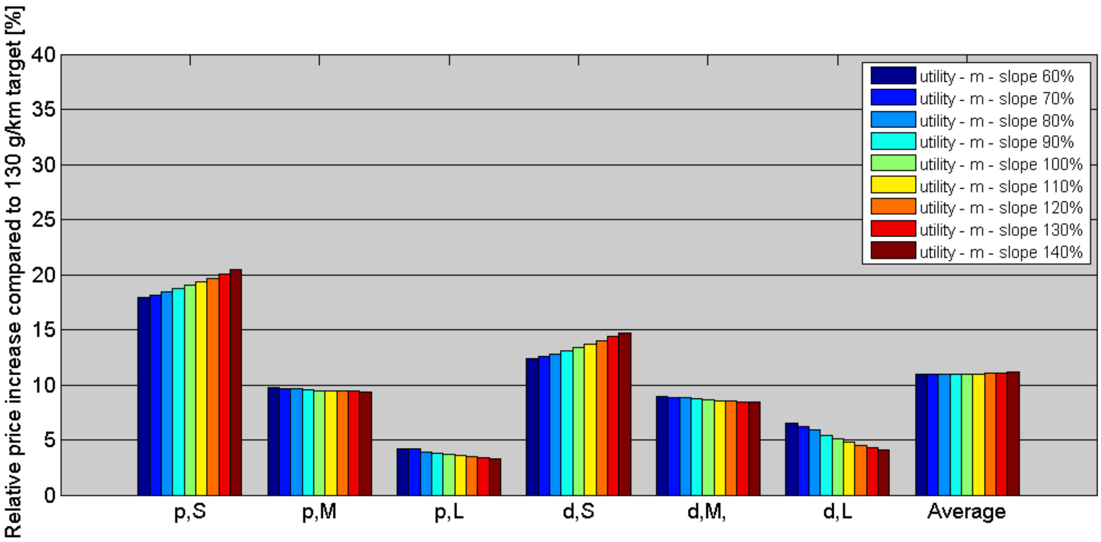


Figure 50 Relative price increase relative to 2009 per segment for utility-based limits applied per manufacturer for U = mass, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.

Results expressed as cost impacts relative to 2009

The absolute manufacturer cost increase per manufacturer relative to 2009 resulting from applying a mass-based CO_2 limit function with different slope values at the level of manufacturer groups is depicted in Figure 51. The distribution of absolute manufacturer cost increases over market segments is presented in Figure 52. The relative retail price increase per manufacturer relative to 2009 is depicted in Figure 53. The distribution of relative retail price increases over market segments relative to 2009 is presented in Figure 54. An alternative representation of the relative price increase is presented in Figure 55.

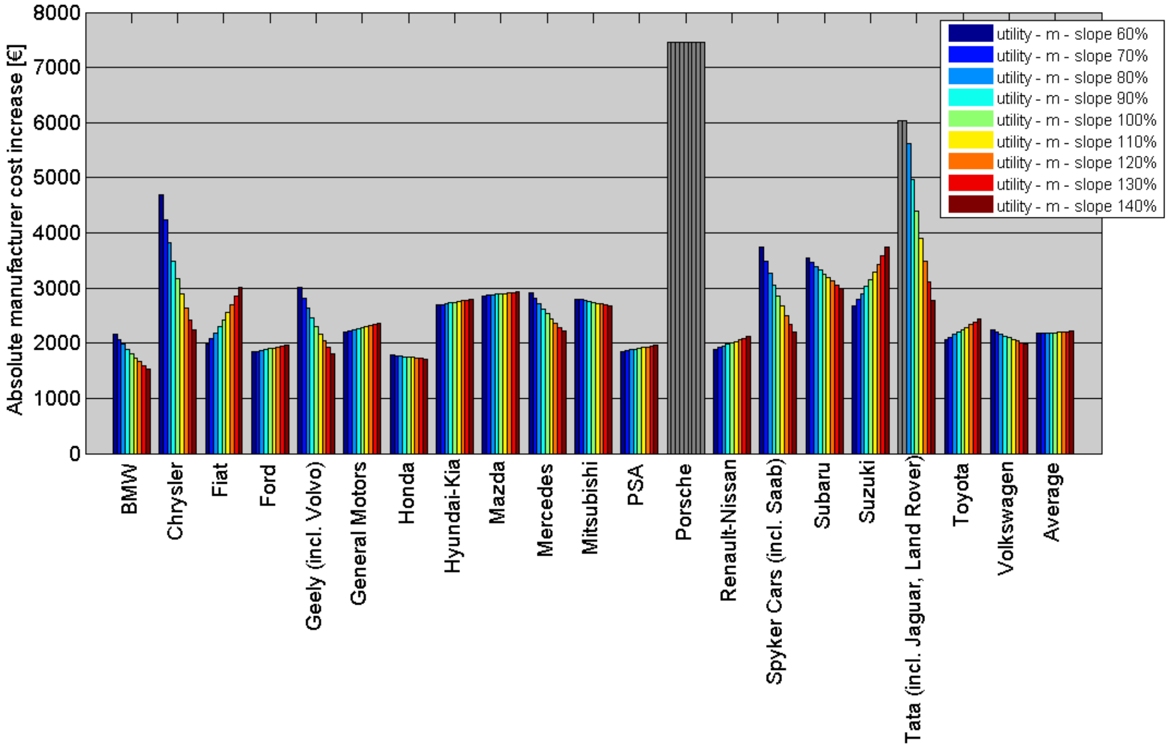


Figure 51 Absolute manufacturer cost increase relative to 2009 per manufacturer for utility-based limits applied per manufacturer for U = mass. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

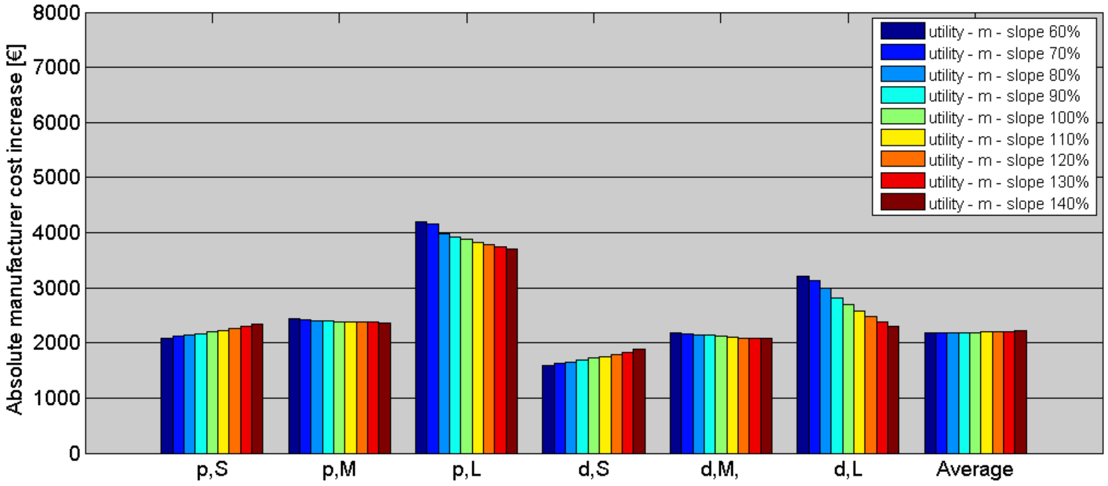


Figure 52 Absolute manufacturer cost increase relative to 2009 per segment for utility-based limits applied per manufacturer for U = mass.

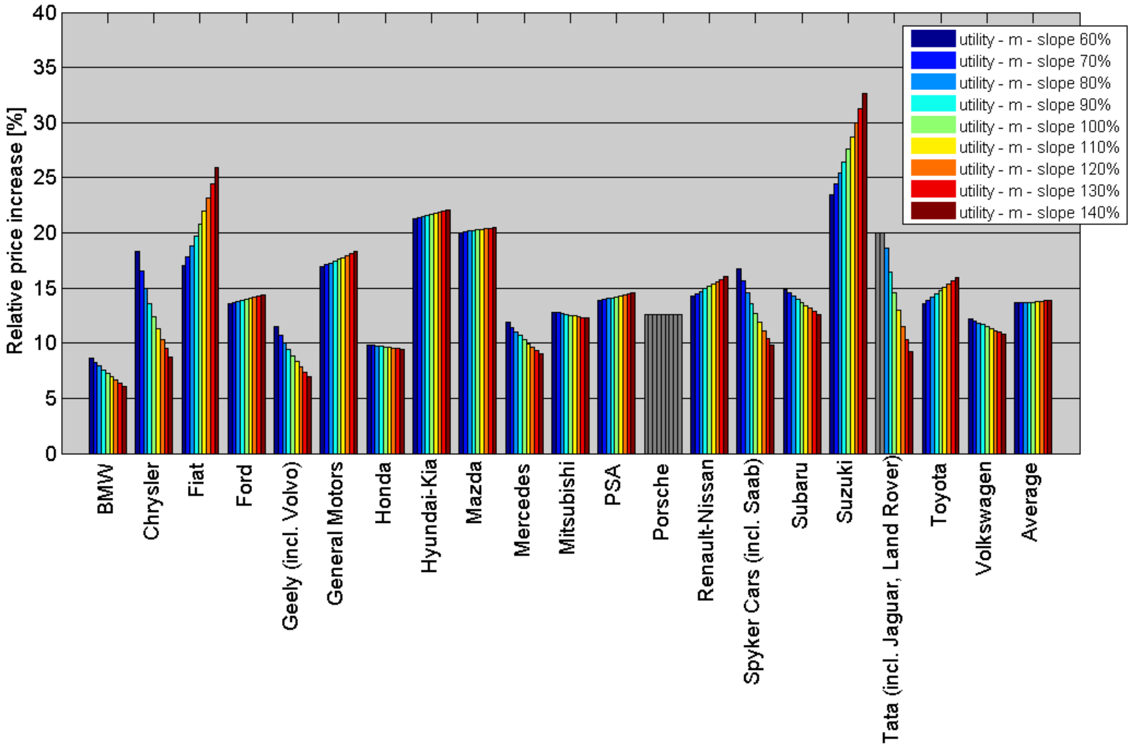


Figure 53 Relative retail price increase compared to 2009 per manufacturer for utility-based limits applied per manufacturer for U = mass. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

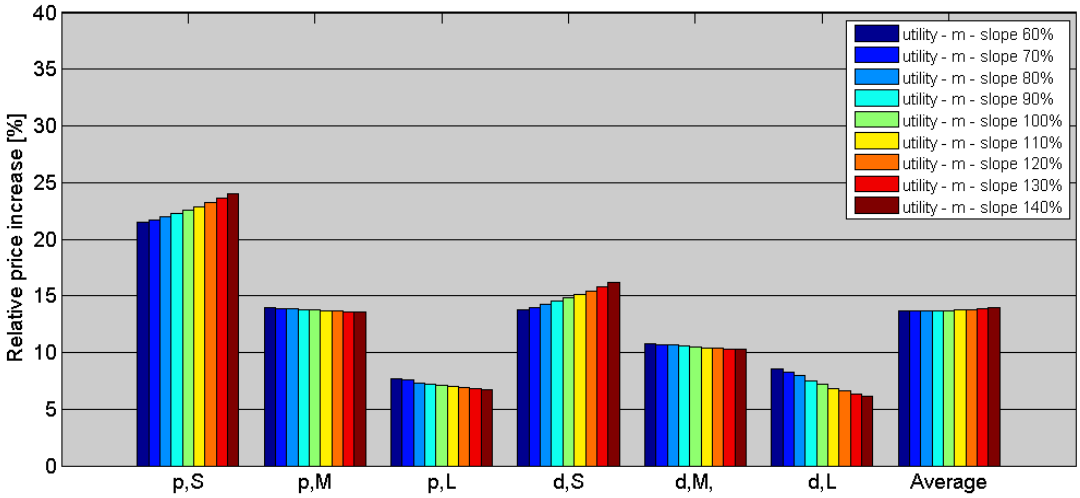


Figure 54 Relative retail price increase compared to 2009 per segment for utility-based limits applied per manufacturer for U = mass.

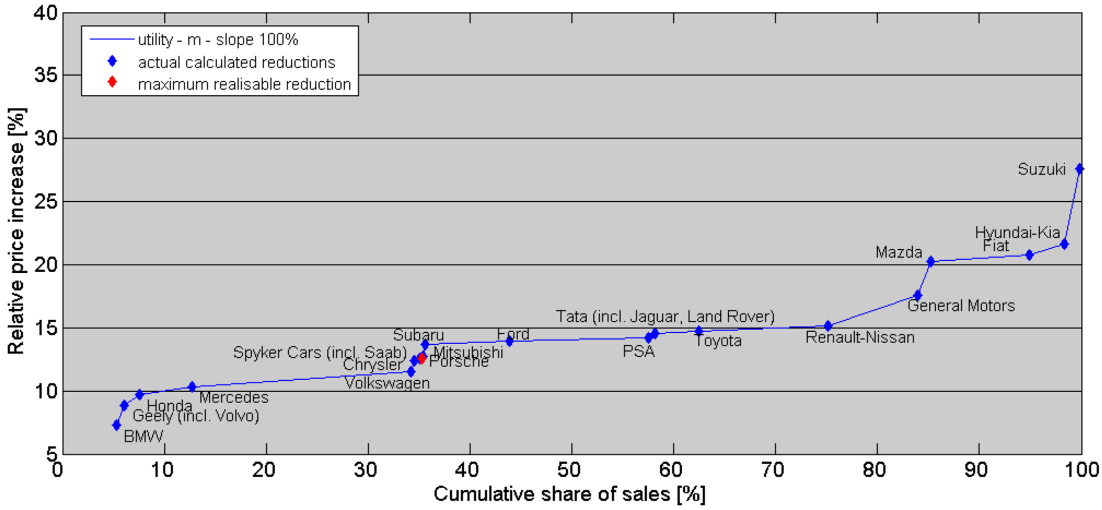


Figure 55 Relative retail price increase compared to 2009 per manufacturer for utility-based limits applied per manufacturer for U = mass, and a limit function with slope = 100%. Red markers indicate the manufacturer groups that are not able to meet their target.

According to Figure 55 Porsche has the eighth lowest relative price increase. This is the case because Porsche is attributed the highest possible CO_2 reduction while the manufacturer is not able to meet the target, even with the maximum potential. However, since more manufacturer groups are close to the maximum possible reduction, these other manufacturer groups have costs comparable to Porsche. Since Porsche has by far the highest average sales price, the calculated relative price increase for Porsche is relatively low.

Manufacturers not able to meet their mass-based target for 2020

For some of the slopes assessed, a number of manufacturer groups are unable to meet their 2020 CO_2 emission target, even with the maximum reduction possible (see cost curves developed in task 1.1 in [TNO 2011]). These manufacturer groups are indicated with grey bars in the figures above and are listed in Table 46. They are attributed the maximum possible reduction. As a result the overall average CO_2 emission target of 95 g/km is not exactly met. The overall average CO_2 emission is depicted in Table 46.

Table 67 Manufacturer groups that cannot meet their target with the maximum possible reduction.

Slope	Manufacturer groups unable to meet target of 95 g/km	Resulting average emissions in 2020 [g/km]
60%	Porsche, Tata (incl. Jaguar, Land Rover)	95.1
70%	Porsche, Tata (incl. Jaguar, Land Rover)	95.1
80%	Porsche	95.0
90%	Porsche	95.0
100%	Porsche	95.0
110%	Porsche	95.0
120%	Porsche	95.0
130%	Porsche	95.0
140%	Porsche	95.0

Conclusions regarding the case: mass-based limit function applied per manufacturer

- For some slopes assessed, a number of manufacturer groups are unable to meet their CO_2 emission target, even with the maximum reduction possible. These groups mainly sell relatively 'large' vehicles and a relatively high percentage of these sales consist of petrol vehicles.
- Aside from the groups that cannot meet the target, average costs per vehicle for each manufacturer group scale linearly with the slope of the limit function. For manufacturers with a sales-averaged mass below the overall average mass the costs increase with increasing slope

while for manufacturers with above-average mass the costs decrease with increasing slope. Sensitivity to changing slope is very different for the different manufacturer groups depending on the difference between the average mass of the manufacturer group and the overall fleet average mass.

- Overall average costs are sensitive to the slope of the utility based limit function but the sensitivity is limited for most of the manufacturer groups.
- Preferably the absolute manufacturer costs and relative price increase should both increase (or at least not decrease) with vehicle size and CO_2 emission. For the 2009 reference situation, this is achieved for the absolute manufacturer costs. However, for the relative price increase, this is not the case for any slope value; the effect on small vehicles is highest and the effect on large vehicles is lowest, irrespective of the fuel type.
- Especially when looking at the relative cost increase some manufacturers will be faced with a higher burden than other manufacturers with similar average CO_2 emissions.
    - **Fiat**: Fiat shows relatively high manufacturer cost and relative price increase, compared to for instance PSA, which has similar average CO_2 emissions (Annex G). However, Fiat has lower average mass and therefore more stringent target and higher costs (especially for higher slope values. Moreover Fiat sales prices are relatively low, resulting in an even higher relative price increase.
    - **Suzuki**: The relative retail price increase of Suzuki is relatively high and very sensitive to the slope of the limit function. 2009 CO_2 values for Suzuki and Renault-Nissan are almost the same (see Annex G) but the average mass is smaller for Suzuki leading to tighter CO_2 limits values and thus to higher costs than is the case for Renault-Nissan. A further important difference is the fact that the average retail price for Suzuki is about 15% lower than for Renault-Nissan.
    - **Porsche**: Even at the maximum possible reduction, Porsche does not meet its target for a single slope. This is because Porsche sells relatively many large vehicles in 2009 of which more than 85% are petrol vehicles. For these sports vehicles and SUVs CO_2 emissions are well above average for the segment and above average for their utility value.
    - **Tata** and **Chrysler**: These manufacturer groups are very sensitive to the slope value. This is a result of the average mass, being relatively far from the overall fleet average mass. Both groups manufacture mainly 'large' vehicles. Since these vehicles are also relatively expensive, the impact of the slope value on the relative price increase is comparable to the overall average.

10.3.3 Results for footprint as utility parameter

Results expressed as cost impacts relative to a baseline in which 130 g/km is maintained between 2015 and 2020

Figure 56 shows the absolute manufacturer cost increases resulting from applying a footprint-based CO_2 limit function with different slope values at the level of manufacturer groups. These costs are relative to the situation in which the current 130 g/km legislation is maintained between 2015 and 2020 The distribution of absolute manufacturer cost increases over market segments is presented in Figure 57. The relative retail price increases per manufacturer group and the distribution over the segments are respectively shown in Figure 58 and Figure 59.

NOTE: Certain manufacturers are not able to meet their target given the available reduction potential defined by the cost curves. These manufacturers are indicated with grey bars in the figures below. Moreover they are listed in Table 68 for the utility parameter footprint.

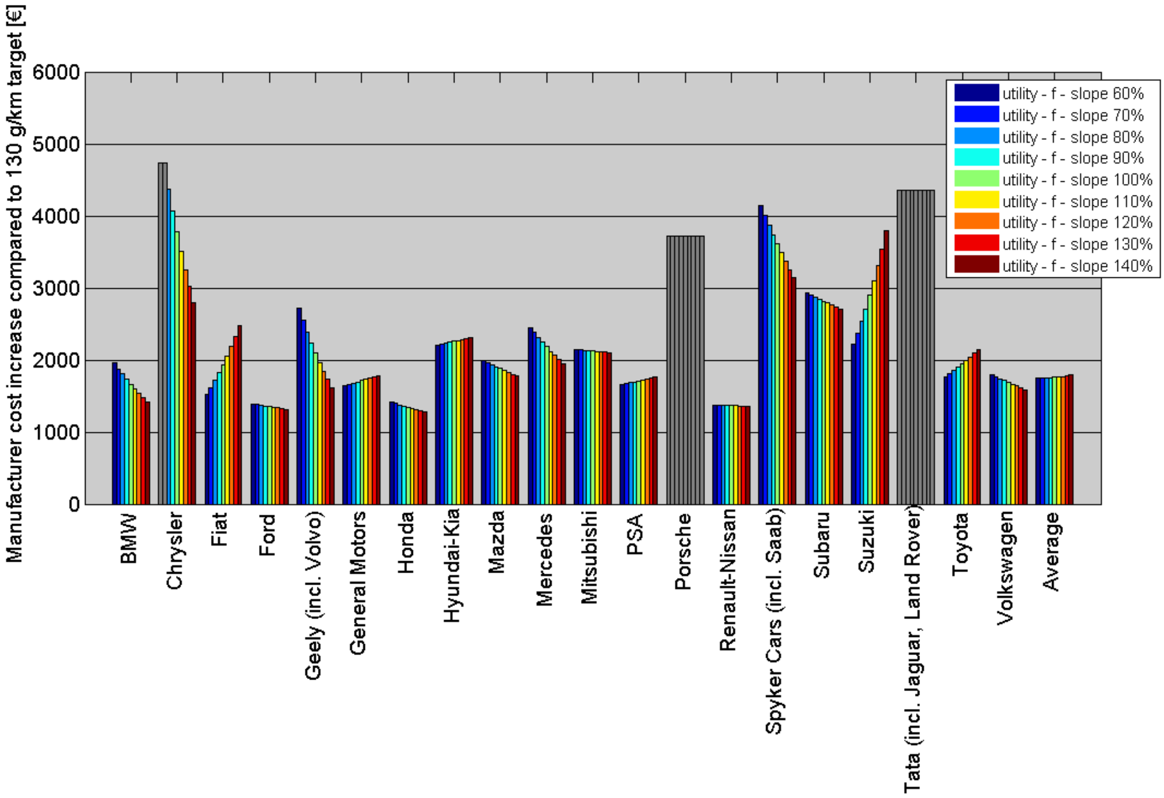


Figure 56 Absolute manufacturer cost increase per manufacturer for utility-based limits applied per manufacturer for U = footprint, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

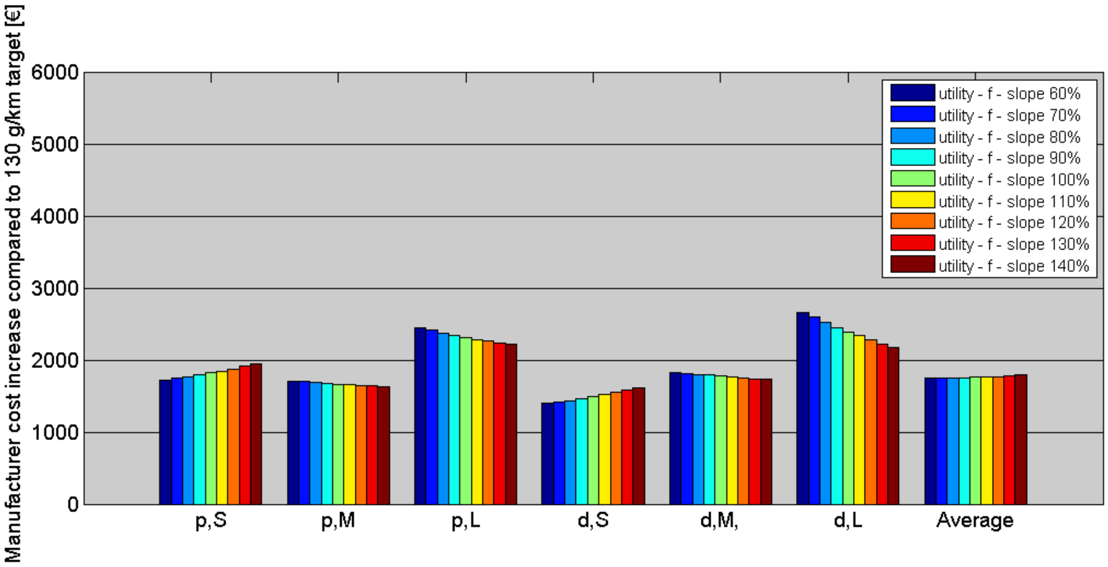


Figure 57 Absolute manufacturer cost increase relative to 2009 per segment for utility-based limits applied per manufacturer for U = footprint, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.

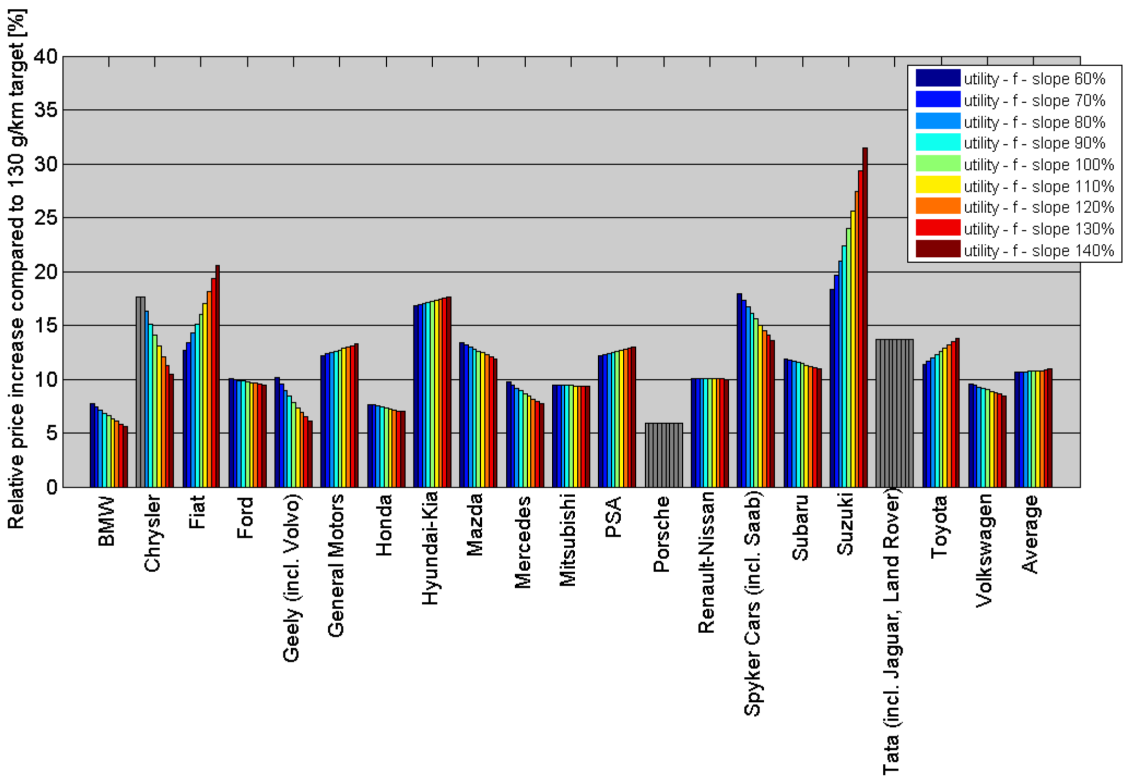


Figure 58 Relative price increase per manufacturer for utility-based limits applied per manufacturer for U = footprint, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

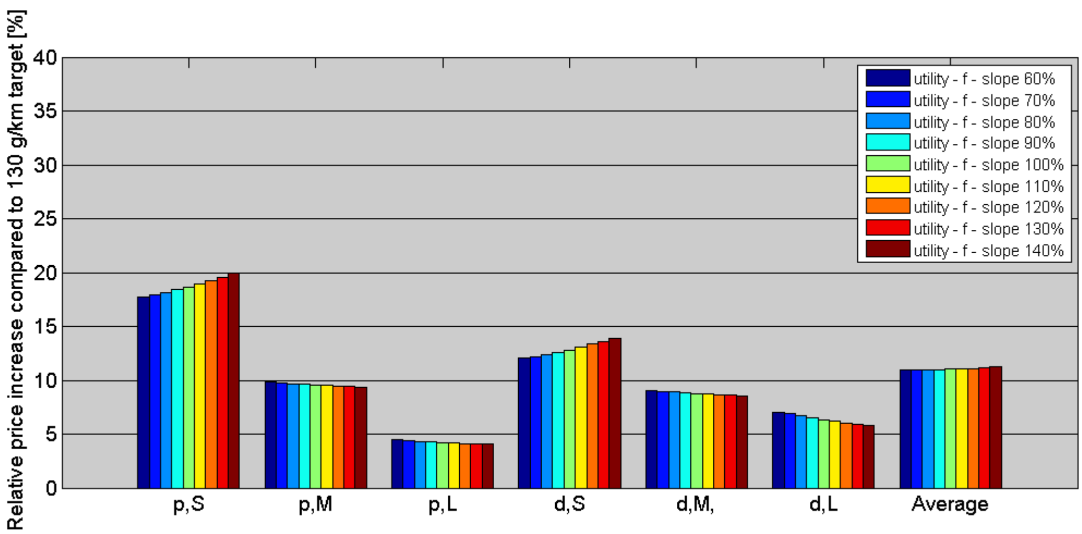


Figure 59 Relative price increase relative to 2009 per segment for utility-based limits applied per manufacturer for U = footprint, compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.

Results expressed as cost impacts relative to 2009

The absolute manufacturer cost increase per manufacturer resulting from applying a footprint-based CO_2 limit function with different slope values or a percentage reduction at the level of manufacturer groups is depicted in Figure 60. The distribution of absolute manufacturer cost increases over market segments is presented in Figure 73. Dividing absolute retail price increase (factor 1.44 higher than absolute manufacturer costs) by the average base retail price per manufacturer group yields the relative retail price increase as depicted in Figure 62. The distribution of relative retail price increases over market segments is presented in Figure 63. An alternative representation of the distributional impact is presented in Figure 64.

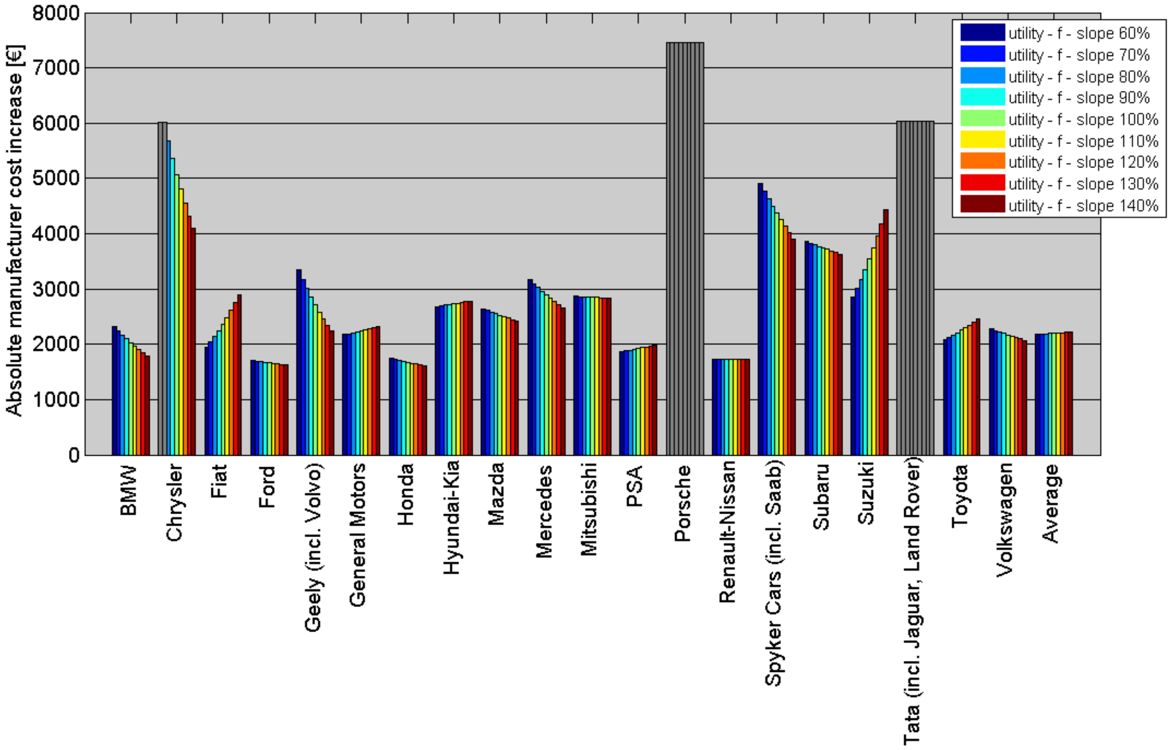


Figure 60 Absolute manufacturer cost increase relative to 2009 per manufacturer for utility-based limits applied per manufacturer for U = footprint. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

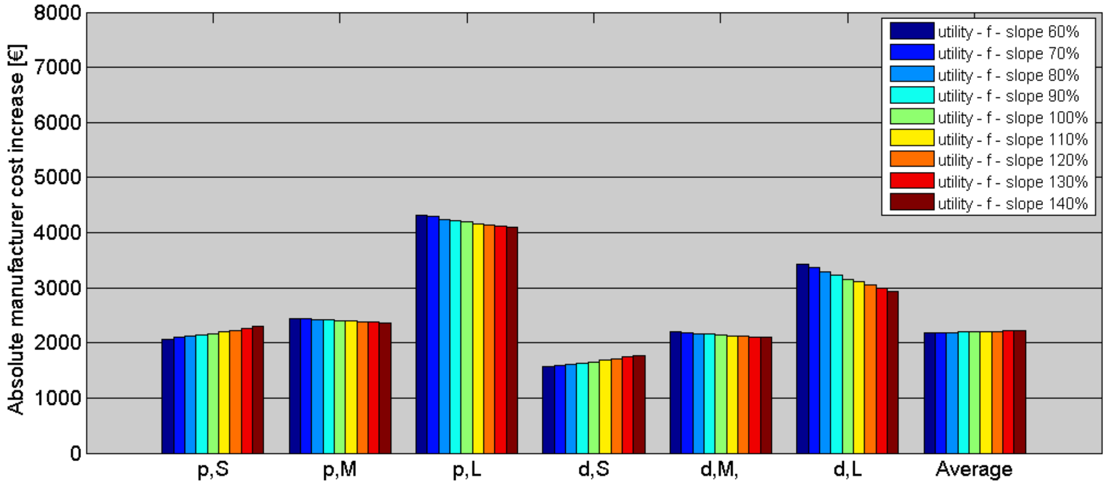


Figure 61 Absolute manufacturer cost increase relative to 2009 per segment for utility-based limits applied per manufacturer for U = footprint.

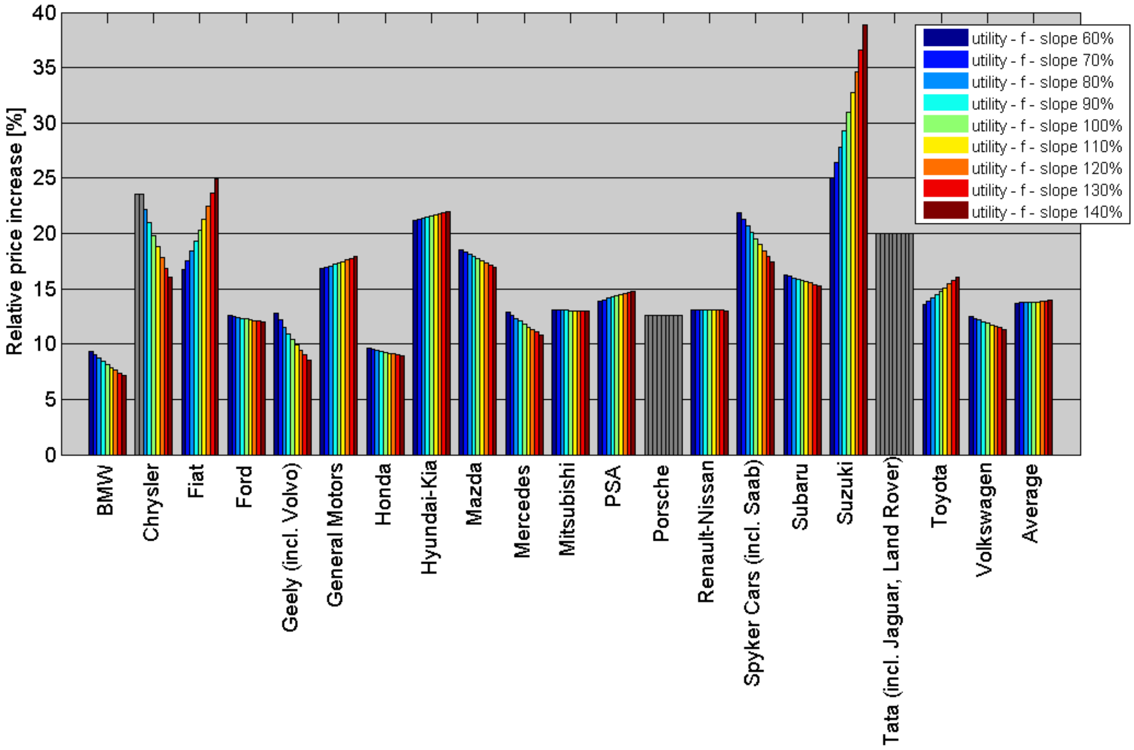


Figure 62 Relative retail price increase compared to 2009 per manufacturer for utility-based limits applied per manufacturer for U = footprint. A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

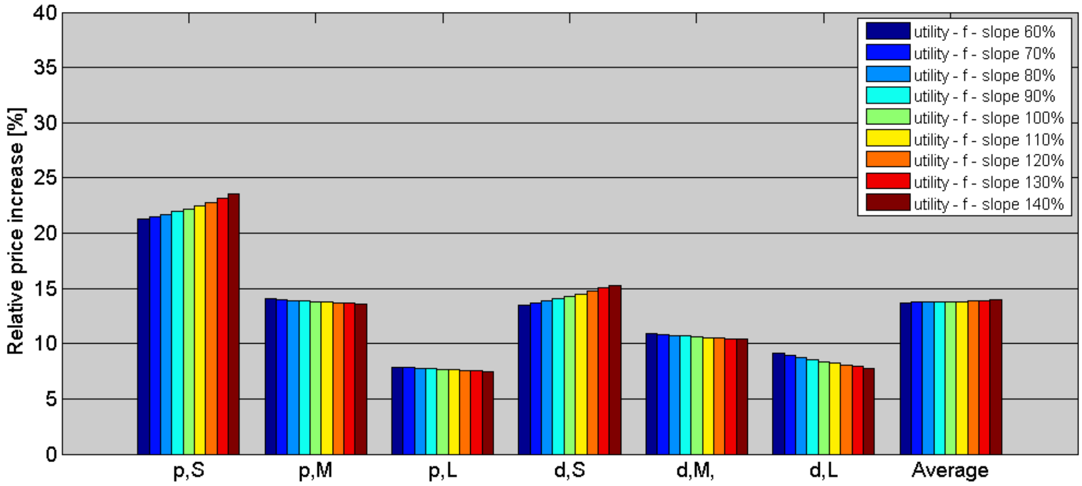


Figure 63 Relative retail price increase compared to 2009 per segment for utility-based limits applied per manufacturer for U = footprint.

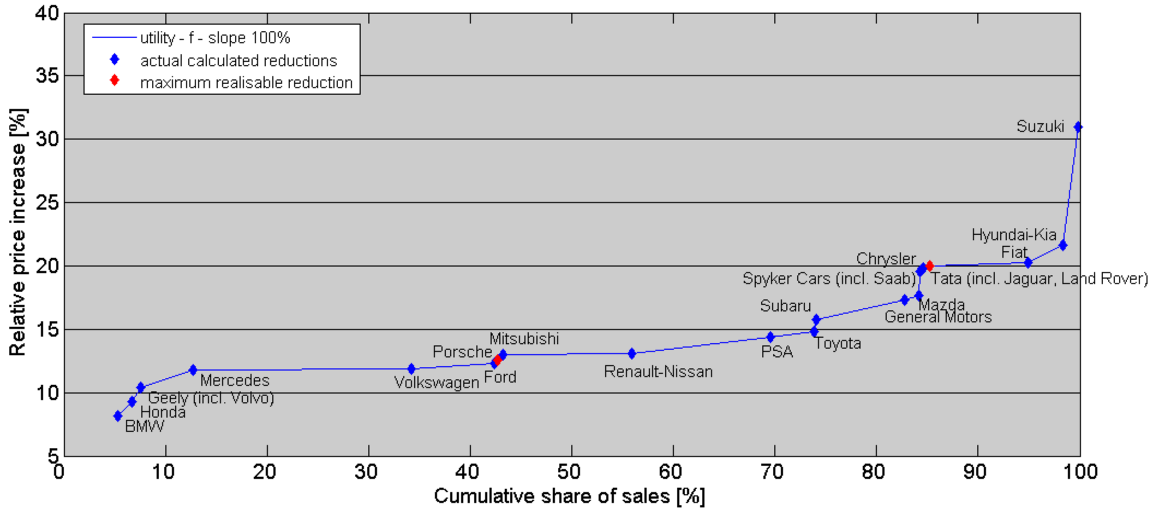


Figure 64 Relative retail price increase compared to 2009 per manufacturer for utility-based limits applied per manufacturer for U = footprint, and a limit function with slope = 100%. Red markers indicate the manufacturer groups that are not able to meet their target.

According to Figure 64 Porsche has the seventh lowest relative price increase. This is the case because Porsche is attributed the highest possible CO_2 reduction while the manufacturer is not able to meet the target. However, since more manufacturer groups are close to or even on the maximum reduction possible, these other manufacturer groups have costs comparable to Porsche. Since Porsche has by far the highest average sales price, the calculated relative price increase for Porsche is low. To a lesser extent this argument holds for Tata.

Manufacturers not able to meet their mass-based target for 2020

For some slopes assessed, a number of manufacturer groups is unable to meet the CO_2 emission target, even with the maximum reduction possible (see task 1.1 in [TNO 2011]). These are indicated with grey bard in the figures above and listed in Table 47. They are attributed the maximum possible reduction. As a result the overall average CO_2 emission target of 95 g/km is not met. The overall average CO_2 emission is depicted in Table 47 behind the slope value.

Table 68 Manufacturer groups that cannot meet their target with the maximum possible reduction.

Slope	Manufacturer groups unable to meet target of 95 g/km	Resulting average emissions in 2020 [g/km]
60%	Chrysler, Porsche, Tata (incl. Jaguar, Land Rover)	95.2
70%	Chrysler, Porsche, Tata (incl. Jaguar, Land Rover)	95.2
80%	Porsche, Tata(incl.Jaguar,LandRover)	95.2
90%	Porsche, Tata(incl.Jaguar,LandRover)	95.2
100%	Porsche, Tata(incl.Jaguar,LandRover)	95.2
110%	Porsche, Tata(incl.Jaguar,LandRover)	95.1
120%	Porsche, Tata(incl.Jaguar,LandRover)	95.1
130%	Porsche, Tata(incl.Jaguar,LandRover)	95.1
140%	Porsche, Tata(incl.Jaguar,LandRover)	95.1

Conclusions regarding the case: footprint-based limit function applied per manufacturer

- The overall picture for limit functions based on footprint and applied per manufacturer is very similar to that of mass based utility functions applied per manufacturer.
- Compared to mass as a utility parameter, for footprint a larger number of manufacturer groups is unable to meet the CO_2 emission target, even with the maximum reduction possible. Again, these groups mainly sell relatively ‘large’ vehicles and a relatively high percentage of these sales exist

of petrol vehicles. The extra manufacturer group not meeting the target (Chrysler) has a relatively low footprint compared to their mass, resulting is a tighter target for footprint than for mass.

- The average costs for meeting the target appear slightly higher for footprint than for mass. However differences are negligible.
- Again for each manufacturer average costs per vehicle scale linearly with the slope of the limit function in case the manufacturer group can meet its target. For manufacturer groups with a sales-averaged footprint below the overall average mass the costs increase with increasing slope while for manufacturers with above-average footprint the costs decrease with increasing slope. Sensitivity to changing slope is very different for the different manufacturers depending on the difference between the average footprint of the manufacturer group and the overall average footprint.
- For e.g. **Geely (incl. Volvo)** and **Chrysler**, the target is easier to reach with mass as utility parameter than for footprint. This is because their average mass per sold vehicle is further from the overall average than their average footprint per sold vehicle is from the overall average footprint. As a result their target is tighter when footprint is used as a utility parameter.
- For **Mitsubishi** and **Renault-Nissan** the sensitivity to the slope is reduced compared to the case of mass as utility parameter.
  - For footprint the average values for these manufacturers are closer to the overall average than for mass.
- For **Mazda** and **Ford** the sensitivity is completely reversed compared to the case of mass as utility parameter. This is caused by the fact that the average footprint for Mazda is above the overall average while for mass the average value for Mazda is below the overall average (Annex G).

10.4 Impact of electric vehicles on the cost for meeting the 2020 target

10.4.1 Scenario characteristics

By 2020 the sales share of electric vehicles within the passenger vehicle segment is expected to be significantly larger than in the sales 2010 database. Therefore it is important to assess the sensitivity of the cost impact results for this expected trend. Since estimating the share of newly sold electric passenger cars in 2020 was not within the scope of this study, three penetration scenarios were taken from a study by CE Delft [Kampman 2011]. These scenarios are shortly described in Table 48, including a fourth scenario developed by TNO to assess the impact of solely including Full Electric Vehicles (FEVs). A more detailed overview of EV shares and EV emissions in the various scenario's is presented in Table 48.

As a result of penetration of low emissions vehicles, the average CO_2 emissions of ICEV (Internal Combustion Engine Vehicle) are allowed to be as high as the emission values indicated in Table 48 to still achieve an overall average of 95g/km.

Table 69 Overview of scenario characteristics for electric vehicle sales penetration in 2020.

Scenario characteristics 2020	Baseline scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4 (TNO)
Sales share FEVs	0.0%	0.8%	0.3%	1.7%	10.0%
Sales share PHEVs	0.0%	3.4%	1.8%	6.2%	0.0%
Sales share EREVs	0.0%	1.2%	0.5%	2.3%	0.0%
Total sales share EVs	0.0%	5.5%	2.7%	10.2%	10.0%
Average CO2 emissions per EV [g/km]	-	48	45	47	0
Sales share of ICEVs	100.0%	94.5%	97.3%	89.8%	90.0%
Average ICEV emissions to reach 95 g/km [g/km]	**95.0**	**97.7**	**96.4**	**100.5**	**105.6**

The baseline scenario is the situation in which EVs are not taken into account. Scenario 1 was developed by CE Delft [Kampman 2011] and is intended to provide the 'most realistic' outlook of EV developments, based on the state-of-the-art information that was gathered in the previous work phases of this project. Scenario 2 is based on limited EV uptake due to high battery costs and limited incentives. Scenario 3 is the most optimistic one, from the EV development perspective, in which

R&D leads to a rapid decrease of battery cost and increase of battery lifetime, from 2015 onwards. The fourth scenario was developed by TNO to investigate the impact of a simplified case in which only FEVs are implemented.

10.4.2 Additional manufacturer costs for electric vehicles

In order to determine the average cost per vehicle for reaching the target, while taking the penetration of EVs into account, the additional manufacturer costs of EVs compared to ICEVs (2002 baseline) are calculated. This is done by accumulating costs for components used in the electric drive train and subtracting the costs avoided by not implementing a conventional drive train. The costs for electrification and for the conventional drive train motor are taken from task 1.1.9, while the transmission costs for the ICEVs are based on expert opinion. The final additional manufacturer costs are listed in Table 70.

Table 70 Additional manufacturer costs of EVs compared to ICEVs.

Additional manufacturer costs	FEV			PHEV petrol			PHEV diesel			EREV petrol			EREV diesel		
EV characteristics															
EV range [km]	150	175	200	50	50	50	50	50	50	50	50	50	50	50	50
Motor Power (peak) [kW]	62	80	85	28	30	30	28	30	30	66	80	84	67	81	85
Engine power [kW]	-	-	-	58	80	95	59	81	96	48	51	51	48	52	52
Battery capacity [kWh]	16.0	21.0	24.0	5.9	6.4	6.3	6.0	6.5	6.4	5.7	6.1	6.0	5.8	6.2	6.0
Cost electrification															
Battery [€]	6784	8747	9766	2579	2752	2711	2604	2787	2753	2493	2646	2585	2513	2667	2607
Motor [€]	435	551	582	208	222	220	210	224	223	464	552	580	470	558	586
Engine & Tranmission [€]	0	0	0	2000	2350	2450	2500	2800	2900	1000	1100	1100	1400	1600	1600
Generator [€]	0	0	0	0	0	0	0	0	0	432	463	462	436	467	466
Inverter & Boost converter [€]	690	878	929	337	359	356	341	364	361	1423	1615	1659	1439	1632	1677
Control unit & Harness [€]	240	270	300	240	270	300	240	270	300	360	390	420	360	390	420
Heat pump [€]	810	900	990	810	900	990	810	900	990	810	900	990	810	900	990
Avoided ICE costs															
ICE engine power [kW]	55	80	110	55	80	110	55	80	110	55	80	110	55	80	110
Engine & Tranmission [€]	1650	2400	3300	1650	2400	3300	1650	2400	3300	1650	2400	3300	1650	2400	3300
Total extra manufacturer costs [€]	**7309**	**8946**	**9267**	**4524**	**4453**	**3727**	**5055**	**4945**	**4227**	**5332**	**5266**	**4496**	**5778**	**5814**	**5046**

10.4.3 Effect of EV penetration on overall average additional manufacturer costs

For every scenario a different distribution of small, medium and large vehicles and different shares of FEVs, PHEVs and EREVs is assumed. As no sales distribution over small, medium and large FEVs is available from [Kampman 2011], a distribution of respectively 4:5:1 was assumed. Because of distributional differences between the scenarios, the Table 71). This value is highest for scenario 4 since it includes only FEVs, which are the most expensive of the EVs.

As a result of the increased average emissions allowed for ICEVs, the average additional manufacturer costs for those vehicles decrease. For this calculation in the cost assessment model the virtual target for ICEVs is set to the values listed as '*Average ICEV emissions to reach 95 g/km'* in Table 69. The resulting costs for the 100% slope situation with mass as the utility parameter can be found in Table 71.

Table 71 Overall costs to reach an average of 95 gCO_2/km for scenarios that include sales shares of electric vehicles relative to the 2009 reference situation, a 100% slope and mass as the utility parameter.

Utility parameter = mass Slope = 100%	Baseline scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4 (TNO)
Scenario characteristics					
Sales share FEVs	0.0%	0.8%	0.3%	1.7%	10.0%
Sales share PHEVs	0.0%	3.4%	1.8%	6.2%	0.0%
Sales share EREVs	0.0%	1.2%	0.5%	2.3%	0.0%
Total sales share EVs	0.0%	5.5%	2.7%	10.2%	10.0%
Average CO_2 emissions per EV [g/km]	-	48	45	47	0
Scenario impact on ICEVs					
Sales share of ICEVs	100%	94.5%	97.3%	89.8%	90.0%
Average ICEV emissions to reach 95 g/km [g/km]	95	97.7	96.4	100.5	105.6
Results					
Average additional manufacturer cost per EV [€]	-	5302	5186	5358	8323
Average ICEV costs to meet target ICEV [€]	2188	1952	2061	1741	1420
Average overall costs to meet 95 g/km target [€]	**2188**	**2136**	**2145**	**2110**	**2111**

Finally, the average manufacturer costs per passenger car, including electric vehicles, can be determined. As can be seen in Table 71, the penetration of EVs slightly lowers the average additional manufacturer costs needed to reach an overall average of 95 gCO_2/km in all scenarios. For instance, the average overall costs to meet the 95 gCO_2/km target are 2.4% lower for 'Scenario 1' than for the 'Baseline scenario' without EV penetration.

From these values cannot be concluded that the production of EVs decreases the overall additional manufacturer costs under all circumstances. For instance, the '*Average ICEV emissions to reach 95 g/km'* do not influence the *'Average ICEV costs to meet target ICEV'* linearly. The introduction of the first EV has the highest relative impact on the additional manufacturer costs, as manufacturer have to 'climb' less far up the progressively increasing cost curve.

However, this analysis does show that for this situation (100% slope, mass as utility parameter) manufacturing and selling electric passenger vehicles can become a cost effective means for achieving a target of 95gCO_2/km. As discussed above, this effectiveness depends on the degree of penetration, the distribution over electric vehicle types and the price action of electric vehicle components e.g. batteries.

In Table 72, a similar assessment is depicted for a 100% slope situation but with footprint as the utility parameter. Similar to mass as the utility parameter, the penetration of EVs slightly lowers the average additional manufacturer costs needed to reach an overall average of 95 gCO_2/km in all scenarios. For instance, the average overall costs to meet the 95 gCO_2/km target are 2.4% lower for 'Scenario 1' than for the 'Baseline scenario' without EV penetration.

Again, it cannot be concluded that the production of EVs decreases the overall additional manufacturer costs under all circumstances. But also this analysis does show that for this situation (100% slope, footprint as utility parameter) manufacturing and selling electric passenger vehicles can become a cost effective means for achieving a target of 95 gCO_2/km.

Table 72 Overall costs to reach an average of 95 gCO_2/km for scenarios that include sales shares of electric vehicles relative to the 2009 reference situation, a 100% slope and footprint as the utility parameter.

Utility parameter = footprint Slope = 100%	Baseline scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4 (TNO)
Scenario characteristics					
Sales share FEVs	0.0%	0.8%	0.3%	1.7%	10.0%
Sales share PHEVs	0.0%	3.4%	1.8%	6.2%	0.0%
Sales share EREVs	0.0%	1.2%	0.5%	2.3%	0.0%
Total sales share EVs	0.0%	5.5%	2.7%	10.2%	10.0%
Average CO_2 emissions per EV [g/km]	-	48	45	47	0
Scenario impact on ICEVs	0%	0	0	0	0%
Sales share of ICEVs	100%	94.5%	97.3%	89.8%	90.0%
Maximum ICEV emissions to reach 95 g/km [g/km]	95	97.7	96.4	100.5	105.6
Results					
Average additional manufacturer cost per EV [€]	-	5302	5186	5358	8323
Average ICEV costs to meet target ICEV [€]	2197	1964	2072	1755	1434
Average overall costs to meet 95 g/km target [€]	**2197**	**2147**	**2155**	**2123**	**2123**

10.5 Assessment of cost impacts of different scenarios

The figures and tables below show the results of runs with the cost assessment model using the alternative cost curves for scenario a), b) and c) as defined in section 2.6. The results are compared with those for the original 2020 cost curves as defined in section 2.4.

With respect to the overall costs of meeting the target assessments for mass and footprint as utility parameter yield similar results. Assuming that a large part of the progress made between 2002 and 2009 is to be attributed to other origins than application of technologies from the cost curves leads to costs for meeting the target that are about € 600 lower than for the case based on the original cost curves. Using alternative data for costs and reduction potentials of hybridization and weight reduction from EPA studies has a more limited effect. The combination of scenario a) and b) leads to costs that are about € 1000 lower than the base case.

Results for the scenarios a) to c) would change the conclusion from the assessment of impacts of introducing EVs by 2020 as presented in section 10.4. The lower costs for meeting the target by means of reducing CO_2 emissions from conventional vehicles will mean that additional costs for manufacturing EVs will no longer be outweighed by reduced costs for reduced efficiency improvements in conventional vehicles.

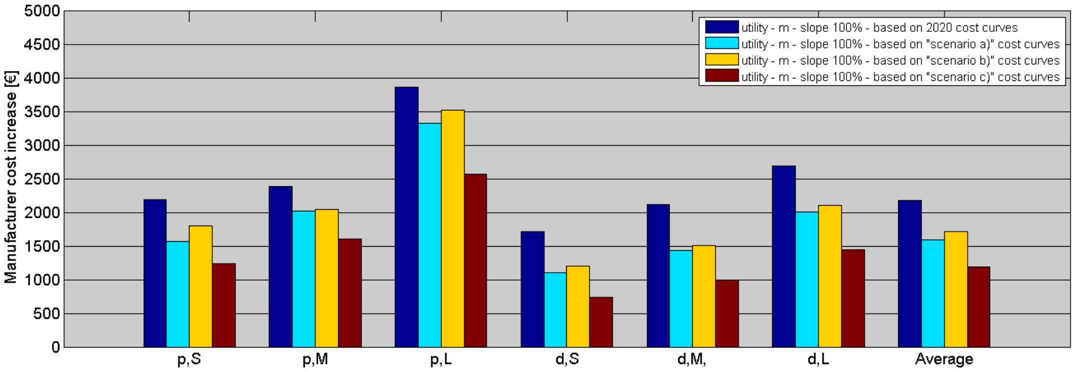


Figure 65 Additional manufacturer costs per segment relative to the 2009 situation with reference mass as the applied utility parameter and a 100% slope.

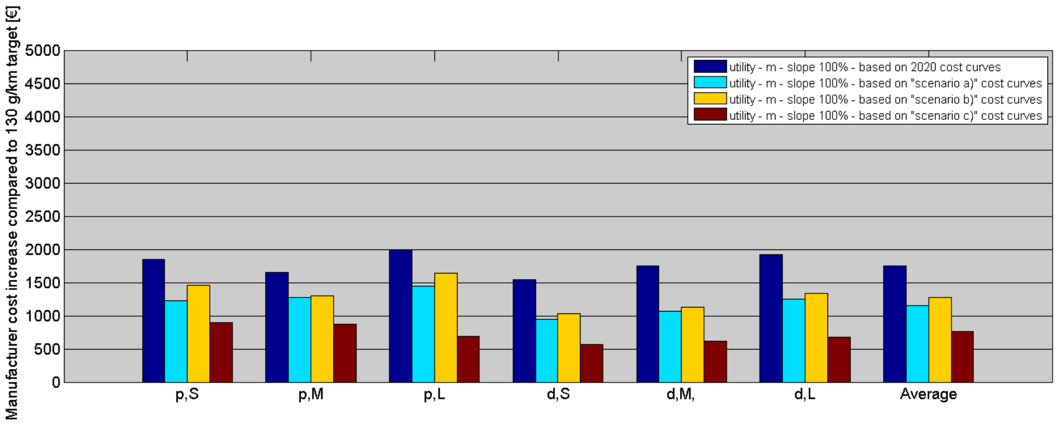


Figure 66 Additional manufacturer costs per segment relative to maintaining 130 g/km with reference mass as the applied utility parameter and a 100% slope.

Table 73 Additional manufacturer costs per segment with reference mass as the applied utility parameter and a 100% slope.

	Additional manufacturer cost relative to 2009 [€]						
Utility parameter: reference mass Slope: 100%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	2199	2390	3872	1719	2119	2698	2188
Scenario a)	1570	2019	3331	1111	1437	2016	1595
Scenario b)	1802	2044	3526	1199	1504	2106	1715
Scenario c)	1241	1606	2570	740	991	1447	1198

	Additional manufacturer cost relative to maintaining 130 g/km [€]						
Utility parameter: reference mass Slope: 100%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	1852	1653	1993	1552	1748	1930	1750
Scenario a)	1222	1283	1452	943	1067	1248	1158
Scenario b)	1455	1308	1647	1032	1134	1338	1277
Scenario c)	894	869	691	573	620	680	760

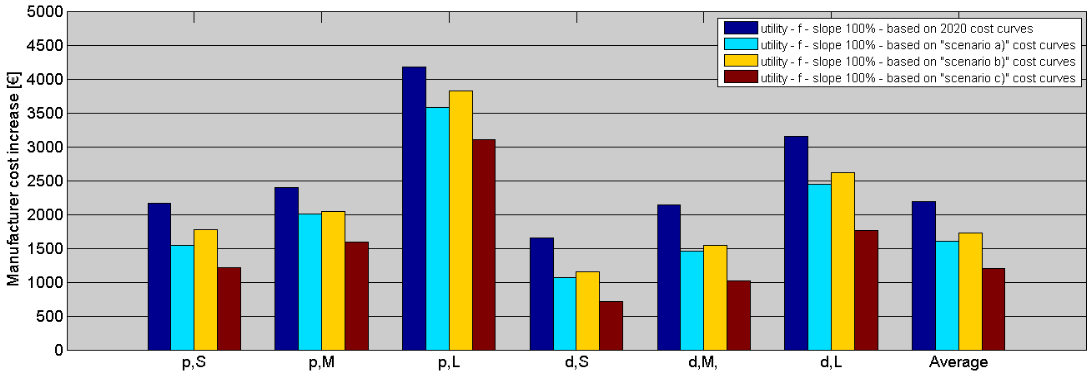


Figure 67 Additional manufacturer costs per segment relative to the 2009 situation with footprint as the applied utility parameter and a 100% slope.

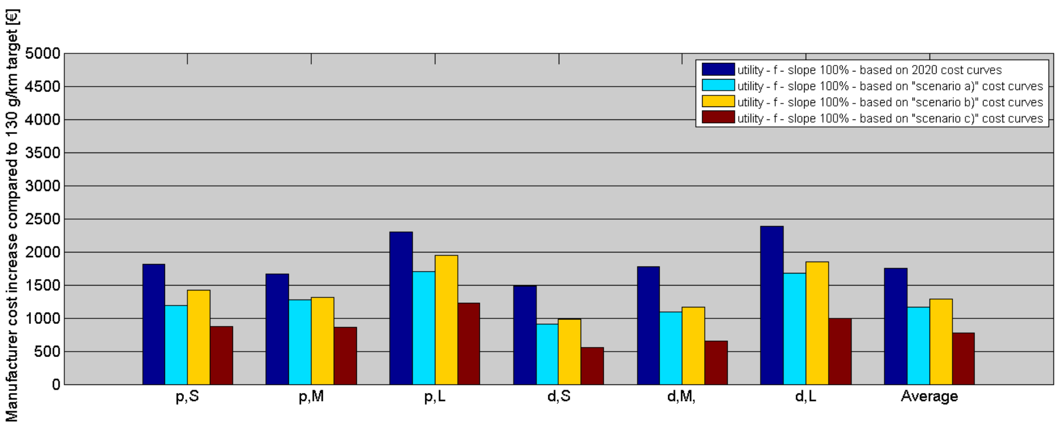


Figure 68 Additional manufacturer costs per segment relative to maintaining 130 g/km with footprint as the applied utility parameter and a 100% slope.

Table 74 Additional manufacturer costs per segment with footprint as the applied utility parameter and a 100% slope.

	Additional manufacturer cost relative to maintaining 130 g/km [€]						
Utility parameter: footprint Slope: 100%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	1818	1664	2310	1489	1775	2393	1760
Scenario a)	1195	1275	1706	907	1094	1678	1168
Scenario b)	1426	1312	1952	987	1171	1851	1294
Scenario c)	870	863	1230	552	649	998	772

	Additional manufacturer cost relative to 2009 [€]						
Utility parameter: footprint Slope: 100%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	2166	2400	4189	1657	2145	3160	2197
Scenario a)	1543	2011	3585	1074	1464	2446	1605
Scenario b)	1773	2049	3831	1155	1542	2618	1732
Scenario c)	1217	1599	3109	720	1019	1765	1210

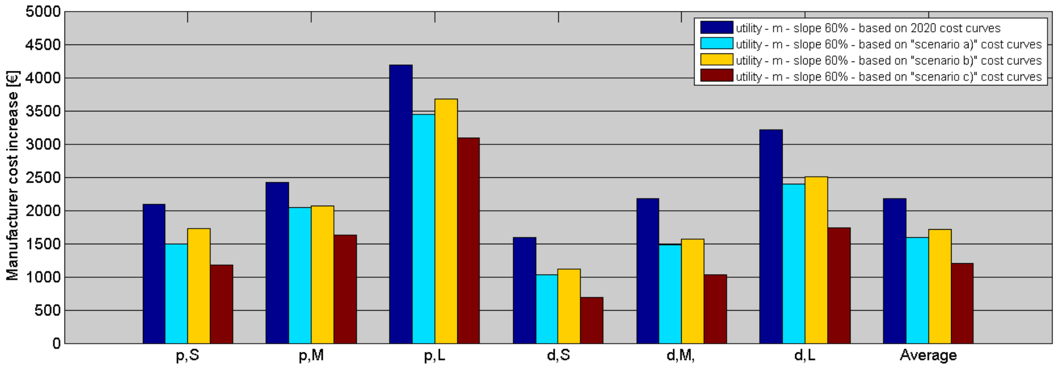


Figure 69 Additional manufacturer costs per segment relative to the 2009 situation with reference mass as the applied utility parameter and a 60% slope.

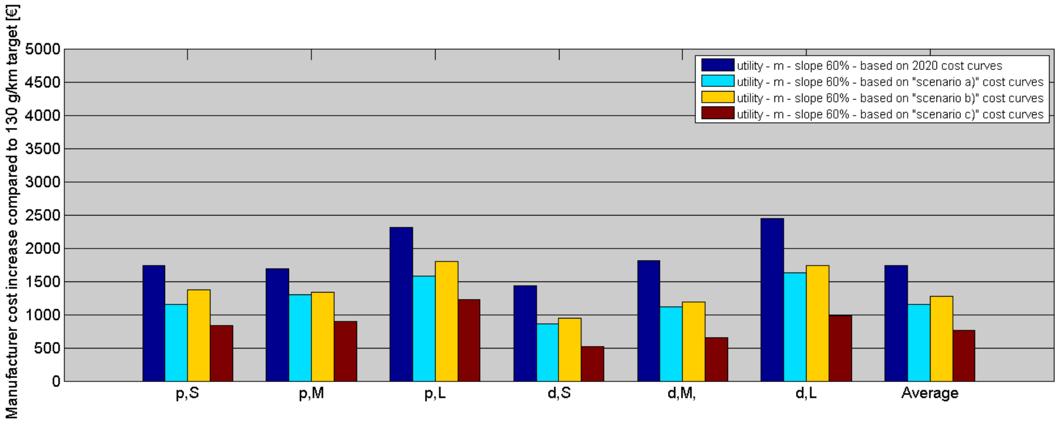


Figure 70 Additional manufacturer costs per segment relative to maintaining 130 g/km with reference mass as the applied utility parameter and a 60% slope.

Table 75 Additional manufacturer costs per segment with reference mass as the applied utility parameter and a 60% slope.

	Additional manufacturer cost relative to maintaining 130 g/km [€]						
Utility parameter: reference mass Slope: 60%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	1745	1695	2316	1431	1814	2449	1748
Scenario a)	1150	1308	1577	865	1118	1634	1158
Scenario b)	1377	1334	1805	949	1195	1740	1280
Scenario c)	832	898	1225	522	660	980	765

	Additional manufacturer cost relative to 2009 [€]						
Utility parameter: reference mass Slope: 60%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	2092	2432	4195	1599	2184	3217	2186
Scenario a)	1498	2044	3456	1032	1489	2401	1596
Scenario b)	1724	2070	3684	1116	1565	2507	1717
Scenario c)	1179	1634	3105	690	1030	1748	1203

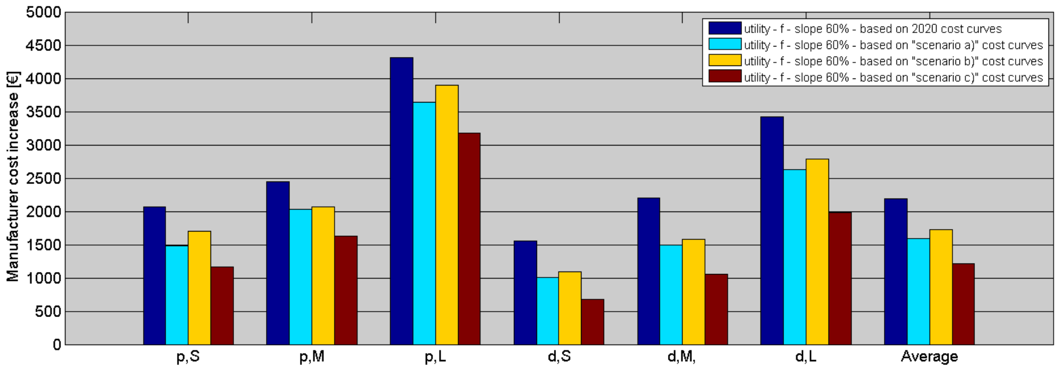


Figure 71 Additional manufacturer costs per segment relative to the 2009 situation with footprint as the applied utility parameter and a 60% slope.

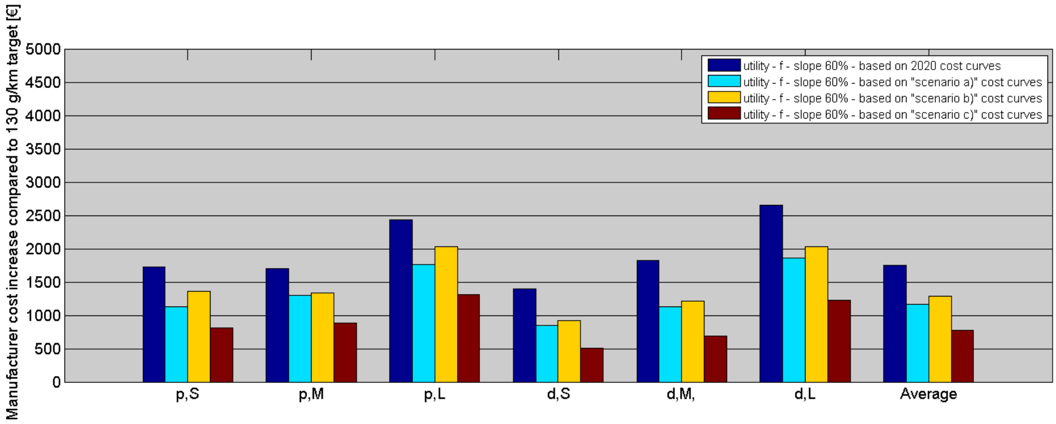


Figure 72 Additional manufacturer costs per segment relative to maintaining 130 g/km with reference mass as the applied utility parameter and a 60% slope.

Table 76 Additional manufacturer costs per segment with footprint as the applied utility parameter and a 60% slope.

	Additional manufacturer cost relative to maintaining 130 g/km [€]						
Utility parameter: footprint Slope: 60%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	1727	1711	2443	1396	1831	2664	1754
Scenario a)	1135	1304	1769	845	1133	1870	1164
Scenario b)	1360	1342	2031	924	1215	2031	1290
Scenario c)	818	892	1309	512	686	1224	775

	Additional manufacturer cost relative to 2009 [€]						
Utility parameter: footprint Slope: 60%	**pS**	**pM**	**pL**	**dS**	**dM**	**dL**	**Average**
Based on 2020 cost curves	2074	2447	4322	1564	2201	3431	2191
Scenario a)	1482	2041	3648	1012	1503	2637	1601
Scenario b)	1707	2078	3910	1092	1585	2798	1728
Scenario c)	1165	1629	3188	679	1056	1992	1213

10.6 Conclusions

For various slope values for utility-based limit functions, some manufacturer groups are not able to meet their specific target, which is needed to achieve the overall average per sold vehicle within the EU of 95 g/km. These are mostly manufacturers with relatively large vehicles, high petrol shares and small total sales. As a result of the latter, the overall target is only missed by a small amount.

A second general conclusion is that costs, to be made for reaching the target, increase with an increasing slope independent of the assessed utility parameter. However, the sensitivity of the average costs to the slope value is relatively small.

The average costs for meeting the target appear slightly lower for mass than for footprint. However, this difference is negligibly small.

Nevertheless, in general the targets defined by limit functions based on utility parameter mass are met by more manufacturer groups than for footprint based targets. For the specific manufacturers for which this applies the average footprint is further away from the overall average than is the case for their average mass.

Mass as a utility parameter has the obvious advantage of consistency with the present legislation for 2015, but may be less appropriate in the longer term as it reduces the potential of weight reduction as an option for contributing towards meeting the target.

In [TNO 2009] a simplified assessment was made for a target of 95 g/km. In this study various scenarios were assessed with respect to the impact of technological choices and learning effects on the cost curves. From the four discerned scenarios the one with fast learning effects and extreme downsizing as main technology and the one with slow learning and hybridisation as main technology are chosen for comparison with the present assessment, since they are at the same time the most extreme options and appear both to be happening in the portfolio of OEMs (Table 77).

Table 77 Results from first exploration in previous study [TNO 2009] on average cost impacts (expressed as absolute manufacturer cost increase and relative retail price increase) for meeting the 95 g/km target for passenger cars in 2020 for the scenarios "Extra strong downsizing" and "Full hybridisation" with respectively fast and slow penetration.

	Strong downsizing / Learning: fast penetration						Hybridisation / Learning: Slow penetration					
	p,S	p,M	p,L	d,S	d,M	d,L	p,S	p,M	p,L	d,S	d,M	d,L
CO_2-emission [g/km]	80	101	125	78	95	122	82	100	128	75	93	124
Absolute manufacturer cost increase [€]	2012	2294	3113	1695	2087	2772	2686	3088	4094	2584	2855	3476
Relative price increase	22%	15%	12%	17%	12%	11%	18%	12%	40%	15%	11%	24%

Table 78 Results from this study with respect to average cost impacts (expressed as absolute manufacturer cost increase and relative retail price increase) for meeting the 95 g/km target for passenger cars in 2020 with a 100% slope and mass and footprint as utility parameters, relative to the 2009 baseline situation.

	Utility parameter:mass / 100% slope						Utility parameter:footprint / 100% slope					
	p,S	p,M	p,L	d,S	d,M	d,L	p,S	p,M	p,L	d,S	d,M	d,L
CO_2-emission [g/km]	86	100	138	84	101	133	86	100	136	85	101	129
Absolute manufacturer cost increase [€]	2199	2390	3872	1719	2119	2697	2166	2400	4189	1657	2145	3160
Relative price increase	23%	14%	7%	15%	10%	7%	22%	14%	8%	14%	11%	8%

From the comparison between the 2009 study and the current assessment it can be concluded that average CO_2 emissions per segment seem to be slightly higher than expected in the 2009 study (except for the medium petrol segment). This is the result of relatively high sales in the small segment. Furthermore, additional manufacturer cost to meet the 95 g/km target are in between the costs calculated according to the “Extra strong downsizing” and “Full hybridisation” scenario. This is to be expected since both technological pathways have now been integrated in a single set of cost curves. The manufacturer cost and relative price increases of the large segment are relatively low because some manufacturers, of mainly large vehicles, cannot meet the target and, as described above, are therefore attributed the maximum possible reduction (and costs). Still these costs are lower than the costs needed to achieve the actual target.

Finally, assessing scenarios that include market penetration of electric vehicles, shows that manufacturing and selling electric passenger vehicles can become a cost effective means for achieving a target of 95 gCO_2/km. However, this effectiveness depends on various parameters such as the degree of penetration, the distribution over electric vehicle types and the price action of electric vehicle components e.g. batteries. From the performed assessment cannot be concluded that the production of EVs decreases the overall additional manufacturer costs under all circumstances.

10.7 References

[Smokers 2006] Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars. Smokers R., Vermeulen R et al. (2006), Contract nr. SI2.408212, Final Report, TNO Report, Oct 31, 2006.

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[TNO 2009] Assessment with respect to long term CO_2 emission targets for passenger cars and vans Deliverable D2: Final Report. Assessment with respect to long term CO_2 emission targets for passenger cars and vans Deliverable D2: Final Report, 2009.

[Kampman 2011] Impacts of Electric Vehicles - Deliverable 5. Impact analysis for market uptake scenarios and policy implications. Kampman, B., Essen, H. van, Braat, W., Grünig, M., Kantamaneni, R., Gabel, E. Delft, CE Delft, January 2011

11 Assessment of impacts of an additional vehicle-based CO_2 limit

11.1 Introduction

The analysis presented in this chapter concerns the impacts that a vehicle-based CO_2 limit might have on new car CO_2 emissions and the industry. For clarity, it is not proposed that a vehicle-based limit would be the sole means of reducing average CO_2 emissions to 95 gCO_2/km by 2020. The analysis specifically looks at the impact, both in terms of cost and CO_2 emissions reductions, of a range of options for a vehicle-based limit which could be required in addition to the manufacturer-specific fleet average target resulting from the 95 gCO_2/km target.

This task provides an analysis of the direct impacts of a vehicle-based limit for those vehicles that are affected by the limit. The total impact on costs of meeting the 95 g/km target by using the combination of a fleet average target and a vehicle-based limit is assessed in Task 3.7.

A vehicle-based limit should ensure that manufacturers also focus on improving the efficiency of high emission vehicles rather than relying on low emission vehicles to offset them. Such a limit would reduce the flexibility that a simple target offers the manufacturers, and this may increase the total costs. However, it could also act as a spur for the development of innovative solutions which would produce substantial cuts in vehicle emissions at the upper end of the market, and these solutions could then filter down to the lower and higher volume end of the market as costs reduce.

11.2 The baseline fleet

The Polk Marketing Systems data set was used in this analysis and a selection of limit curve shapes and parameters were analysed. Some cleaning of the Polk data set was required in order to remove entries that had erroneous or negative values or were not class M1 vehicles.

The baseline fleet used in this analysis was a notional 2015 fleet derived from the 2009 data set. In order to generate this fleet, each entry's CO_2 emissions were reduced proportionately in order to achieve fleet average CO_2 emissions of 130 gCO_2/km. The costs of reducing emissions from this 2015 level of emissions to the limit were then estimated.

In practice, the 2015 fleet can be expected to be quite different in terms of vehicle weight and CO_2 distribution, however it is difficult to forecast how this will evolve over the 6 year period between 2009 and 2015 and for the purposes of this initial analysis, a simple reduction factor was considered adequate. The fleet average CO_2 emissions according to the Polk data were 147.25gCO_2/km[84] so emissions were reduced by 11.7% in order to achieve a fleet average of 130gCO_2/km.

11.3 Emission Limits and Cost Curves

The fleet data forms the basis of a spreadsheet which allows the user to define a series of limit curves by adjusting the curve parameters (see the Annex K). Four shapes of curve are defined.

- Flat – a constant limit CO_2 value which is not dependent of other variables such as gross vehicle weight and footprint
- Linear – a limit which increases at a defined rate as gross vehicle weight or footprint increases
- Truncated linear – a limit which increases in a similar fashion to the linear limit but becomes a flat limit at a defined value for gross vehicle weight or footprint
- Curved – a curved limit which follows a similar shape to the truncated linear limit

The limit curves were defined using either reference mass (estimated by taking the kerb weight and adding 60kg) or vehicle footprint as the utility parameter. A breakdown of the distribution of registrations in 2009 by these parameters can be seen in the following charts:

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[84] Average CO_2 in 2009 according to the European Commission monitoring database was 145.7g/km, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0655:FIN:EN:PDF

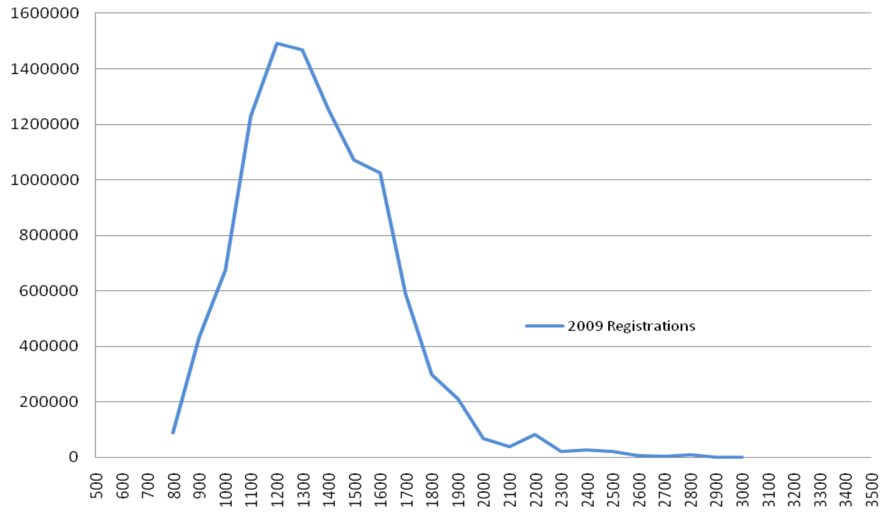

Figure 73 2009 new passenger car registrations in relation to mass

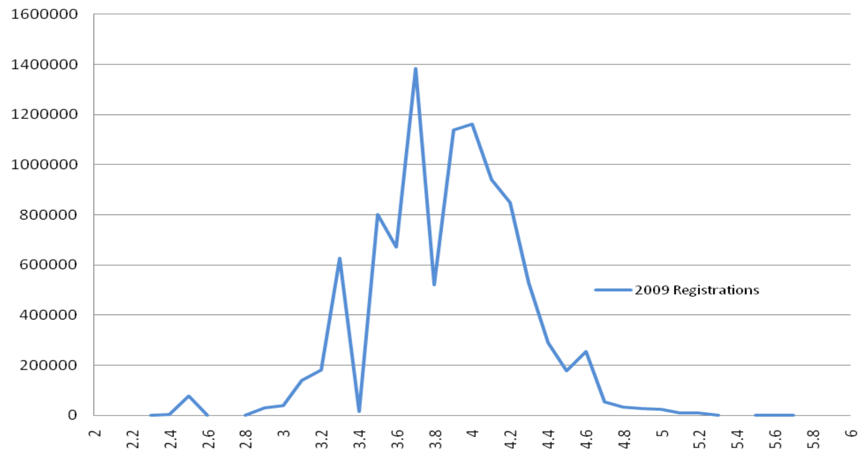

Figure 74 2009 new passenger car registrations in relation to footprint

The coefficients which define the curves can be customised and the limits are displayed in relation to the actual distribution of vehicle emissions in 2015. By way of example, the following chart shows limits set to achieve fleet average CO_2 emissions of 115 gCO_2/km:

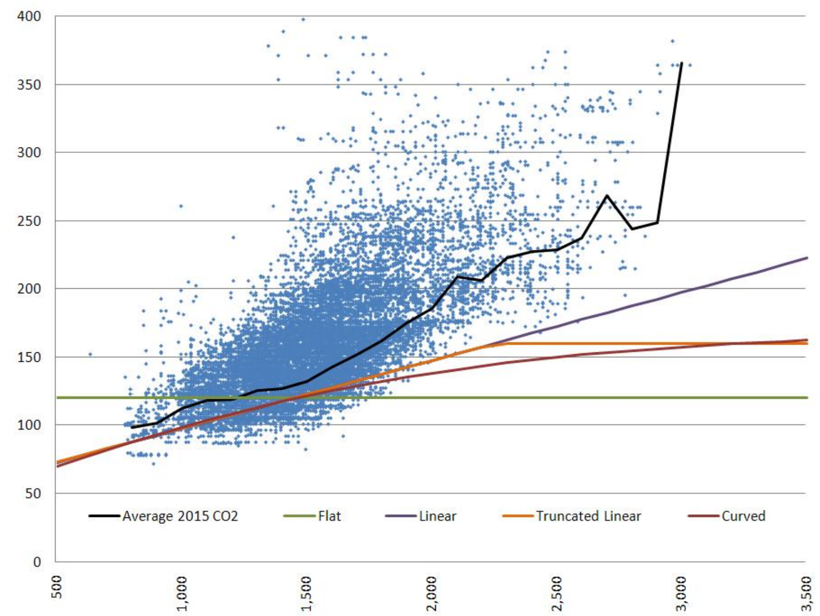

Figure 75 2009 passenger vehicle CO_2 emissions for a given reference mass (each blue point represents at least one registration). The chart further shows the average CO_2 emissions in 2015 by reference mass (black line), four limit curves(flat, linear, truncated linear and curved) and

Full results for a target reduction in average CO_2 emissions to 120, 115 and 110 gCO_2/km for reference mass and vehicle footprint are given in Annex K.

The spreadsheet then calculates the resulting sales weighted average CO_2 emissions which would be achieved if emission reduction modifications and technologies were applied to vehicles exceeding the limit so that they reach the limit (or approach as close to the limit as possible).

The costs of achieving this reduction are calculated using the cost curves derived in section 2.4. The curves as shown in Figure 76 and Figure 77 are defined by the following generalised equation:

$$y = \sum_{i=1}^{9} a_i \cdot x^i$$

with a_i the coefficients as listed in Table 79, x the CO_2 reduction in [%] and y the additional manufacturer costs in [€].

Table 79 Coefficient values and end points for polynomial cost curves for petrol and diesel vehicles in 2020, relative to 2002 baseline vehicles.

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S				8.134E+05	-9.302E+05	3.859E+05	-6.922E+04	1.319E+04	6.453E+02	60.1%	5870
p,M				1.207E+06	-1.386E+06	5.381E+05	-7.426E+04	9.017E+03	9.985E+02	61.1%	6775
p,L	9.431E+07	-2.233E+08	2.180E+08	-1.121E+08	3.226E+07	-5.187E+06	4.602E+05	-1.672E+04	1.574E+03	61.9%	8265
d,S					2.193E+05	-1.757E+05	5.709E+04	9.584E+01	1.657E+03	53.0%	4711
d,M					4.147E+05	-3.757E+05	1.308E+05	-9.708E+03	2.151E+03	53.0%	5571
d,L				-1.549E+05	1.069E+06	-8.804E+05	2.701E+05	-2.236E+04	2.585E+03	52.8%	6946

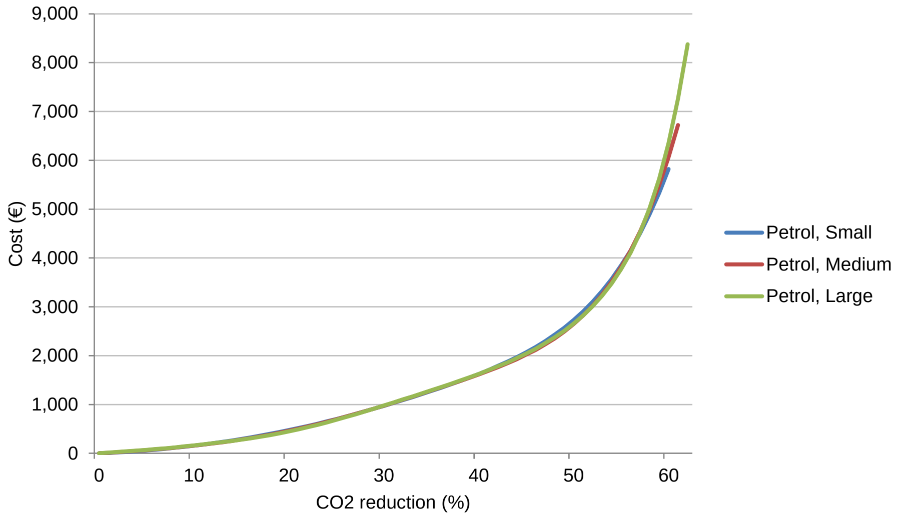

Figure 76 Cost curves for small, medium and large petrol vehicles based on 2002 reference vehicles.

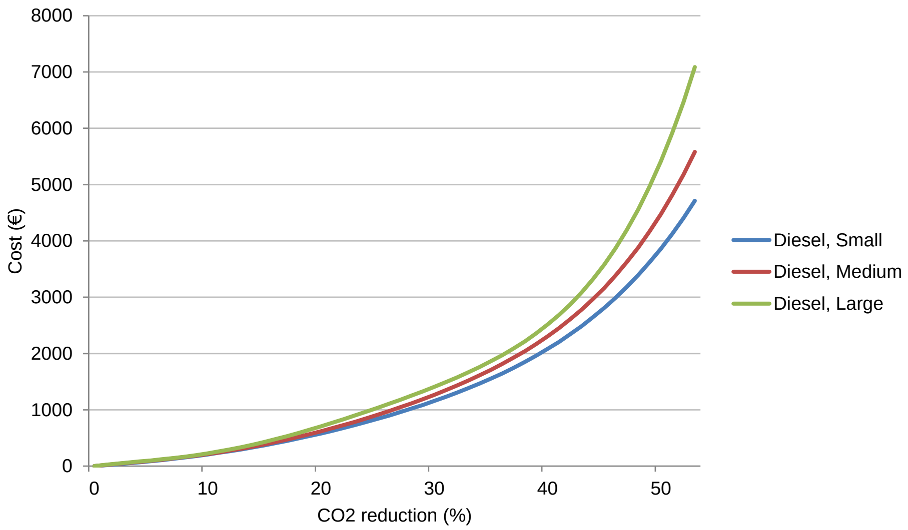

Figure 77 Cost curves for small, medium and large diesel vehicles based on 2002 reference vehicles.

The utility parameters were used to establish whether an entry in the data set is above or below the limit and the cost curves are then applied to the vehicles exceeding the limit in order to establish what the costs associated with reducing emissions to the limit would be. Once up to the maximum reduction potential has been applied to each vehicle, we are left with vehicles with 'residual' emissions i.e. vehicles that still exceed the limit after the maximum reduction has been applied.

There are two main penalty options available to deal with these vehicles. The first is to exclude vehicles that exceed the limit from the market. This would be a radical step to take and it is likely that this would be met with substantial resistance, both from car manufacturers and governments. The second option, one adopted under the existing emissions reduction legislation, is to impose a financial penalty or 'buy-out' premium.

11.4 Buy-out premiums

Buy-out premiums need to be set at a sufficiently high level that there will be an economic incentive for the manufacturers to take the emission reduction route rather than the buy-out premium route. The marginal costs of manufacturers close to the reductions they have to realise to meet their equivalent of the 95 g/km target, are generally between €50 to €150 depending on vehicle type, size and emissions. An initial, flat buy-out premium of €100 per g/km in excess of the limit has therefore been chosen in order to evaluate what the total buy-out penalty for industry could be.

It should be noted that this analysis looks at the entire market, and therefore includes low volume manufacturers which may be covered by future legislation, and it is predominantly vehicles from these manufacturers which are unable to achieve the limit through emissions reductions. If these low volume manufacturers are removed from the data set, the number of vehicles not achieving the limit after emissions reductions would be small.

11.5 Results

The tables and graphs given in Annex K illustrate the impact that a selection of different limits would have on the new car market both in terms of the CO_2 reduction potential and the costs associated with achieving that reduction. For each curve, the parameters have been chosen to generate a reduction in fleet average CO_2 emissions from 130 gCO_2/km average to 120 gCO_2/km, 115 gCO_2/km or 110 gCO_2/km. The limits have been adjusted so that the smaller market segments (which tend to be made up of lower CO_2 and lower priced vehicles) require relatively small CO_2 emissions reductions, and hence incur relatively low costs. This ensures that they are not disproportionately affected by the emissions limit relative to the price paid by consumers. Larger vehicles tend to be more expensive and so the cost of reduction can be higher with a more limited relative impact on vehicle price. The steepness of the limit defines how much these vehicles have to lower their CO_2, with a steeper limit incurring proportionately greater costs on smaller vehicles than a shallower limit. In case of the linear and truncated limit function, the steepness is based on the slope of the 100% line, defined in task 3.3.

The results table for each curve presents:

- Total sales under the limit and the proportion of the fleet that these sales represent;
- Total sales over the limit and the proportion of the fleet that these sales represent;
- Total cost to reduce the fleet to the limit (or as close to the limit as possible) and the average cost per vehicle;
- Average CO_2 emissions of the fleet after the reduction;
- Number of vehicles still exceeding the limit after CO_2 reduction;
- Average exceedance in gCO_2/km;
- Total buy-out cost;
- Average buy-out cost.

The chart found below each table illustrates the average cost per vehicle of achieving the limit by market segment.

The following tables give a summary of the detailed results found in Annex K.

Table 80 Proportion of the 2015 new car market which exceeds the limit.

Utility Parameter	Target gCO_2/km	Flat	Linear	Truncated Linear	Curved
Reference Mass	120	41%	57%	59%	55%
	115	62%	74%	72%	72%
	110	74%	85%	84%	82%
Vehicle Footprint	120	43%	55%	54%	52%
	115	62%	70%	68%	70%
	110	74%	83%	77%	82%

Table 81 Average cost per vehicle of reducing emissions to the cap. Note that this is the average cost per vehicle that exceeds the limit (not the costs averaged across the whole fleet).

Utility Parameter	Target gCO_2/km	Flat	Linear	Truncated Linear	Curved
Reference Mass	120	€ 926	€ 570	€ 771	€ 646
	115	€ 990	€ 735	€ 921	€ 796
	110	€ 1,201	€ 912	€ 1,098	€ 947
Vehicle Footprint	120	€ 895	€ 681	€ 791	€ 678
	115	€ 986	€ 801	€ 915	€ 814
	110	€ 1,201	€ 983	€ 1,131	€ 985

Table 82 Estimates of the total costs for reducing the emissions of all vehicles that exceed the limit to the limit or as close to the limit as possible within the restrictions imposed by the cost.

Utility Parameter	Target gCO_2/km	Flat	Linear	Truncated Linear	Curved
Reference Mass	120	€ 3.8bn	€ 3.3bn	€ 3.8bn	€ 3.6bn
	115	€ 6.2bn	€ 5.5bn	€ 6.2bn	€ 5.7bn
	110	€ 9.0bn	€ 7.8bn	€ 8.7bn	€ 7.8bn
Vehicle Footprint	120	€ 3.8bn	€ 3.7bn	€ 4.1bn	€ 3.5bn
	115	€ 6.1bn	€ 5.6bn	€ 6.2bn	€ 5.6bn
	110	€ 8.9bn	€ 8.1bn	€ 8.7bn	€ 8.0bn

Table 83 Proportion of the 2015 fleet which exceeds the limit before any emissions reductions are applied.

Utility Parameter	Target gCO_2/km	Flat	Linear	Truncated Linear	Curved
Reference Mass	120	41%	57%	59%	55%
	115	62%	74%	72%	72%
	110	74%	85%	84%	82%
Vehicle Footprint	120	43%	55%	54%	52%
	115	62%	70%	68%	70%
	110	74%	83%	77%	82%

Table 84 Number of vehicles that remain above the limit after the maximum reduction permitted by the cost curves is applied.

Utility Parameter	Target gCO_2/km	Flat	Linear	Truncated Linear	Curved
Reference Mass	120	105177	15785	86289	39610
	115	221969	24848	178718	57619
	110	316266	35612	264325	85305
Vehicle Footprint	120	105510	58308	110549	58677
	115	214417	79795	187306	85790
	110	305147	142622	277689	144903

Table 85 Total value of the buy-out premiums. This is based on a premium of €100 per gCO_2/km above the limit remaining after the maximum emissions reduction has been applied.

Utility Parameter	Target gCO_2/km	Flat	Linear	Truncated Linear	Curved
Reference Mass	120	€ 184mn	€ 26mn	€ 162mn	€ 57mn
	115	€ 353mn	€ 44mn	€ 288mn	€ 89mn
	110	€ 581mn	€ 64mn	€ 455mn	€ 129mn
Vehicle Footprint	120	€ 174mn	€ 90mn	€ 185mn	€ 92mn
	115	€ 338mn	€ 139mn	€ 308mn	€ 153mn
	110	€ 558mn	€ 230mn	€ 489mn	€ 233mn

11.6 Conclusions

The above analysis demonstrates that it would be feasible to incorporate vehicle-based CO_2 limits into emissions reduction legislation and that a limit could make a useful contribution towards achieving the overall $95gCO_2/km$ target. The cost curves developed for this study show that in most cases vehicle emissions could be reduced to the limit assuming that the correct incentives were in place to stimulate manufacturers to make these reductions.

As the tables above demonstrate, the linear limit tends to come out as the cheapest of the four limits investigated for a given average emission reduction. Moreover it seems that the ‘ceiling’ of the truncated linear limit has to be rather low in order to reach a certain average CO_2 with a similar slope as the linear limit function. This results in higher costs for the truncated limit function. Using this truncated function also leads to less stringent limits for smaller vehicles and therefore less vehicles over cap. The linear limit is also the most achievable (measured in terms of how many vehicles remain above the limit after the emission reductions have been applied).

The flat limit has the greatest number of vehicles already under the limit, but is the most expensive of the four options, with disproportionately large reductions being required at the larger end of the market (both in terms of reference mass and in terms of footprint) and very little in the way of reductions being achieved at the smaller end of the market.

The average cost per vehicle of reducing emissions to the cap is slightly lower when using footprint as the utility parameter than when using mass. However, due to the higher number of vehicles remaining above the limit after the maximum reduction permitted by the cost curves is applied, the total buy-out cost are higher for footprint as the utility parameter.

The level at which any limit is set will depend on to what extent it is desired that the limit acts to reduce fleet average CO_2 emissions towards 95 gCO_2/km and the magnitude of the costs which the industry could be expected to bear. The summary tables above show that for the linear limit function each 5 gCO_2/km reduction in average CO_2 emissions, the additional cost per affected vehicle is in the region of €120 to €185. Particular attention should be paid to the gradient of the limit as this is the principle parameter which defines how the costs are spread across the market. If the gradient is set too steep then the costs shift towards smaller vehicles which tend to be priced lower and sold in greater volumes than larger vehicles.

The cost curves suggest that the reductions necessary to meet the limits can be made in the majority of cases, with maximally 1.4% of new registrations for the linear cap (mostly low volume high performance vehicles) being unable to reduce their emissions to the limit. Revenue generated through the buy-out premium could therefore be expected to be only a few per cent of the costs of emissions reductions and insufficient to justify a feebate (or bonus/malus) system whereby the manufacturers with a high emissions reduction performance would be rewarded using the buy-out credits charged to the manufacturers of vehicles which cannot be reduced below the limit. Instead the premium could exist to ensure that the manufacturers are more likely to adopt emissions reductions as the more cost-effective approach of complying with legislation.

12 Assessment of impacts of a combined target for passenger cars and vans

12.1 Introduction

Until now CO_2 legislation has been developed and implemented for passenger cars and light commercial vehicles separately. A reason for that is that the two vehicle categories represent different markets, with to a large extent unrelated vehicle models. Given the different characteristics and applications of passenger cars and vans, the two categories may have different CO_2 emission reduction potentials, both from a technical and from an economic perspective.

On the other hand there is also overlap between the categories. The class I and II segments of the van market contain a large share of passenger car derived vans. And even for dedicated van platforms, often engines and other powertrain components are shared with passenger car models.

The latter consideration has motivated the question of whether it would be feasible and beneficial to bring passenger cars and vans under a common regulatory target. Based on available evidence, this task explores the feasibility and possible consequences of a combined target for passenger cars and vans.

For the moment three approaches have been identified through which the targets for passenger cars and vans could be combined. One approach, which has already been explored in the 2008 study by AEA, CE Delft, TNO and Öko-Institut[85], is to allow manufacturers to pool their targets for passenger cars and vans, whereby over- or underachievement in one market can be compensated by under- or overachievement in the other market. A tighter integration of the targets would be to set a single target for the combined sales of passenger cars and vans. An alternative to combining the targets for passenger cars and vans in this way, would be to bring vehicles / vehicle platforms that are designed to be both cars and vans at the same time under the passenger car legislation.

12.2 Approach 1: Allowing pooling of the targets for passenger cars and vans

Pooling of the targets for passenger cars and vans would mean that manufacturers can compensate underachievement in one category (expressed in average g/km above target times total sales in that category) by an equivalent overachievement in the other category (expressed in average g/km below target times total sales in that category). The distance to target in passenger cars (M1) and vans (N1) can be compared with different weights:

1) sales:

$$\text{sales}_{M1} \times \Delta CO_{2\,M1} + \text{sales}_{N1} \times \Delta CO_{2\,N1} = 0$$

2) total mileage (= sales × avg. annual mileage × avg. lifetime):

$$\text{sales}_{M1} \times \text{mileage}_{M1} \times \text{lifetime}_{M1} \times \Delta CO_{2\,M1} + \text{sales}_{N1} \times \text{mileage}_{N1} \times \text{lifetime}_{N1} \times \Delta CO_{2\,N1} = 0$$

For the analysis in the 2008 study only option 1) was used, as possible differences in mileage for different vehicle categories are also not taken into account in the internal averaging per manufacturer as well as in the pooling between manufacturers that is allowed under the separate regulatory targets for passenger cars and vans. The second option does, however, highlight that shifting g/km reductions from one category to the other may have consequences for the net fleetwide GHG emission reduction that is achieved. This is due to the very different average mileages of passenger cars and vans. Indicative figures for the annual mileage, as used in the 2006 study by TNO, IEEP and LAT[86], are 16,000 km p.a. for passenger cars and 23,500 km p.a. for vans.

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85 http://ec.europa.eu/clima/studies/transport/vehicles/docs/2008_co2_lcv_en.pdf
86 http://ec.europa.eu/clima/studies/transport/vehicles/docs/report_co2_reduction_en.pdf

The analysis on pooling passenger cars and vans for the 2015 targets showed that for many manufacturers the marginal costs for meeting the vans target in 2015 are higher than for passenger cars, so that they would reduce less on vans and more on passenger cars. For the 2020 target such a comparison of marginal costs is not yet possible and hence this should be done in further study. A light commercial vehicle database of sufficient quality has now been obtained in the currently starting Service Request 3 under the Framework Contract on Vehicle Emissions, and will be used in that project to assess (marginal) costs of meeting the 2020 target for vans using the same detailed methodology as was applied to passenger cars in the Service Request 1 of which this task is a part.

In the 2008 report the following general conclusions were drawn with respect to pooling of the CO_2 targets for passenger cars and vans:

- Due to the fact that for most manufacturers the sales of light commercial vehicles are much smaller than the passenger car sales[87], the overachievement in g/km CO_2 reduction for passenger cars that is necessary to compensate an underachievement in light commercial vehicles is much smaller than the g/km underachievement in light commercial vehicles;
- Pooling of passenger car and van targets is not possible for Isuzu and LDV due to the lack of passenger car sales;
- Pooling of passenger car and van targets may reduce the costs for meeting the combination of targets for both vehicle categories for most manufacturers (as it increases the room for internal averaging) and may allow more flexibility in achieving the target for light commercial targets.

Conclusion

- In principle pooling of targets for passenger cars and vans is also a feasible option for the 2020 targets. The general pro's and con's, identified in the study assessing the 2015 vans target, remain valid.
- The impacts of pooling on the achieved CO_2 reductions and associated costs in the passenger car and van categories, overall and per manufacturer, depend on the marginal costs for meeting the respective targets, but can not be assessed at this moment. For the 2020 passenger car target these marginal costs have been estimated in the present Service Request 1. For light commercial vehicles, however, such numbers are not yet available, but will be generated in the now starting Service Request 3 of this Framework Contract on Vehicle Emissions.

12.3 Approach 2: A combined target for passenger cars and vans

Using the existing targets of 95 g/km for passenger cars and 147 g/km for vans as a starting point, and taking account of the factor of 9 to 10 difference in sales volumes for these two categories, the sales-weighted target for the combined sales of passenger cars and vans would be 100 g/km.

Figure 78 and Figure 80 display the type approval CO_2 emission values of passenger cars and vans as function of the value of the utility parameter for mass resp. footprint. In addition Figure 79 and Figure 81 indicate the overall sales averages for both vehicle categories, the combined average and the utility-based limit functions with 100% slope derived on the basis of the sales-weighted fits and the 2020 targets of 95 and 147 g/km respectively.

Considerations for mass as utility parameter

For mass, Figure 78 shows that the datasets for passenger cars and vans have significant overlap. Nevertheless the sales-weighted least squares fits through both datasets, which form the basis for determining utility-based limit functions, are significantly different. Over a large part of the spectrum, vans show on average higher CO_2 emissions (up to 50 g/km for larger vehicles). Due to the fact that the sales volume of passenger cars is a factor of 9 to 10 larger than that of light commercial vehicles, the sales weighted fit through the combined database is found to be fairly close to the fit for the passenger car dataset. For the same reason the combined overall sales-weighted target of around 100 g/km (see Figure 79) is also closer to the 95 g/km target for passenger cars than to the 147 g/km target for vans. Determining a linear mass-based limit function on the basis of such a combined fit

[87] Annual passenger car sales in the EU 27 are about a factor of 9 to 10 larger than sales of light commercial vehicles. See: http://www.acea.be/collection/statistics

would thus lead to target values which, especially for large vans, would be significantly lower – and hence more ambitious – than what would be the case with a separate target for vans.

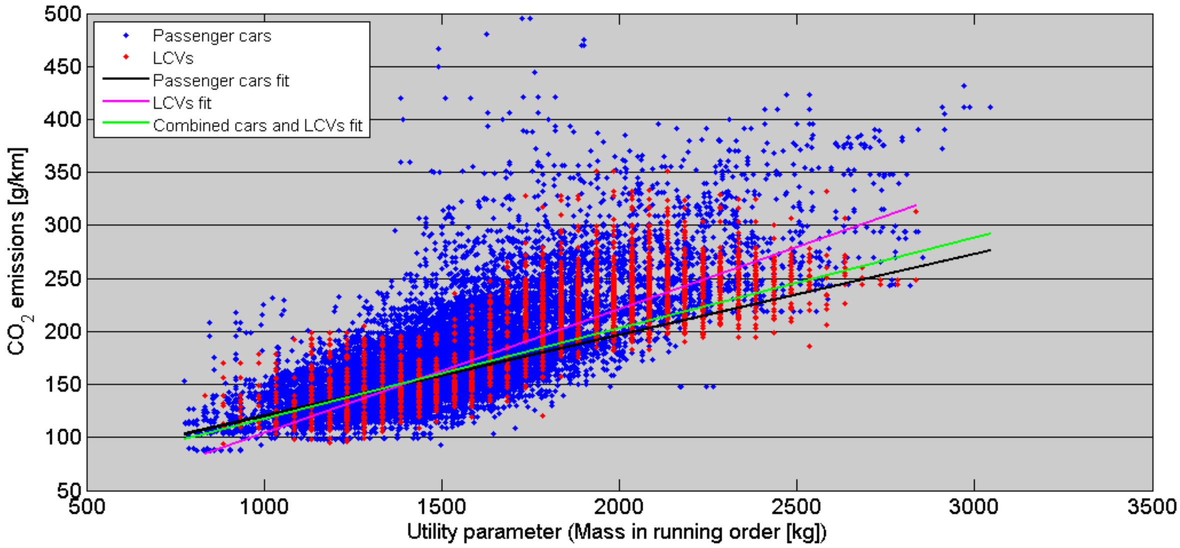

Figure 78 CO_2 and mass values of passenger car sales in 2009 and light commercial vehicle sales[88] in 2010, and the sales weighted least squares fits through both datasets.

The above is further exemplified in Figure 79. Especially for higher mass values, the limit function for passenger cars is several tens of g/km below that for vans. Defining a combined target results in a limit function with 100% slope, which is close to the blue line. Other slopes can be realised by pivoting the green line around the indicated combined average target. Knowing that the vans market is dominated by diesel vehicles which have a lower reduction potential than petrol vehicles, as well as a lower reduction potential compared to passenger cars, it is clear that such a combined limit function would lead to unattainable targets for manufacturers that sell only or mostly light commercial vehicles. For manufacturers that sell more passenger cars than vans the stricter target values for vans would be compensated by less stringent target values for passenger cars. For manufacturers that do not sell vans, setting a combined target for passenger cars and vans would generally mean a relaxation of their reduction target.

Considerations for footprint as utility parameter

Figure 80 shows that for footprint the datasets for passenger cars and vans have hardly any overlap. Vans generally have higher footprint values and the spread in these values is also much larger. For the same footprint value vans generally have much lower CO_2 emissions than passenger cars (the line for vans is below the line for passenger cars). It is also clear that the sales-weighted fits have very different slopes.

In contrast to what is observed for mass as utility parameter, for footprint the sales weighted fit through the combined dataset for passenger cars and vans is found to be close to the fit for vans alone. The 10 times higher sales still give a large weight to the passenger car data, but the large spread in utility values for vans creates a strong leverage resulting in a combined fit that is much flatter than the fit through the passenger car data alone. A linear limit function with 100% slope, based on the sales weighted fit through the combined dataset for footprint as utility parameter (see Figure 81), is thus also completely different from the 100% slope limit function for passenger cars.

The combined 100% slope limit function sets targets for vans that are much lower than is the case for the 100% limit functions for the separate 147 g/km vans target for 2020. At the same time it sets targets for large passenger cars that are so low that they are unattainable, while for small passenger cars the target is relaxed to levels that are already realised in 2009. In order for the limit function to demand meaningful and attainable reductions from both passenger cars and vans the slope would

[88] The "grouping" of vehicles on discrete mass and footprint values is the result of binning of vehicles in the database supplied by JATO.

need to be increased to above 100%, by pivoting around the combined target in Figure 81. However, slope values that bring the limit function closer to the original 100% slope limit function for passenger cars result in setting targets for medium-sized and large vans that are at or even above the levels already realised in 2010. A reasonable compromise does not seem possible with a linear limit function defined in this way.

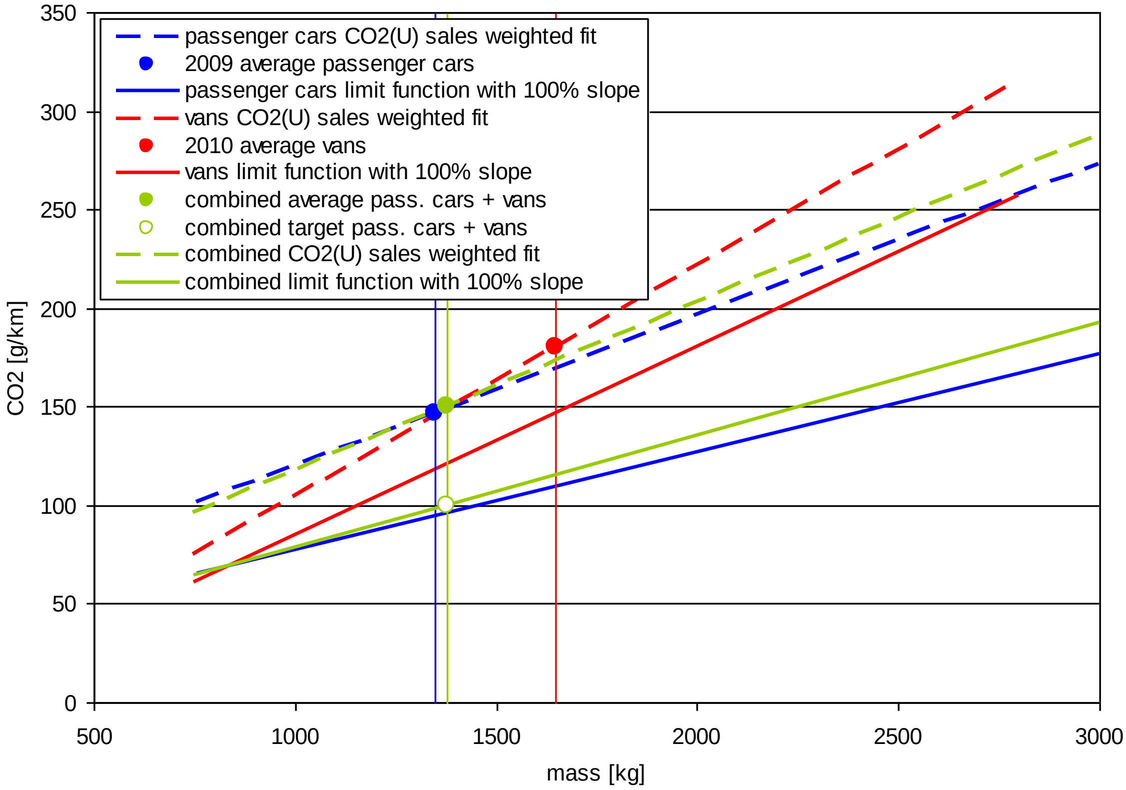

Figure 79 Sales weighted fits through CO_2 and mass for the passenger car sales in 2009 and light commercial vehicle sales in 2010 separately and combined, and the mass-based limit functions with 100% slope based on these fits. The width of the lines indicates the spread in utility values for both vehicle categories.

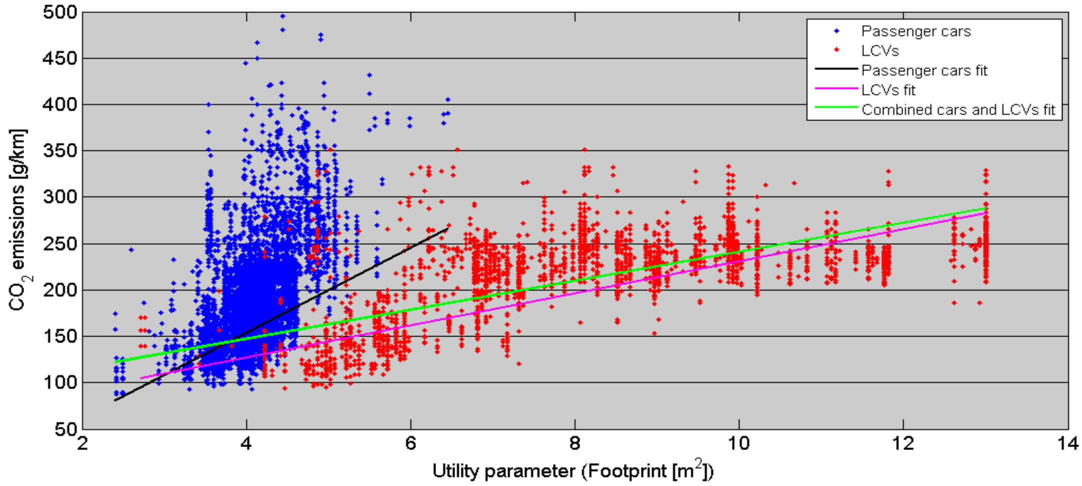

Figure 80 CO_2 and footprint of passenger car sales in 2009 and light commercial vehicle sales[88] in 2010, and the sales weighted least squares fits through both datasets.

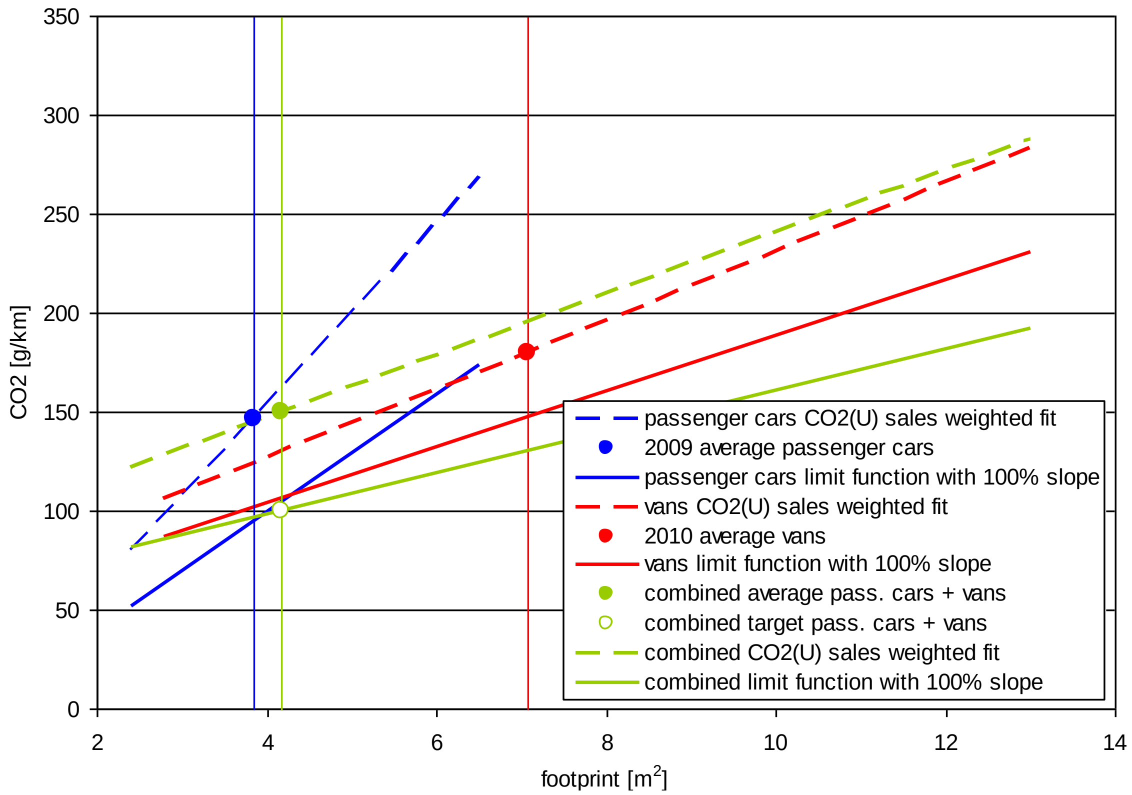

Figure 81 Sales weighted fits through CO_2 and footprint for the passenger car sales in 2009 and light commercial vehicle sales in 2010 separately and combined, and the mass-based limit functions with 100% slope based on these fits. The width of the lines indicates the spread in utility values for both vehicle categories.

The only way in which this conundrum could possibly be resolved to some extent would be to define a non-linear limit function with a high slope at low footprint values and a lower slope at higher footprint values. But even then the large difference in sales between passenger cars and vans, as well as the very different CO_2 values for passenger cars and vans for footprint values between 4 and $6m^2$, would make it extremely difficult to find a compromise that could still represent meaningful targets for medium size vehicles in both categories.

Conclusion

- Based on the overall targets defined in the current regulations for 2020, a combined target for passenger cars and vans would result in a new car sales-weighted average of 100 g/km. Due to a factor of 10 difference in sales volumes, the average utility value as well as the combined target would be much closer to the values for passenger cars than for vans.
- Technically speaking the methodology, developed for defining targets and utility-based limit functions for the two vehicle categories separately, can be applied also to a combined database for both categories.
- In the case of mass as utility parameter, however, a combined linear limit function is likely to lead to targets that are unattainable for vans.
- In the case of footprint as utility parameter, a combined linear limit function that still requires some meaningful reduction effort from vans is likely to lead to targets that can not be attained by passenger cars with above average footprint values.
- In the case of mass as utility parameter a combined target would lead to less stringent targets for manufacturers that do not sell vans. For manufacturers that do not sell passenger cars the combined targets would be much stricter and likely to be unattainable.
- In the case of footprint as utility parameter a combined target would lead to more stringent, and probably difficult to attain targets for manufacturers that do not sell vans. For manufacturers that do not sell passenger cars, the combined targets are stricter than those based on a separate vans target for the case of a 100% sloped limit function, but are likely to be much less demanding for the higher slope values that are needed to make the target attainable for large passenger cars.

12.4 Approach 3: Bringing car-derived vans under the passenger car target

As mentioned above the vans market contains a significant number of passenger car derived vans or vans with engines that are shared with passenger car models. At the same time the passenger car market contains vehicles that are van-derived. Examples of the latter, such as the Citroen Berlingo, are almost equally popular in both markets.

For vehicle models that are based on the same type of technologies it could be argued that they have similar CO_2 reduction potentials and could thus be brought under a single regulatory target. It is certainly true that vans that have technologies in common with passenger car models will be able to benefit from technology cross-over from passenger cars to vans.

The option of bringing car-derived vans under the passenger car target, however, has two important drawbacks:

- It requires a legally waterproof definition of what is a passenger car derived van. It will be difficult to objectively establish the status of a vehicle model without information from the manufacturer. Letting the manufacturer decide in which category a vehicle falls, is likely to give rise to arbitrariness and may provide perverse incentives.
- Singling out this group and joining it with passenger cars greatly reduces the size of the remaining sales that would still fall under the vans target. This strongly reduces the room for internal averaging by manufacturers. It would also make it more difficult to set low emission targets for light commercial vehicles as the remaining vans will be vehicles with more limited reduction potential and limited possibilities to benefit from technology cross-over.

12.5 Conclusion

In general three approaches are identified to arrive at a combined target for passenger cars and vans:

1. allowing manufacturers to pool their targets for passenger cars and vans, whereby over- or underachievement in one market can be compensated by under- or overachievement in the other market;
2. setting a single target for the combined sales of passenger cars and vans in combination with a single utility-based limit function that is applied to both passenger cars and vans;
3. bringing vehicles / vehicle platforms that are designed to be both cars and vans at the same time under the passenger car legislation.

Approach 1) is technically feasible for the 2020 targets and does not appear to have major drawbacks in principle. The viability, however, needs to be determined by detailed impacts that go beyond generic arguments. These details can not be assessed at this point in time. An important condition for avoiding undesired consequences is that the marginal costs for meeting the separate targets for passenger cars and vans are about the same. Pooling on the basis of sales and mileage weighted CO_2 emissions is preferred to avoid that shifting reductions from vans to passenger cars leads to a lower net GHG emission reduction at the overall fleet level.

The impacts of approach 2) strongly depend on the choice of utility parameter. Setting a combined utility-based limit function is likely to lead to unattainable targets for either vans (mass) or passenger cars (footprint). The risk of undesirable distributional impacts (disproportionate impacts on a limited number of manufacturers) is considerable, especially given the fact that for reaching the 2020 target manufacturers will have to use a substantial part of the available reduction potential and are thus more likely to “hit the ceiling” of the cost curves.

The main problem with approach 3) is the legal definition of which vans would qualify for inclusion in the (possibly adapted) passenger car target. Also, this option reduces the room for internal averaging which manufacturers have available to meet the specific targets that are set for the remaining light commercial vehicles that do not fall under the passenger car target.

Important factors that hinder the establishment of a combined target without undesired impacts are that:

- the EU27 passenger car sales are 9 to 10 times larger than the sales of light commercial vehicles;
- the new van sales consist almost entirely of diesel vehicles, which have a more limited reduction potential and offer that reduction at a higher cost than petrol vehicles;
- not all manufacturers sell both passenger cars and vans, and even among those that do the proportions are very different.

All in all approach 1) appears the most feasible. However, overall the evaluation of existing evidence with respect to the different approaches does not seem to create a convincing motivation to strive for a combined target for passenger cars and vans. Since a final judgement on the approaches is strongly affected by detailed consequences of the specific way in which the targets are set, the subject would still benefit from closer scrutiny. This will to a large extent be possible based on results from the currently starting Service Request 3.

13 Evaluation of results for various options and development of proposals for favourable modalities

13.1 Introduction

By 2020 the average CO_2 emissions of newly registered cars will have to be reduced to 95 g/km. To meet this target a number of modalities and compliance mechanisms can be applied in order to

- equally distribute the burden over car manufacturers
- allow higher emissions for cars with a higher utility
- minimize additional manufacturer costs for reaching the target
- avoid perverse incentives
- etc

The main modalities that can be adopted are therefore

- the obligated entity to which CO_2 targets apply,
- the geographical area for which sold cars are taken into account,
- the shape of the limit function
- the utility parameter, and
- penalties or excess premiums.

Options for additional provisions include:

- an additional vehicle-based limit
- supercredits for low-emitting vehicles

Utility parameters have already been discussed and evaluated in previous tasks before the detailed impact assessment. The conclusions drawn in these previous tasks are therefore only discussed briefly in section 13.2.

Section 13.3 will deal with the influence of some additional provisions on the cost of compliance and distributional impacts. These additional aspects are discussed in a separate section because they are not part of the current legislation and it has not yet been decided if and how these aspects will find their way into the legislation for the 95 gCO_2/km target. Although not an actual modality, this section will also deal with the impact of the penetration of electric vehicles, as they might influence the overall additional manufacturer costs significantly.

Finally the overall conclusions on favourable modalities based on insights from the impact assessment will be described in section 13.4.

13.2 Early stage selection of favourable modalities

In tasks 3.1, 3.3 and 3.4 various options for modalities were identified and discussed. The suitability of a number of modalities was investigated in an early stage of the assessment in order to limit the number of modality combinations to be proposed for further detailed assessment to a set of most relevant and most favourable options. As explained in the introduction, these are

- the obligated entity to which CO_2 targets apply,
- the geographical area for which sold cars are taken into account and
- the shape of the limit function.

Moreover the options for the utility parameter have been discussed in Task 3.1, leading to the selection of two potential parameters for further analysis. The final choice of favourable utility parameter will be discussed in section 13.4.

13.2.1 Obligated entity to which CO_2 targets apply

As explained in task 3.1, the responsibility for reaching the target currently lies primarily with the manufacturer groups. But, as already explored in previous projects, alternatively this responsibility could also be placed on individual manufacturers or alternatively on trade organisations or even member states. There are, however, no good reasons to deviate from the existing situation. The current primary responsible entity, the manufacturer group, is the party that is most directly able to affect the CO_2 emissions. Setting the target at the level of manufacturer groups allows significant room for internal averaging, while allowing pooling creates further flexibility on a more aggregate level.

Similarly, there is no good reason to deviate from the aggregation level of the target. A lower level of aggregation, for example having the target relate to individual vehicle types, would limit the manufacturer's flexibility to meet the target whereas, again, the upper limit of the aggregation level is determined only by the ability of the manufacturer to form or join a pool. Therefore manufacturer groups were determined to be the favourable entities to which the CO_2 target applies.

13.2.2 Geographical area for which sold cars are taken into account

The geographical area for which sold cars are taken into account in order to reach the target is currently the EU. In other words, the average of all cars sold within the EU has to be equal to or lower than the CO_2 target set. Similar to the explanation in section 13.2.1, there is no good reason to deviate from the geographical area of the target.

13.2.3 Shape of the limit function

For the implementation of the 95 gCO_2/km target at the level of individual manufacturer groups three types of utility-based limit functions were considered in task 3.3, i.e.:

- linear sloped line targets,
- linear sloped line targets with horizontal cut-offs at the upper or the lower end and
- non-linear curves which approach horizontal cut-offs.

This analysis showed that in the European market situation floors and ceilings of non-linear limit functions do not have significant impacts unless they are set at unreasonable levels. Since the non-linear curves ought to be based on the linear curves with cut-off, the same conclusions were drawn for the continuous limit functions with floors and ceilings. Conclusively, these types of limit functions proved to be interesting theoretical concepts, but they were not taken into account in the remainder of this study.

Having selected linear limit functions, different utility parameters and multiple slope variations are possible. Since this slope value can have a significant effect on the additional manufacturer costs and distributional impacts, it is taken into account in the detailed assessment. The considerations for a final slope value are therefore discussed in section 13.4.

13.2.4 Utility parameter

In order to determine an appropriate utility parameter, the following criteria were used:

- good/acceptable measure of a vehicle's 'utility',
- preference for a continuously-variable function,
- availability of required data,
- understandable,
- minimising perverse effects and
- not excluding technical options.

Based on these criteria two main options were shortlisted, namely empty vehicle weight (or reference mass) in kg and footprint (vehicle track width x wheel base) in m^2. Due to lack of data at the time, this latter option was not assessed in [Smokers 2007][89]. Its suitability was therefore individually studied in task 3.1 and found to be better than for instance pan area, which was studied in [Smokers 2007].

[89] "Possible regulatory approaches to reducing CO_2 emissions from cars". Smokers, R., et al. (2007) Final Report, October, 2007.

Both options (vehicle weight and footprint) were deemed to show a reasonably close correlation to CO_2 emissions. Weight has the obvious advantage of consistency with the present legislation for 2015, but may be less appropriate in the longer term as it reduces the potential of weight reduction as an option for contributing towards meeting the target.

Since choice for a single utility parameter can have a significant effect on the additional manufacturer costs and distributional impact, it is taken into account in the detailed assessment. The considerations for a final utility parameter are therefore discussed in section 13.4, taking into account quantitative results from the detailed cost assessment. For reasons of conciseness results of the initial qualitative evaluation are also reported in section 13.4.

13.3 Influence of additional aspects on the cost of compliance and distributional impacts

13.3.1 Introduction

As explained in section 13.1, this section will deal with the influence of additional aspects on the cost of compliance and distributional impacts. These additional aspects are discussed in a separately, since they are not part of the current legislation and it has not yet been decided if and how these aspects will find their way into the legislation for the 95 gCO_2/km target. The additional aspects are

- the impact of excluding vehicles which exceed a vehicle-based CO_2 limit and
- the effects on costs of compliance of various levels of penetration of electric and hydrogen vehicles in the new car fleet

Although this latter aspect is not an actual modality, this section will also address it, since it might influence the overall additional manufacturer costs significantly.

13.3.2 Impact of excluding vehicles which exceed a vehicle-based CO_2 limit

As a complementary option to the main instrument of setting a target for the sales-weighted average emissions one could consider an additional vehicle-based limit that would exclude vehicle from the market which exceed a given emission threshold. Such an additional vehicle-based limit would ensure that manufacturers also focus on improving the efficiency of high emission vehicles rather than relying on marketing low emission vehicles to offset them. The limit can be uniform or utility based and could be enforced by either excluding non-compliant vehicles from the market or penalizing these vehicles.

In task 3.4 the impacts of a vehicle-based CO_2 limit on manufacturer product portfolios and on their cost of compliance were analysed. The utility based linear limit was deemed favourable since it tends to result in the lowest additional manufacturer costs. For clarity reasons, the slope selected for the vehicle-based limit function was equal to the 100% slope of the general limit function for reaching the 95 gCO_2/km target for manufacturer groups. Finally, three values for overall average CO_2 emissions, in case all sales would comply with this vehicle-based limit function, were analysed, i.e. 110 gCO_2/km, 115 gCO_2/km and 120 gCO_2/km. For the further impact analysis of such a vehicle based-limit, the 115 gCO_2/km option was selected, since it is low enough to give an incentive to reduce CO_2 levels for high CO_2 emitting vehicles and the number of vehicles not being able to meet their individual target is much lower than for the 110 gCO_2/km limit function.

With the vehicle-based limit function in place, a number of vehicles will exceed the limit even after the maximum potential CO_2 reduction has been applied. This applies to about 0.2% of new registrations with a sales weighted exceedance of the cap of 18 g/km. This share of new registrations is lower than the value given in Task 3.4 (approximately 0.3%), since now only manufacturers are analysed with more than 10000 registrations in 2009. As stated in task 3.4, one possible penalty option to deal with these vehicles is to exclude them from the market. This results in a different fleet composition in 2020 and therefore the parameters of the general limit function will change to the values listed in Table 86 so that the sales weighted average of the remaining vehicles still arrives at 95 g/km. Since the excluded vehicles have a long 'distance to target', the relative effect on the additional manufacturer costs is greater than the share of their sales in the total sales. While the measure would have impact on about 0.2% of the vehicles, it leads to a reduction of average additional manufacturer costs of approximately 1.0% or €16. This results in average reduced costs of €8222 per excluded vehicle.

Table 86 Characteristics of assessed limit functions with and without vehicles exceeding the cap even after the maximum reduction has been applied[90]. A mass-based limit function is used and costs are relative to the 2009 reference situation.

mass-based limit function (aU + b)	**sales**	*a*	*b*	*average cost*
100% slope with all vehicles taken into account	100%	0.049	28.5	**2188**
100% slope excluding individual vehicles exceeding target after maximum CO_2 reduction	99.8%	0.048	29.9	**2172**

In case footprint is used as the utility parameter more vehicles (approximately 0.6%) exceed the cap even after application of the maximum CO_2 reduction potential. This share of new registrations is lower than the value given in Task 3.4 (approximately 0.8%), since now only manufacturers are analysed with more than 10000 registrations in 2009. The fact that the share not being able to meet the cap in case of footprint as the used utility parameter, is consistent with a conclusion from task 3.3 on the evaluation of modalities for the sales-weighted target, i.e. that for a footprint-based limit function, more manufacturer groups are unable to meet a given target then is the case for an equivalent mass-based limit function used to set the same overall target. The larger number of excluded vehicles also results in a greater reduction of the additional manufacturer costs (approximately 2.1%). The relative effect on costs compared to the share of vehicles that are excluded is greater for footprint than for mass. This 2.1% or €45 results in average reduced costs of €7217 per excluded vehicle.

Table 87 Characteristics of assessed limit functions with and without vehicles exceeding the cap even after the maximum reduction has been applied. A footprint-based limit function is used and costs are relative to the 2009 reference situation.

footprint-based limit function (aU + b)	**sales**	*a*	*b*	*average cost*
100% slope with all vehicles taken into account	100%	29.4	-18.1	**2197**
100% slope excluding individual vehicles exceeding target after maximum CO_2 reduction	99.4%	28.2	-13.7	**2152**

The relative cost reduction that could be achieved by excluding the vehicles which are not able to meet the additional vehicle-based cap – *i.e.*, the relative reduction in the average cost of compliance for the rest of the fleet – is, although about three times the relative effect on vehicle sales, still relatively small. However, the effect does become significant when analysing the reduced costs per excluded vehicle. Per excluded vehicle the avoided reduction costs over all vehicles that are still sold equal €8222 and €7217 for the mass and footprint-based limit function respectively. These values are of similar order of magnitude as the profit margins of the manufacturers on larger cars that are not too high end in the market. For many manufacturers the reduced compliance costs might thus at least partly compensate the reduced profits resulting from no longer selling certain high emitting vehicles. To what extent this means that such a vehicle-based cap could be introduced without harming the overall profitability of manufacturers too much however is a question that requires some more detailed analysis of the manufacturers that are most strongly affected by an additional vehicle based limit and the specific vehicles to which this applies.

Nonetheless, for certain manufacturers selling high CO_2 emitting vehicles, such a vehicle-based limit might result in significantly lower turnover because they will no longer be able to sell certain vehicles in their portfolio.

It is expected that the exclusion of vehicles, unable to meet the cap, would be perceived as a radical step to take and it is therefore likely that this would be met with substantial resistance, both from vehicle manufacturers, governments, and possibly also the segments of society which are able to

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[90] CO_2 limit = a U + b, with U the utility parameter.

and interested in purchase of the targeted vehicles. However, the fact that the 'utility value' of these vehicles is low compared to their impact on the CO_2 emissions could be an argument for exclusion.

13.3.3 Effects on costs of compliance of various levels of penetration of alternative energy vehicles in the new car fleet

Even though the penetration of alternative energy vehicles (such as battery electric or hydrogen fuel cell vehicles) is not a modality, it is a variable that may significantly affect the overall additional manufacturer costs and is therefore discussed in this task. Electric vehicles (EVs, including full-electric vehicles (FEVs), plug-in hybrid vehicles (PHEVs) and Extended Range Electric Vehicles (EREVs)) were selected as an example in this exploration because they are already available in the market to a reasonable extent and seem to be penetrating more robustly than other alternative energy vehicles. Therefore, in task 3.3, the effect of various penetration levels of EVs on the additional manufacturer cost for meeting the overall target of 95 gCO_2/km, was calculated under the current assumption that FEVs count as zero CO_2 emission vehicles under the CO_2 regulation. Type approval CO_2 emissions for PHEVs and EREVs are not zero and are determined as a weighting of two tests carried out with a battery that is fully charged respectively fully discharged at the start of the test. Typical values are often of the order of 50 g/km or lower. No super credits were assumed in these calculations as these are discussed separately.

Effect of the penetration of alternative energy vehicles on additional ICEV manufacturer costs

As can be seen in Table 88 and Table 89, the penetration of EVs leads to a reduction of the additional manufacturer costs for meeting the target, irrespective of the utility parameter. The differences between the two utility parameters within each scenario are smaller than 0.6%.

Table 88 Impacts on additional manufacturing costs of taking various electric vehicle penetration scenarios into account. A mass-based limit function is used and costs are relative to the 2009 reference situation. Data taken from task 3.3.

mass-based limit function (aU + b)	**EV share**	**average EV emissions [g/km]**	**average ICEV emissions [g/km]**	*average cost*
Baseline scenario	0.0%	-	95.0	**2188**
Scenario 1	5.5%	48	97.7	**2136**
Scenario 2	2.7%	45	96.4	**2145**
Scenario 3	10%	47	100.5	**2110**
Scenario 4	10%	0	105.6	**2111**

Table 89 Impacts on additional manufacturing costs of taking various electric vehicle penetration scenarios into account. A footprint-based limit function is used and costs are relative to the 2009 reference situation. Data taken from task 3.3.

footprint-based limit function (aU + b)	**EV share**	**average EV emissions [g/km]**	**average ICEV emissions [g/km]**	*average cost*
Baseline scenario	0.0%	-	95.0	**2197**
Scenario 1	5.5%	48	97.7	**2147**
Scenario 2	2.7%	45	96.4	**2155**
Scenario 3	10%	47	100.5	**2123**
Scenario 4	10%	0	105.6	**2123**

From these tables can be concluded that the average additional manufacturer costs of the scenario 1 to 4 (with penetration of EVs) are lower that the costs for the baseline scenario (without penetration of EVs). It can therefore be concluded that manufacturing electric vehicles could become a cost effective measure to reach the 95 gCO_2/km target from a manufacturer perspective. The net reduction in additional manufacturer costs associated with diminished reduction efforts required for conventional vehicles more than outweighs the additional manufacturing costs of the EVs relative to ICEVs.

An important condition for this statement is that electrically driven vehicles account for substantially lower CO_2 emissions than their ICE counterparts. In reality, although the 'tank-to-wheel' (TTW) emissions from such electric drive trains are zero, their complete ‘well-to-wheel’ (WTW) emissions are not. Depending on the applied energy sources, the WTW emissions could be as high as the WTW emissions from cars running on fossil fuels. However, with clear objectives at the European level to improve decarbonisation of the electricity sector by 2020[91], it is likely that average WTW CO_2 emissions will be lower for vehicles driving on electric energy than for conventional vehicles.

Since currently EVs are attributed zero emissions within the fleet average system, there is no legislative incentive for manufacturers to improve the energy efficiency of EVs. However, a strong incentive for that is likely to come from customer demands with respect to increased range and reduced costs.

In order to realistically account for the CO_2 impact of electric vehicles, it is necessary to understand their total CO_2 impact (including upstream emissions for electricity production and their impact on the real-world emissions of conventional vehicles) and to define an approach for handling them with respect to the European CO_2 regulation. The question of whether it is desirable to account for the WTW emissions depends on numerous economical, political and societal factors. Recommendations to resolve this future issue are not made within this study.

Effects of super credits

In the currently active legislation that was introduced to reach a target of 130 gCO_2/km by 2015, super credits were introduced in order to encourage the development and application of propulsion technologies that lead to very low or zero (tailpipe) CO_2 emissions, such as battery-electric or hydrogen fuel cell based powertrains. Such super credits are given to manufacturers until 2015 for every car sold that emits less than 50 gCO_2/km. In calculating the average specific emissions of CO_2, each new passenger car with specific CO_2 emissions of less than 50 g/km is counted as 3.5 cars in 2012 and 2013, 2.5 cars in 2014, 1.5 cars in 2015, and 1 car from 2016 onwards.

In principle the super credits mechanism could be re-introduced after 2016 as long as it is discontinued before the next target year, since otherwise it would erode the net impact of the CO_2 legislation. If the super credits mechanism would be applied in the period between 2016 and 2020, the sales of very low CO_2 emitting vehicles (hydrogen or electric) might lead to a decreased incentive for car manufacturers to reduce CO_2 emissions of high emitters, since they can compensate for such vehicles.

For instance, a similar super credits scheme could be introduced in 2017; each new passenger car with specific CO_2 emissions of less than 50 g/km would be counted as 3.5 cars in 2017 and 2018, 2.5 cars in 2019, 1.5 cars in 2020, and 1 car from 2021 onwards. In case all manufacturers would already comply with the 95 g/CO_2/km target by 2017 with the super credits mechanism in place, the actual average emissions would be like depicted in Table 90 and Table 91. As can be seen, the leverage of such a scheme can have quite a negative impact on the average emission in the years prior to the target year. It does therefore not seem recommendable to continue the super credits policy after 2016.

Note: these effects result from the fact that the regulatory metric in place at the moment and until 2020 assesses only the tailpipe (“Tank-To-Wheel”) emissions. An alternative metric taking into account the upstream emissions of the energy carrier might avoid these perverse effects.

This leads to the conclusion that applying the super credits mechanism has the drawback that it could lead to an erosion of the 95 gCO_2/km target in case the mechanism is continued until after the target year 2020. Even when the mechanism is only applied between 2015 and 2020 it could result in higher net CO_2 emissions. This hazard only increases with more vehicles becoming eligible, because the regulation on 95 gCO_2/km fleet average will already be such a strong incentive for manufacturers to market EVs that super credits will be unnecessary.

[91] Directive 2009/28/EC, “Promotion of the Use of Energy from Renewable Sources” (issued April 23, 2009), established 20% share of energy from renewable sources as mandatory national targets for 2020.

Table 90 Average CO_2 emissions if a similar super credits scheme is applied for the 2020 target as the scheme currently applied for the 2015 target, assuming manufacturers will already reach their 2020 target by 2017. Mass-based limit function.

mass-based limit function (aU + b)	year	supercredit factor	average EV emissions [g/km]	average ICEV emissions [g/km]	average emissions [g/km]
Baseline scenario	2017-2020	-	-	95.0	95.0
Scenario 1	2017/2018	3.5	48.0	104.5	101.4
Scenario 2	2017/2018	3.5	44.7	99.8	98.3
Scenario 3	2017/2018	3.5	46.9	114.1	107.3
Scenario 4	2017/2018	3.5	0.0	131.9	118.8
Scenario 1	2019	2.5	48.0	101.8	98.9
Scenario 2	2019	2.5	44.7	98.4	97.0
Scenario 3	2019	2.5	46.9	108.7	102.4
Scenario 4	2019	2.5	0.0	121.4	109.3
Scenario 1	2020	1.5	48.0	99.1	96.3
Scenario 2	2020	1.5	44.7	97.1	95.7
Scenario 3	2020	1.5	46.9	103.2	97.5
Scenario 4	2020	1.5	0.0	110.8	99.8
Scenario 1	2021	1.0	48.0	97.7	95.0
Scenario 2	2021	1.0	44.7	96.4	95.0
Scenario 3	2021	1.0	46.9	100.5	95.0
Scenario 4	2021	1.0	0.0	105.6	95.0

Table 91 Average CO_2 emissions if a similar super credits scheme is applied for the 2020 target as the scheme currently applied for the 2015 target, assuming manufacturers will already reach their 2020 target by 2017. Footprint-based limit function.

footprint-based limit function (aU + b)	year	supercredit factor	average EV emissions [g/km]	average ICEV emissions [g/km]	average emissions [g/km]
Baseline scenario	2017-2020	3.5	-	95.0	95.0
Scenario 1	2017/2018	3.5	48.0	104.5	101.4
Scenario 2	2017/2018	3.5	44.7	99.8	98.3
Scenario 3	2017/2018	3.5	46.9	114.1	107.3
Scenario 4	2017/2018	3.5	0.0	131.9	118.8
Scenario 1	2019	2.5	48.0	101.8	98.9
Scenario 2	2019	2.5	44.7	98.4	97.0
Scenario 3	2019	2.5	46.9	108.7	102.4
Scenario 4	2019	2.5	0.0	121.4	109.3
Scenario 1	2020	1.5	48.0	99.1	96.3
Scenario 2	2020	1.5	44.7	97.1	95.7
Scenario 3	2020	1.5	46.9	103.2	97.5
Scenario 4	2020	1.5	0.0	110.8	99.8
Scenario 1	2021	1.0	48.0	97.7	95.0
Scenario 2	2021	1.0	44.7	96.4	95.0
Scenario 3	2021	1.0	46.9	100.5	95.0
Scenario 4	2021	1.0	0.0	105.6	95.0

13.4 Impact of detailed assessment on favourable modalities

13.4.1 Introduction

As discussed in section 13.2, the suitability of a number of modalities was already investigated before the detailed analysis involving use of a costs assessment model to compare options for modalities with respect to their effect on average cost of compliance and distributional impacts. This resulted in manufacturer groups as the entities to which the CO_2 target applies, total EU as the geographical area in which the target has to be met and a linear sloped utility limit function. For the utility parameter however both footprint and reference mass were found suitable. Therefore both utilities were taken into account in the detailed assessment. The impact of this detailed assessment on the choice for a final utility parameter is therefore discussed in more detail in this section.

13.4.2 Linear limit function slope considerations

For the linear curves, various slopes were analysed in a similar way as in prior studies such as [Smokers 2007]. Nine different slopes were analysed, all derived from the 100% slope (see text box below).

> ***100% slope***
> *The "100% slope" limit functions is constructed by firstly introducing a sales-weighted least squares fit through the CO_2 emission values of all 2009 vehicle models plotted as function of their respective utility values. Hereafter this line is lowered to meet the average of 95 g/km in such a way that the relative reduction is equal for all utility values. This way the "100% slope" base limit function is defined as the limit function for which the burden of CO_2 reduction between 2009 and 2020 is evenly distributed over the range of utility values. Relative to this reference alternatively sloped limit functions can be defined. The labelling of these slopes is based on a percentage of the 100% slope. Finally nine slopes were analysed, i.e. 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130% and 140%.*

Comparing the 100% slope based on 2010 data, reveals a much flatter slope than the 100% slope based on 2006 data, which is the result of a relatively large reduction of CO_2 emissions from vehicles with relatively high utility values. Closer analysis even leads to the conclusion that the 100% limit function based on 2010 data is even slightly flatter than the limit function for the 130 gCO_2/km target for 2015, which was a 60% slope function based on 2006 sales data (Figure 82).

For reference mass as a utility parameter it was already concluded in [Smokers 2007] that the 60% slope function based on 2006 sales data was sufficiently flat to prevent gaming. Since the 100% slope function based on 2010 is even flatter, the slope of the limit function does not need to be lowered below 100%. Footprint is a utility parameter that is more difficult to game with since changing it requires structural changes to the design and construction of the vehicle. However, to prevent incentives towards larger cars, also here the limit function cannot be too steep.

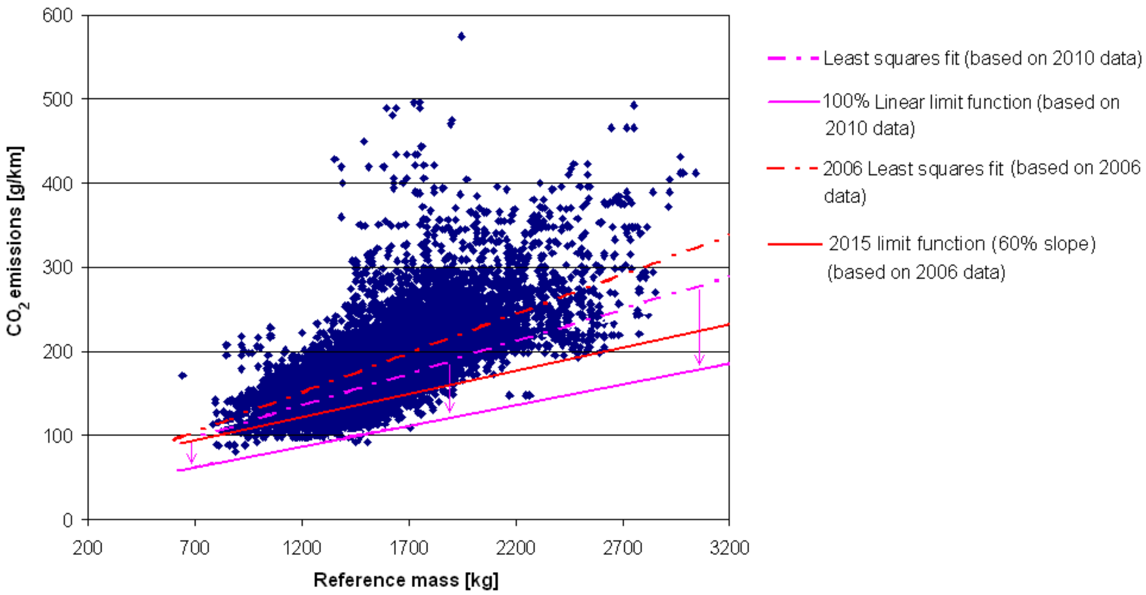

Figure 82 The 100% slope mass-based limit function (based on 2010 data) compared to the 2006 60% mass-based limit function (based on 2006 data) for the 2015 target.

13.4.3 Utility parameter considerations

Qualitative pros and cons of both utility parameters

As stated in section 13.2.4, two parameters were found to be suitable, i.e. reference mass and footprint. The most important advantages and disadvantages of both possibilities, as assessed prior to the study of costs of compliance, are listed in Table 92 and Table 93.

Table 92 Pros and cons of reference mass as utility parameter prior to the cost calculations.

Reference mass	
Pros	**Cons**
Easily / objectively measured	Not a direct measure of utility
Accepted by industry (continuity with current legislation)	Possibilities for gaming depend on slope of limit function
Good correlation with CO_2 emissions	Easy options for gaming: “Brick in the boot”
	Makes weight reduction as CO_2 reduction measure much less attractive

Table 93 Pros and cons of footprint as utility parameter prior to the cost calculations.

Footprint	
Pros	**Cons**
Easily / objectively measured	Relatively tough on compact / high cars (e.g. MPVs)
Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions	May promote tendency towards larger cars unless compensated for such autonomous footprint increase
Better proxy for utility than mass	
Used in US legislation	
Good correlation with CO_2 emissions	

Comparison of both utility parameters based on additional manufacturer cost

The results of the cost assessment and distributional impacts do not significantly contribute to the selection of either utility parameter. Differences in cost and distributional impacts are found to be relatively small:

- From task 3.3 it was concluded that for the 100% slopes, using the footprint based limit function resulted in negligibly higher costs by just over 0.4%. Since besides the additional costs, several advantages and disadvantages are known for both parameters, this difference seems too small to motivate the choice of the favourable utility parameter.
- Task 3.3 also showed that a footprint based utility parameter leads to an extra manufacturer group not being able to meet its target. However, the sales share of this manufacturer group is only 0.7% of total sales. Similarly to the cost comparison between the two parameters, this difference does not seem significant enough for selecting a favourable utility parameter.
- Finally, the difference in distributional impact between the mass and footprint-based limit functions, lies mainly with large petrol vehicles. These vehicles tend to have relatively higher costs for footprint than for mass. Therefore manufacturers such as Chrysler, Spyker (incl. Saab) and Tata (incl. Land Rover and Jaguar) have higher additional manufacturer costs for reaching their target. On the other hand, manufacturers with higher sales volumes, such as Ford, have lower manufacturer costs when a footprint-based limit function is applied.

Comparison of both utility parameters based on impacts of the penetration of low emitting vehicles

The penetration of EVs could potentially lead to a reduction of additional manufacturer costs to meet the target of 95 gCO_2/km, as was concluded from task 3.3. However, the impact from this penetration is very similar for both utility parameters. The differences between the additional manufacturer costs based on either mass or footprint as the utility parameter are below 0.6%. This difference also seems too small to motivate the choice of the favourable utility parameter.

Comparison of both utility parameters based the of impacts of excluding vehicles exceeding a vehicle-based CO_2 limit

A decision on whether a vehicle based limit-function should be introduced has not yet been taken. However, in case such a mechanism would be applied, it is useful to know the differences between both utility parameters.

From section 13.3.2 it was concluded that the additional manufacturer costs, in case vehicles exceeding a vehicle-based CO_2 limit are excluded from the market, are slightly lower for footprint compared to mass as a utility parameter. On the other hand, the usage of footprint as a utility parameter, leads to the exclusion of more vehicles, which can be perceived as a negative effect. Finally, the cost reduction per excluded vehicle[92] is very similar for both utility parameters. This makes that in case a vehicle-based limit function would be applied, this is no ground to decide upon a favourable utility parameter.

Favourable utility parameter

Since no obviously favourable utility parameter arises from the cost assessments, the choice will need to be based on general pros and cons as discussed above. From these pros and cons two potential effects of the utility parameter choice seem more important than other ones.

Firstly, an important argument is that mass reduction will be an important measure for future CO_2 reduction beyond 130 g/km. If mass is used as a utility parameter, applying this measure is made unattractive, since it would lead to a stricter CO_2 target for a manufacturer. Since the choice for footprint as a utility parameter would not influence the CO_2 target of a manufacturer in case of light weighting its vehicles, this parameter seems favourable based on this effect.

Moreover the argument that footprint is a better measure for utility is a valid one from a consumer perspective. Consumers tend to buy certain vehicles because of their size, e.g. to transport more people or goods or to transport people with more legroom and comfort, while they do not purchase a certain car because it is heavy. Since footprint is a much better proxy for vehicle size and resulting utility than mass, footprint seems favourable from a consumer perspective.

As a result of these arguments, footprint seems to be the single favourable utility parameter.

A risk of changing the utility parameter could be that European policy making on cars and CO_2 is perceived by stakeholders as inconsistent, and might make critical stakeholders wonder what changes are to be expected for a next generation standard beyond 2020. The evaluation of alternative utility parameters, however, has made clear that other options generally do not provide any significant advantages compared to footprint but usually do have disadvantages and aspects that make them less practical or even unfeasible in practice. Whereas mass was chosen for the 2015 target, partly because the at least equally attractive alternative of footprint was not available due to the absence of data in the Monitoring Mechanism, there are no alternatives in view now that are potentially better than footprint or mass but can not be applied yet for practical reasons.

13.4.4 Penalty or excess premium

If the average CO_2 emissions of a manufacturer's fleet (sales of new cars) exceed its limit value, the manufacturer has to pay an excess emissions premium for each car registered. According to COM(2007) 856, this premium amounts to €95 for every g/km of exceedance from 2019 onwards.

In Figure 83, the marginal costs for realising the final 1 g/km CO_2 to meet the manufacturer's equivalent of the 95 g/km target are depicted. The relative reduction at which the marginal costs are equal to the excess premium level of €95/g/km (which is a proxy of the hypothetical reduction effort after which it could become cheaper to pay the premium) is different for every manufacturer, because the 2002 baseline emission values (on which the relative reductions are based) are different. As can be concluded from this figure, the excess premium level from 2019 onwards is slightly higher than the average cost per reduced gCO_2/km for every manufacturer (which is € 91 g/km). Therefore, this level of excess premium should provide enough incentive for the majority of manufacturers to reduce the CO_2 levels of their vehicle fleet rather than paying the penalty for exceeding its limit value. In order for the excess premium to be an incentive for all manufacturers (apart from the ones not being able to meet that target at all) to reach their equivalent of the 95 g/km target, this excess premium level should be much higher. E.g. the cost for Spyker Cars (incl. Saab) to reduce the final 1 g/km to meet their target will cost € 196 according.

[92] Calculated for both utility parameters by dividing the reduction of additional manufacturer costs as a result of the exclusion of vehicles by the share of vehicles excluded.

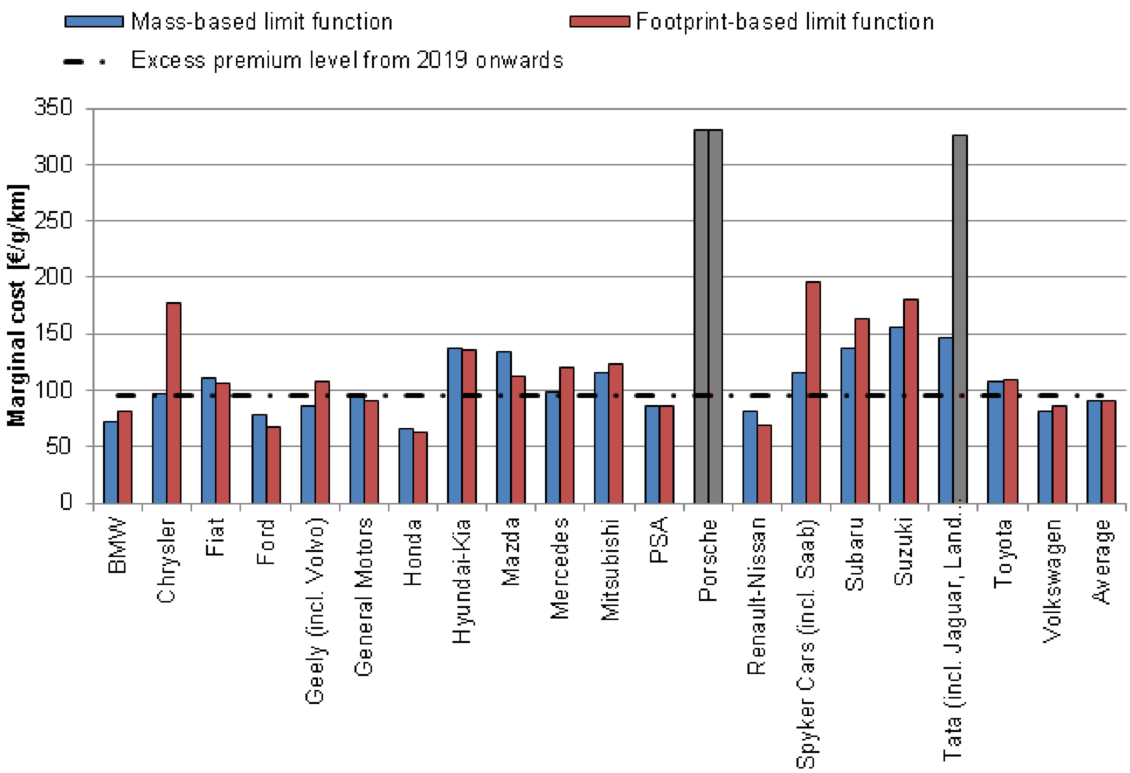

Figure 83 Maximum marginal cost for every analysed manufacturer group for both reference mass and footprint as utility parameters and a 100% slope for reaching the average 95 g/km in 2020. The grey bars indicate manufacturers that can not reach their target even with the maximum reduction possible.

13.5 Overall recommendations for favourable modalities

By 2020 the average CO_2 emissions of newly registered vehicles will have to be reduced to 95 g/km. For meeting this target, a number of modalities and compliance mechanisms can be applied, and the underlying objectives to the choice of which are the most appropriate include

- equally distribute the burden over car manufacturers
- allow higher emissions for cars with a higher utility
- minimize additional manufacturer costs for reaching the target
- avoid perverse incentives

13.5.1 Favourable modalities

For this purpose five modality types were assessed with the goal of defining favourable modality characteristics.

Firstly, manufacturer groups were determined to be the favourable entities to which the CO_2 target should apply, since a lower level of aggregation would limit the manufacturer's flexibility to meet the target whereas, again, the upper limit of the aggregation level is determined only by the ability of the manufacturer to form or join a pool.

The geographical area for which sold cars are taken into account in order to reach the target is currently the EU. In other words, the average of all cars sold within the EU has to be equal to or lower than the CO_2 target set. Similar to the explanation in section 13.2.1, there is no good reason to deviate from the geographical area of the target.

Thirdly, a linear utility-based limit function was chosen over utility-based limit functions with floors and ceilings, since in the European market situation floors and ceilings of non-linear limit functions do not have significant impacts unless they are set at unreasonable levels. Having selected a linear function, the slope can be chosen such that vehicles with higher utility value are allowed proportionally higher CO_2 emissions. However, making the slope too steep can lead to gaming by manufacturers. Analysis of various slopes resulted to the selection of a 100% slope. Since this 100% mass-based limit function (based on 2010 data) is already flatter than the limit function for the 130 gCO_2/km target for 2015 (which was a 60% slope function based on 2006 sales data) and this 2015 limit function was found to be sufficiently flat to prevent gaming, the slope for 2020 does not need to be lowered below 100%. Footprint is a utility parameter that is more difficult to game with than mass, since changing it requires complex and expensive structural changes to the design and construction of the vehicle. However, to prevent incentives towards larger cars, also here the limit function cannot be too steep.

Since no obviously favourable utility parameter (reference-mass or footprint) arose from the cost assessments, rather qualitative considerations lead to the utility parameter footprint to be the preferred over reference mass as the fourth favourable modality. An important argument was that mass reduction will be an important measure for future CO_2 reduction beyond 130 g/km. If mass is used as a utility parameter, applying this measure is made unattractive, since it would lead to a stricter CO_2 target for a manufacturer. Since the choice for footprint as a utility parameter would not influence the CO_2 target of a manufacturer in case of light weighting its vehicles, this parameter seems favourable based on this effect. Moreover the argument that footprint is a better measure for utility is a valid one from a consumer perspective. Consumers tend to buy certain vehicles because of their size, e.g. to transport more people or goods or to transport people with more legroom and comfort, while they do not purchase a certain car because it is heavy. Since footprint is a much better proxy for vehicle size and resulting utility than mass, footprint seems favourable from a consumer perspective.

A risk of changing the utility parameter could be that European policy making on cars and CO_2 is perceived by stakeholders as inconsistent, and might make critical stakeholders wonder what changes are to be expected for a next generation standard beyond 2020. The evaluation of alternative utility parameters, however, has made clear that other options generally do not provide any significant advantages compared to footprint but usually do have disadvantages and aspects that make them less practical or even unfeasible in practice. Whereas mass was chosen for the 2015 target, partly because the at least equally attractive alternative of footprint was not available due to the absence of data in the Monitoring Mechanism, there are no alternatives in view now that are potentially better than footprint or mass but can not be applied yet for practical reasons.

If the average CO_2 emissions of a manufacturer's fleet of new registrations exceed its limit value, the manufacturer has to pay an excess emissions premium for each car registered. From 2019 onwards, this premium amounts to €95 for every g/km of exceedance and for every new car sold. This level of excess premium is higher than the average cost of the final 1 g/km that has to be reduced in order to reach the 95 g/km target. Therefore the excess premium level of €95 for every g/km of exceedance does not need to be changed in order for it to still function as an incentive to the majority of the manufacturers for pursuing CO_2 reduction.

13.5.2 Additional provisions

Besides actual modalities, two options for additional provisions were assessed, i.e. an additional vehicle-based limit and super credits for low-emitting vehicles. The reason for applying an additional vehicle-based limit could be that it would give manufacturers an incentive to reduce the CO_2 emissions of their whole car portfolio. This way, high emissions of large cars could not be fully compensated by selling small low CO_2 emitting vehicles. Conclusions from a detailed analysis were that the relative cost reduction that could be achieved by excluding the vehicles which are not able to meet the additional vehicle-based cap is relatively small. However, the effect does become significant when analysing the reduced costs per excluded vehicle. Per excluded vehicle, the avoided reduction costs are of similar order of magnitude as the profit margins of the manufacturers on larger cars that are not too high end in the market. For many manufacturers the reduced compliance costs might thus at least partly compensate the reduced profits resulting from no longer selling certain high emitting vehicles. To what extent this means that such a vehicle-based cap could be introduced without harming the overall profitability of manufacturers too much, however this is a question that requires some more detailed analysis of the manufacturers that are most strongly affected by an additional vehicle based limit and the specific vehicles to which this applies. Nonetheless, for certain manufacturers selling high CO_2 emitting vehicles, such a vehicle-based limit might result in significantly lower turnover because they will no longer be able to sell certain vehicles in their portfolio. It is expected that amongst other reasons, this might lead to substantial resistance, both from vehicle manufacturers, governments, and possibly also the consumers and other stakeholders in society. Still, the fact that the ‘utility value’ of these vehicles is low compared to their impact on the CO_2 emissions could be an argument for exclusion.

Super credits were introduced in order to encourage the development and application of propulsion technologies that lead to very low or zero (tailpipe) CO_2 emissions, such as battery-electric or hydrogen fuel cell based powertrains. However, the leverage of the currently active super credits scheme can have quite a negative impact on the overall CO_2 emissions. For instance, if the mechanism is continued until after the target year 2020, it could lead to an erosion of the 95 gCO_2/km target. Even if the mechanism is only applied between 2015 and 2020 it could result in higher net CO_2 emissions. This hazard only increases with more vehicles becoming eligible, since the 95 gCO_2/km will already be such an important incentive for manufacturers to market EVs that super credits will be unnecessary. It does therefore not seem recommendable to continue the super credits policy.

14 Note on the link between the costs associated with the introduction of CO_2 reduction technology and car prices

Drafted by Ian Skinner (TEPR)[93] and Richard Smokers (TNO)

14.1 Background

One of the most important elements when developing legislation to reduce CO_2 emissions from passenger cars is the estimation of the potential cost implications of meeting different efficiency standards. Within the main report, this has been undertaken with respect to the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars. The aim of making such estimates is to ensure that the standards that are set within legislation are achievable, yet challenging, but that they do not incur excessive costs on manufacturers, consumers or society generally.

Estimates of increased costs to manufacturers have been undertaken in previous studies undertaken for the European Commission, in relation to the development of the initial Regulation. In the IEEP/CE/TNO 2007 study[94] the 130 g/km was estimated to result in an average retail price increase of around € 1100 relative to 2006, equivalent to 5% of the average retail price in 2006 or an annual increase of around 0.6% in the 2006-2015 period.

Since the adoption of this Regulation CO_2 emissions from new cars have declined significantly. Additionally, in spite of the increased costs that manufacturers have faced as a result of Regulation 443/2009, average car prices in the EU appear to have been decreasing in real terms in recent years (see Table 94). ACEA also believes that car prices have decreased in real terms by around 10% in the last decade, and that this trend is not likely to change[95].

Table 94 Changes in real car prices in the EU.

12 months to:	11/03	5/04	11/04	5/05	11/05	5/06	11/06	5/07	1/08	1/09	1/10
Price Change	-0.7%	-1.5%	-1.9%	-1.5%	-1.5%	-1.6%	-1.4%	-1.0%	-3.2%	-3.1%	-0.6%

Source: Various European Commission summaries of reports published by DG Competition; see http://ec.europa.eu/competition/sectors/motor_vehicles/prices/report.html*. The information was taken from the high level numbers communicated by the Commission in the summary reports and press releases, as these data are not included in the full reports themselves.*

Hence, these observed decreases in the average price of cars sold in Europe may seem to suggest that the costs of reducing CO_2 emissions from passenger cars have been overestimated in studies underlying the Impact Assessment carried out for Regulation (EC) No 443/2009 on CO_2 emissions from cars. However, such a conclusion is not necessarily valid, as this note aims to set out.

In order to achieve this, this note considers:

- The ex post evidence regarding the effect of CO_2 legislation on vehicle prices.
- How the costs of compliance have been estimated ex ante in support studies.
- Factors (other than CO_2 legislation) that affect manufacturers' costs.
- The factors that influence how additional costs are translated into changes in vehicle prices.
- Whether the ex post evidence provides convincing clues as to how increased costs are passed through to consumers.
- What we can learn from this analysis with respect to improving ex ante estimates of costs and of impacts of CO_2 legislation on industry, consumers and society.

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93 Ian Skinner was contracted via AEA and would like to thank Arno Schroten (CE Delft) for commenting on earlier versions of this note.

94 Service Contract on possible regulatory approaches to reducing CO_2 emissions from cars: Study on the detailed design of the regulation to reduce CO_2 emissions from new passenger cars to 130 g/km in 2012, carried out by IEEP, CE Delft and TNO on behalf of the European Commission (DG ENV, contract nr. 070402/2006/452236/MAR/C3) in 2007.

95 http://www.acea.be/index.php/collection/co2_emissions_faq_on_co2/#Q11

The note draws on evidence gathered in a parallel project for the European Commission's DG Climate Action[96], which is seeking to identify and model the effects of (environmental and safety) regulations on car prices, as well as other literature.

14.2 Discussion

A closer look at the ex post evidence regarding the effect of CO_2 legislation on vehicle prices

As noted above, there appears to be a consensus that car prices have been decreasing in real terms in the last 10 years or so. However, without fully understanding the way in which any figures were calculated, it is not possible to conclude from the figures presented in Table 94 that car prices are actually declining in real terms. In order to draw this conclusion, the figures would have had to have been calculated within each segment. It is important to understand price trends by segment, as otherwise the reduction in average prices could also be the result of a shift in purchasing patterns between segments. For example, if consumers are buying smaller, less powerful or less luxurious cars, the decline in prices could be a result of changes in purchasing patterns between segments rather than real declines in the prices of car models within the various segments. The figures presented in Table 94 could also hide differences in price changes between segments, as the average price could still decline in spite of price increases in some segments.

Without being able to understand fully the way in which the figures presented in Table 94 have been calculated, we would not want to conclude that it is evidence of a decline in car prices in real terms. In this respect, a minimum requirement for reaching a conclusion that prices are decreasing in real terms would be a more transparent and detailed analysis of price trends per segment. Additionally, before it would be possible to attempt to link the impact of the passenger car CO_2 legislation to trends in real prices, it would be important to have counterfactual information in order to enable the estimation of what the business-as-usual baseline would have been in the absence of the legislation.

As a result of undertaking a detailed and transparent assessment of price trends per segment, it would be possible to conclude with more confidence whether car prices are actually declining (or increasing) in real terms. If it was found that prices within segments are decreasing in real terms, it would still not be a valid conclusion to suggest that manufacturers' costs had been overestimated. Similarly, if real car prices are increasing, it would be too simplistic to argue that these increases were a result of the increased costs associated with the development and introduction of CO_2 reduction technologies. As is set out below, there are many other factors that influence manufacturers' costs and car prices.

Understanding (the estimation of) manufacturers' CO_2 related costs

Before we discuss the factors that influence manufacturers' costs and car prices, it is first useful to provide an overview of the way in which the additional costs that manufacturers might face as a result of the introduction (or development) of CO_2 legislation are estimated within reports such as this which have been produced in the context of the development and revision of Regulation 443/2009.

Overall methodology

The methodology for assessing the cost impacts of passenger car CO_2 regulation to industry, consumers and society, as applied in European Commission's Impact Assessments and the underlying support studies, comprises of the following main steps:

- Identification of technological options for reducing CO_2 emissions from cars;
- Assessment of reduction potential and manufacturer costs of individual options;
- Combining options into feasible packages and construction of cost curves that predict total additional manufacturer costs as a function the achieved level of CO_2 reduction:
    - o Separate cost curves are constructed for 6 different segments (small / medium size / large vehicles running on petrol resp. diesel);
- Application of these cost curves into a cost assessment model that for each manufacturer group estimates the average costs per vehicle for meeting its specific target:
    - o Manufacturer specific targets are derived from utility based limit functions;

[96] "Effects of regulations and standards on vehicle prices" (Ref: CLIMA.A.4/SER/2010/0001), led by AEA and involved Ian Skinner (as an Associate), which ran from September 2010 to September 2011.

- Application of the cost assessment model to estimate:
  - overall average additional manufacturer costs resulting from compliance with different target levels and with different alternative modalities for implementing a given target level;
  - distributional impacts, i.e. comparing costs impacts to individual manufacturer groups;
- Translation of average additional manufacturer costs per segment into consumer price increases using a constant mark-up factor;
- Performing runs with the TREMOVE model for various scenarios (target level and modalities), using the consumer price increases, together with the achieved CO_2 emissions and reduced fuel consumption as input data. These runs assess the second order impacts of these changes on vehicle prices and usage costs on car ownership, car usage and modal split and estimate the net cost effectiveness of the policy measure from a user, as well as from a societal, perspective.

Sources of information on technology costs

The assessment of the reduction potential and manufacturer costs of individual options is generally based on a review of recent literature, on the evaluation of recent vehicle models with relevant technology and the input obtained from consultations with automotive manufacturers' trade associations (ACEA, JAMA, KAMA), individual manufacturers, suppliers' trade organisations (CLEPA) and individual suppliers. All input data are critically reviewed using the consultants' in-house expertise and are translated into single point estimates of costs and reduction potentials for further use in the development of the cost curves.

Implicit inclusion of learning effects

The estimate of manufacturer costs is done for specific target years (e.g. 2012 – 2015 for the evaluation of the 130 g/km target and 2020 for the evaluation of the 95 g/km target) under the assumption that these technologies have to be applied at a large scale in order to meet the target. Learning effects and economies of scale are thus implicitly included. In questionnaires sent out to industry stakeholders, manufacturers and suppliers are requested to take account of expected economies of scale and learning effects consistent with the assumption of large scale application in the target year. These learning effects are reflected in the fact that the cost curves for 2020 predict lower costs for given reduction levels relative to the 2002 baseline vehicles than the 2012-15 cost curves.

Identified literature sources also tend to deal with this aspect in a rather implicit manner. In some cases concrete assumptions on production volumes are mentioned in combination with the cost estimates, but generally there is no explicit account of how assumptions on (cumulative) production volumes are translated into impacts on the estimated costs.

More details on the technology cost model

The cost assessment model for passenger cars, as developed in the TNO/IEEP/LAT 2006 study[97], used in the IEEP/CE/TNO 2007 study assessing the 130 g/km target for 2015 and updated for the current assessment of the 95 g/km target for 2020, assesses average costs for meeting a target as well as distributional impacts, i.e. cost impacts per manufacturer group per segment (fuels: petrol and diesel, size classes: small / medium / large). The model contains sales data, average CO_2 emissions and price data per segment for all major manufacturer groups selling passenger cars in the EU. Furthermore the model contains cost curves for CO_2 reduction through the application of technical measures for all 6 vehicle segments. The assessment of costs and distributional impacts is based on an algorithm that distributes reduction efforts over the 6 segments in such a way that for each manufacturer the additional manufacturing costs for meeting its target are minimised. The model can be applied to CO_2 targets implemented at the manufacturer level, without or with the option of trading emission credits among manufacturers.

Definition of outputs of the cost assessment

The primary outputs of the cost assessment model are absolute changes in the manufacturer costs of cars in different segments. These changes are presented as a delta relative to an unspecified, but for the purpose of this initial assessment in essence irrelevant, baseline cost development. All else remaining equal this delta then accurately represents the investment part of the societal costs.

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[97] Service Contract to review and analyse the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars, carried out by TNO, IEEP and LAT on behalf of the European Commission (DG Enterprise, contract nr. SI2.408212) in 2006.

It should be noted that **additional manufacturer costs** are not equivalent to costs to the industry. They represent the additional costs for manufacturing vehicles that emit less CO_2 (including pure manufacturing costs as well as development and other overhead costs). These costs only affect the profitability of the industry if they cannot be fully passed through to the consumers so that manufacturers have to lower their profit margins, or if the increased vehicle prices lead to reductions in sales volumes or shifts in sales towards segments with lower margins. Later in this note, the issue of cost pass through is discussed in more detail. Additional manufacturer costs only affect the competitiveness of manufacturers on the European market if cost impacts are not evenly distributed over different manufacturers (or manufacturer groups). The impact on competitiveness of European manufacturers on the global market depends on a multitude of factors, including whether they can pass through additional costs for more efficient vehicles in the European market, whether they can also sell the involved technologies in other markets or, if that is not the case, whether the required additional product differentiation involves additional costs.

Assuming a given pass through strategy the additional manufacturer costs can be translated into a **retail price increase** which represents part of the impact on consumers. In the studies so far a uniform and 100% pass through has always been assumed. In the first order the impact on consumers is further determined by the fuel cost savings that result from the fact that due to the CO_2 regulation cars become more fuel efficient. Additional 2^{nd} order impacts on consumers of increased vehicle prices may include a welfare loss due to a decline in car ownership and a welfare loss due to consumers buying smaller cars or cars with fewer features or lower performance than would have been the case in the absence of CO_2 legislation.

The additional manufacturer costs and the reduced fuel costs (exclusive of taxes) are necessary inputs for an assessment of the **societal costs**. Overall the costs to society are the net sum of the costs to manufacturers and consumers (direct effects) plus the external costs (or benefits). Societal benefits include reduced CO_2 emissions, as well as co-benefits resulting from improved energy security and reduced emissions of air pollutants.

On the basis of changes in vehicle prices and fuel costs inclusive of taxes, the impacts on **costs to governments** (e.g. reduced tax revenue) can be assessed.

The TREMOVE model

The TREMOVE model is used to evaluate the overall impacts on costs and mobility of various options for implementing the CO_2 legislation. The model uses the estimated consumer price increases, together with the achieved CO_2 emissions and reduced fuel consumption as input data. TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates the impacts on transport demand, modal shifts, vehicle stock renewal and scrappage decisions, as well as the emissions of air pollutants and the welfare level, for policies such as road pricing, public transport pricing, emission standards, subsidies for cleaner cars etc. The model covers passenger and freight transport in 31 countries and covers the period 1995-2030. Based on overall costs and impacts the net cost effectiveness (or GHG abatement costs) can also be calculated including second order impacts.

Mark-up factors for translating additional manufacturer costs to increased consumer price

For the translation of average additional manufacturer costs per segment into consumer price increases a constant mark-up factor is used, which represents an assumption that cost increases are uniformly and fully passed through to the consumer. Annex A of TNO/IEEP/LAT 2006 assesses that the overall ratio between vehicle price including taxes and the costs to the manufacturer (including pure manufacturing costs, development costs and other overheads) is 1.67. Based on an indicative evaluation of how various price components do or do not scale with the manufacturer costs, TNO/IEEP/LAT 2006 then estimates that, assuming a 100% cost pass through, for add-on technologies the ratio between retail price increase and additional manufacturer costs is lower, i.e. around 1.44.

In the IEEP/CE/TNO 2007 study the mark-up factor has been adapted to provide consistency with the methodology used in the Impact Assessment SEC(2007) 60, as well as in other Impact Assessments e.g. those related to Euro standards for regulated emission components. In Impact Assessments carried out by the Commission Services price increases resulting from the application of new (environmental) technologies to vehicles are always based on manufacturer cost estimates plus tax. For IEEP/CE/TNO 2007 therefore manufacturer margins and dealer costs and margins have been excluded from the mark-up factor, leading to a resulting mark-up of 1.235 from additional manufacturer costs to retail price increase which only includes taxes.

Hence, in the studies supplying input to the Commission's Impact Assessments, it is assumed that the increased costs associated with the development and introduction of technology to reduce CO_2 emissions lead directly to increased car prices relative to a baseline trend which is not specified.

Ex ante versus ex post cost estimates
An important consideration that arises from the way in which manufacturers costs are estimated is what level of confidence can there be that these estimated costs will be incurred in practice. Within environmental policy more generally, there is some evidence that estimates of ex ante costs often exceed ex post cost estimates, where attempts have been made to compare the two[98,99]. Differences found in e.g. IVM, 2006[100] and TME, 2006[101] turned out to be as high as a factor of 2 to 6.

However, even where discrepancies between ex ante and ex post cost estimates have been identified, there might be a clear explanation that is only relevant to the specific circumstances. As a result the evidence from ex post evaluations, however, cannot easily be generalized to recommendations for improving ex ante assessments. To use two examples from the automotive sector illustrate this:

- Steps to reduce exhaust emissions from diesel engines in the 1990 – 2000 timeframe turned out to be cheaper than initially estimated because, in contrast to ex ante expectations, manufacturers managed to realize these reductions by cheap engine management solutions rather than by expensive add-on technologies.
- In petrol engines reduction of exhaust emissions by using a three-way catalyst in the end was much cheaper than anticipated as catalyst manufacturers managed to develop systems that realize the required conversion efficiencies with platinum loadings that are an order of magnitude lower than was the case in the early products. With platinum being the most costly component this innovation obviously created significant cost reductions.

Looking at the technologies that are being considered for meeting the regulatory CO_2 targets for 2015 and 2020 product improvement creating similar cost leverages as in the examples cited above are not currently foreseen. Nevertheless it is likely that innovations will occur that could reduce costs to levels below what is currently perceived as realistic.

There are many other reasons that potentially underlie differences in ex ante and ex post cost estimates, including the way in which the assessments have been undertaken. A simple reason for any discrepancy between ex ante and ex post costs is that estimating future costs will always be uncertain. Learning effects, especially resulting from innovations in the products and production processes, may be over- or underestimated. Also, it might be possible to gain certain cost advantages through clever system integration, which may be underestimated. In some cases it is also observed that cost studies may sometimes be undertaken for strategic reasons, in an attempt to thwart tougher environmental legislation, for example, which may exert 'upward pressure' on calculated costs.

Especially in the transport sector it is important to estimate ex ante the potential costs associated with the introduction (or development) of new CO_2 legislation using data from industry. Industry is in the best position to understand and be able to estimate the potential costs incurred, as there is only a

[98] For example, see the literature review undertaken in AEA, Metroeconomica and Paul Watkiss Associates (2007) "Assessing how the costs and benefits of environmental policy change over time" (Ref: ENV.G.1/ETU/2006/0107r), Report for the European Commission's DG Environment.
[99] See also discussions in e.g. GHG reduction in transport: an expensive option? Marginal abatement costs for greenhouse gas emission reduction in transport compared with other sectors, Richard Smokers, Ab de Buck, and Margaret van Valkengoed, CE Delft, 2009.
[100] Frans Oosterhuis (IVM), Véronique Monier, Cécile des Abbayes (BIO), Benjamin Görlach (Ecologic), Andrew Jarvis, James Medhurst (GHK), Onno Kuik (IVM), Robin Vanner, Paul Ekins (PSI), Jochem Jantzen, Henk van der Woerd (TME), Peter Vercaemst, D. Huybrechts and E. Meynaerts (VITO), Reviewed by Reyer Gerlagh (IVM), Ex-post estimate of costs to business of EU environmental legislation, Free University, Institute for Environmental Studies (IVM), 2006.
[101] Ex-post estimates of costs to business of EU environmental policies : Case study Road Transport, Institute for Applied Environmental Economics (TME), 2006.

limited amount of relevant information in the public domain[102]. Additionally, engaging with industry is likely to improve the acceptability of the results of the analysis. The eventual costs will depend on economies of scale, which may be different for different products, innovations in products or their production processes. Furthermore, the products and processes may not yet have even been developed. Hence, there is a logical tendency for those estimating potential costs to err on the side of caution.

Consequently, it is likely that the ex ante estimates of the additional costs to manufacturers resulting from the introduction (or development) of passenger car CO_2 legislation are on the pessimistic side. In other words, it is likely that they will prove to be lower in practice. However, as all of the technologies that might be added to a car to reduce its CO_2 emissions either add components and/or complexity to the car, legislation to reduce the CO_2 emissions of passenger cars will always involve a net increase in costs. So, while costs could turn out to be smaller than estimated ex ante, they will not be negative. Consequently, if the prices of new cars are declining, these decreases must be caused by factors other than an over-estimation of manufacturers' additional costs.

What other factors affect manufacturers' costs?

In developing, manufacturing and distributing new cars, manufacturers incur a range of direct and indirect costs. From the perspective of the performance of its business, clearly it is in a manufacturers' interest to reduce these costs as far as possible within wider constraints, such as market conditions, competition, consumer preferences and legislative requirements (including those relating to trade, labour and taxation, as well as the safety and environmental performance of the vehicles)[103].

Manufacturers can take a number of actions to reduce their costs, such as[104]:

- **Increase commonality of parts and share platforms and powertrains.** Manufacturers have been taking action to reduce the number of separate components that are needed across their different model ranges. Additionally, manufacturers are increasingly sharing platforms and powertrains, both between models, but also between manufacturers. Such developments help to reduce the costs of designing, developing and manufacturing cars (as economies of scale reduce the price of the components needed and the complexity is reduced), as well as the costs associated with calibrating engine management systems.
- **Relocating production and manufacturing.** This has several potential benefits in terms of cost reduction, such as:
  - Enabling manufacturers to benefit from lower labour costs, e.g. in Eastern Europe and Asia;
  - Reducing shipping costs as production is moved closer to growing markets and away from the more saturated markets of Western Europe and North America; and
  - Enabling new factories to be designed to meet new production needs, rather than redesigning old factories, which can be more expensive.
- **Managing inventories and supply**. The way in which manufacturers manage inventories, e.g. by applying "Just-in-Time" procedures, aims to reduce associated costs.
- **Reducing the costs of manufacturing.** Manufacturers have taken a number of actions to reduce the costs associated with the manufacturing process. These include more flexible manufacturing processes, which enable vehicles to be manufactured in a way that is more responsive to demand (and therefore which reduces stockpiles of unwanted vehicles), greater use of computer controlled machinery and improved quality assurance processes.
- **Reducing the costs of components.** As noted above, manufacturers can reduce costs by reducing the number of components and by increasing the number of shared parts. Such actions have led to increased competition amongst suppliers and also the need for suppliers to be present in more markets in order to be able to supply more of the same components to more vehicles. These processes have driven a consolidation (through mergers and acquisitions) of first tier suppliers. In order to try to further increase competition amongst suppliers, and therefore further reduce costs, some manufacturers**,** e.g. Ford and General Motors, have made previously in-

[102] In this respect, the car industry differs from, say, the energy sector, where the costs of large installations are fairly well known.
[103] Apart from the introduction of the legislation itself, all of the factors that influence manufacturers' costs would be relevant in the absence of legislation on passenger car CO_2. Hence, in the context of this note, they would only affect the costs in the baseline of any impact assessment, i.e. they would not be directly influenced by the introduction of the legislation.
[104] Based on the literature review undertaken for the "Effects of regulations and standards on vehicle prices" project.

house divisions separate companies. However, spinning-off of suppliers in this way has not been that successful to date in reducing costs.
- **Increasing pressure on other parts of the value chain so as to reduce costs and profit in those areas.** In particular it has been shown (in the DG Competition analysis) that dealer margins on new car sales have reduced over the last decade and dealers now generate a substantially higher percentage profit from sales of spare parts and servicing.

Many of the above actions result in what is on a more aggregated level interpreted as learning effects. Additionally, there are a number of external factors that make future costs uncertain, including:

- **Changes in resource prices.** Resource prices fluctuated significantly in the late 2000s, which make costs uncertain. Given the increased use of rarer, precious metals in alternatively-fuelled cars, many of which are often supplied by a small number of countries, such uncertainties could even increase in the future.
- **Exchange rate fluctuation.** In an increasingly globalised market, fluctuations in exchange rates have an uncertain impact on costs.
- **Taxes and other legislation.** Taxes, such as those on companies and labour, vary between countries and these can be subject to change, particularly after changes in government. Such uncertainties also exist in relation to wider legislation of relevance to manufacturers, including labour legislation, as well as legislation relating to the vehicles themselves, including safety and environmental legislation.

Finally, manufacturers are subject to a number of pressures that require research and development to deliver innovation (and hence affect manufacturing costs), including the need to respond to:

- **Consumer demands** for improvements in quality and performance.
- **Legislative requirements**, including those set by environmental and safety legislation.

As can be seen from the above overview, legislation to improve the environmental performance of vehicles generally, and that which aims to reduce their CO_2 emissions in particular, is only one of several factors that change the costs that manufacturers face in designing and manufacturing their cars. Consequently, the costs that might result from the development and implementation of technologies to reduce CO_2 emissions are incurred within an environment that contains various (external) upward pressures on costs but that is generally seeking to reduce costs.

How can additional manufacturer costs translate into changes in vehicle prices?

On one level, it might be considered that there would be a close relationship between the costs associated with developing and manufacturing a car and the price of that car, and therefore that cost increases would be reflected by increases in price. This overlooks the European and increasingly global nature of the market, whereas consumers still tend to operate within national markets (although this is changing in some countries). It also overlooks the competitive nature of the market, and indeed the differences between markets (both within different countries and different market segments), and the subsequent need for manufacturers to ensure that their cars are competitive in the markets in which they choose to compete. This is especially the case when wider economic conditions are not conducive to selling cars, as has been the case since 2007/8.

However, there are many factors that contribute to determining the price of a car. One important factor is that to the consumer the purchase of a new car often represents more than simply buying a means of transport. The purchase of a new car can also be a statement about a person's aspirations, their perceived place within society or their values. The regression analysis undertaken in the study referenced at footnote 96 suggests that there is a very significant price effect related to vehicle brand. Other factors that are reported as being significant for consumer choices include "innovation", "style" and "design", in addition to factors such as performance, safety and value.

Consequently, rather than simply linking the price of a particular car to the costs associated with its development, manufacture and distribution, manufacturers price their cars according to the markets in which the cars operate and the wider competitive environment. For example Gaulier (2000) concluded that "firms operating in several markets determine their optimal price on the basis of the nature and intensity of competition in each market"[105], while a 2008 Commission evaluation concluded that "vigorous and increasing inter-brand competition has translated into falling real prices against a background of increased market integration at EU level"[106]. In the US, authors have reached similar conclusions on manufacturers' responses to changes in CAFE and other emission control standards, e.g.:

- Falvey (1986) concluded that US manufacturers adopted a strategy of adjusting relative prices in order to meet the CAFE standards between 1978 and 1980[107].
- Goldberg (1998) concluded that one of the impacts of the CAFE standards was to lower the prices for small, efficient cars and increase prices for larger, inefficient cars[108].
- Chen *et al* (2004), in assessing the impact of emission control devices in the late 1970s and early 1980s, concluded that a range of different factors influence prices and that it is was not possible to identify the impact of new regulations on prices. In some cases, car prices decreased in periods where emission control costs were estimated to have increased, which suggested that manufacturers either absorbed the costs of compliance or reduced costs with other strategies. On the other hand, prices sometimes increased by more than would have been expected taking into account the costs of emissions control equipment alone. They also note that one of the principle constraints of a manufacturer's pricing strategy is a desire to moderate price increases[109].

Considerations that need to be taken into account in a market-based pricing strategy include[110]:

- **Competitive pressures**, which can vary between EU Member States, and **other market conditions**, including the performance of the wider economy and oil prices. Additionally, the fact that there has been overcapacity in vehicle production in Europe for a long time has helped to increase competition.
- The extent to which **consumers attach value** to the vehicle beyond its pure transport function. It is worth noting that, in the case of technologies introduced to reduce CO_2 emissions, there is often no added value for the consumer (except in terms of lower fuel costs), although in some cases there may be.
- The extent to which manufacturers include **additional features** in their car to enhance comfort, performance and functionality (e.g. through changes in the size, design, powertrain or by adding accessories), where the impact on price is largely dependent on the perceived added value of the increased comfort, performance or functionality rather than by the production costs.
- The extent to which a manufacturer wishes to **cross subsidise** models, brands, divisions or markets.
- **Manufacturer's margins**, e.g. the relationship between price and cost.
- **Financing offers and warranties**, although these can also be influenced by other actors, e.g. dealers and distributors (see below).

All of these factors contribute to the extent of **cost pass through**, i.e. the extent to which any changes in manufacturers costs are passed on to consumers as price increases. These factors would all play a role in determining the extent to which manufacturers pass on any changes in costs to consumers, even if there were no legislation to reduce CO_2 emissions from passenger cars. Hence, it is within this wider context that the additional costs incurred by legislation to reduce the CO_2 emissions of new cars, such as Regulation 443/2009, will have an impact.

It is also worth noting that Regulation 443/2009 sets out a timescale within which, and a target against which, manufacturers have to decrease CO_2 emissions from new cars. As a result of this clear path and timetable, manufacturers are able to anticipate increases in costs, so they are able to include such considerations in pricing strategies to ensure that prices are not adversely affected, e.g. by using the following mechanisms:

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[105] Gaulier, G. Convergence of Car prices in the EU - an Empirical Analysis for the Period 1993-1999, 2000.
[106] http://ec.europa.eu/competition/sectors/motor_vehicles/documents/evaluation_report_en.pdf
[107] Falvey, R. Fuel Economy Standards and Automobile Prices, 1986.
[108] Goldberg, P. The Effects of the Corporate Average Fuel Efficiency standards in the US, 1998.
[109] For example found in Chen B, Abeles E, Burke A and Sperling D (2004) Effect of Emissions Regulation on Vehicle Attributes Cost and Price.
[110] As with the discussion of factors that influence manufacturers' costs above, these factors that influence pricing strategies would all be relevant in the absence of legislation on passenger car CO_2.

- **Bringing forward actions** to reduce costs;
- **Phasing in cost increases** over time so as to maintain the downward price trend (although slowing the rate of decrease compared to what otherwise might have happened); and/or
- **Delaying the introduction** of other features, e.g. those relating to comfort, performance and functionality, that they were planning to introduce.

As was suggested earlier, if manufacturers aim to moderate price increases overall, then all of these mechanisms could be used in the short-term to ensure that prices do not increase (or do not increase significantly) against a wider background of ongoing cost reductions. In this respect, it could be argued that to date the market has been able to absorb the additional costs resulting from the development of the passenger car CO_2 Regulation, as well as those associated with other environmental and safety legislation. Having said this, it should be recognised that without the introduction of such legislation, real car prices could have been reduced by more than appears to be the case in Table 94.

Moving forward, the introduction of a revised Regulation 443/2009 will also simply be one of many factors that will alter manufacturers' costs post-2015 within this wider context. To date manufacturers are likely to have taken up the cheapest options to reduce CO_2 emissions from passenger cars. It is probable that further CO_2 reductions will cost significantly more, e.g. achieving the next 25% of CO_2 emissions reductions is currently estimated to cost at least three times as much as the cost of achieving the first 25%. Comparing the costs curves for 2012-15 and those for 2020 already indicates that costs for the same level of reduction decrease over time. Similarly the costs of the reduction steps needed to move from 130 g/km to 95 g/km on average are expected to decline beyond 2020 due to learning effects.

Additionally, the price that consumers face, i.e. the costs to the consumer, includes elements that are not under the direct control of manufacturers, such as:

- **Taxes** on new cars and, indirectly, taxes on car ownership and use.
- **Dealer and distributor margins**.
- **Marketing**, as well as **warranties and financing offers** offered by dealers and distributors.

Finally, there is evidence (at least before the introduction of the Euro) that manufacturers respond to other impacts on prices, such as differences in registration taxes, by reducing pre-tax prices in countries with higher taxes and increasing these prices in countries with lower taxes[111].

Does the ex post evidence provide convincing clues?

On the basis of the information on price trends that we were able to identify, it appears that average car prices within the EU have declined in real terms. A more detailed analysis should be able to clarify whether this decrease in average price is caused by price decreases in different vehicle market segments or by shifts in the market towards smaller or less powerful and less luxurious vehicles.

As noted above, as a result of the introduction of the passenger car CO_2 legislation, the costs that manufacturers face must have increased. If the apparent declining trends in car prices in real terms are correct, then the trends are likely to have been dampened by the additional costs associated with applying CO_2 reducing technologies, i.e. car prices might otherwise have declined even further. However, these additional costs and impacts on prices occur within a wider context within which manufacturers act to reduce their costs in order to increase their profits. Manufacturers are able to reduce their costs in a number of ways, while other factors have uncertain impacts on, or act to increase, their costs. Additionally, rather than directly passing on all costs to consumers, manufacturers adopt different pricing strategies according to market conditions; the strategy can also vary between markets and between car types. The size of these other factors on costs and prices is difficult to estimate, but it can be expected that they are at least the same order of magnitude as any impacts resulting from the passenger car CO_2 legislation.

[111] TIS, INFRAS, Erasmus University and DIW (2002) Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars, A study conducted for the European Commission's DG Taxation and Customs Union, contract number TAXUD/00/310.

The apparent decline in car prices would also suggest that, to date, the increased costs resulting from the legislation have not led to net increases in the price of car, and therefore in the costs of passenger car ownership to European consumers. Instead, car price decreases would have been even more significant in the absence of the passenger car CO_2 Regulation.

Given the many factors that affect both the costs that manufacturers face and the prices of cars on the European market, it is likely to be very difficult, if not impossible, to derive ex post evidence of technology costs from observed price trends in this sector.

What we can learn from the above for improving ex ante estimates of costs and of impacts of CO_2 legislation on industry, consumers and society?

The discussion so far has not provided any evidence that the ex ante cost estimates for manufacturers' additional costs incurred by the passenger car CO_2 Regulation were incorrect. There are many factors that influence the costs faced by manufacturers and the prices that they charge in the European market for their vehicles. Hence, it is too simplistic to suggest that the apparent decline in car prices means that the ex ante cost estimates were too high.

While acknowledging the complications with generalizing results from ex post evaluations into recommendations for improving ex ante assessments, IVM 2006 nevertheless provides the following suggestions for better ex ante cost estimates:

1. The reliability of ex-ante cost data can be improved by carefully selecting and evaluating the information sources. Ideally, data from different sources (suppliers, operators, researchers, etc.) should be analysed to arrive at reliable cost estimates.
2. 'Avoided costs' related to environmental policy measures (e.g. lower energy costs due to energy saving) are likely to be at least as challenging to estimate as conventional costs of compliance, but their inclusion in the ex-ante estimate is essential to prevent overestimation of net cost.
3. Ex-ante estimates should keep track of the development of the policy process, as changes in the policy proposals inevitably will imply changes in the estimates. Ideally, each amendment should be accompanied by a revision of the estimated costs.
4. The construction of the 'counterfactual' scenario is a difficult part of cost estimation. A better understanding of business behaviour and the likely response to a given policy measure may be needed.
5. The issue of strategic versus marginal responses needs to be examined in much more detail, with consideration of the heterogeneity of businesses and of their likely responses and of the technological uncertainties that surround these responses.
6. Further research should reveal whether it is possible to formulate general 'rules of thumb' regarding the extent to which cost decreases can be expected as a result of unanticipated substitution options, innovation, economies of scale and learning curve effects. This might lead to some standard reduction factors to be applied in ex-ante cost estimates, dependent upon the specific technology and context at hand.

Furthermore IVM 2006 proposes that the planning of ex-post estimates needs to be built into regulations in order to generate learning about the degree to which they have succeeded. As investments in cost estimates will usually be very small relative to the cost of implementation, IVM 2006 suggests that it would be interesting to investigate the potential efficiencies provided by high-quality cost estimates (in terms of better policy measures). At the same it is stated that, as ex-ante estimates are to make the policy making process more transparent (by revealing potential trade-offs, etc.), ex-ante and ex-post assessments should be kept as 'simple' as possible.

The suggestions 1, 2, 3 and 5 from IVM 2006 are implemented in the current guidelines for and common practice of Impact Assessments as carried out by the European Commission. The underlying support studies generally follow these guidelines. Suggestion 4 is in line with what is concluded in this paper, e.g. with respect to how engineering estimates of technology costs are to be translated into input for TREMOVE calculations. The further research as suggested in point 6 has so far not been done. The evidence and considerations gathered in this paper further contribute to the impression that such research will not easily lead to straightforwardly applicable answers.
While this note does not lead to conclusions on the methodology for estimating additional manufacturer costs, the discussion on cost pass through may have implications for the way in which

impacts on consumers and mobility are assessed, e.g. in the TREMOVE model. As noted above, the current approach is to estimate in first instance the expected level of increase in manufacturer costs relative to an undefined baseline. This cost increase is associated with the application of additional technologies in order to comply with the passenger car CO_2 Regulation. The considerations discussed within this note, i.e. on the complex relationship between costs and prices, suggest that the assessment of impacts on consumers deserves more attention. More specifically, it suggests that the way in which the engineering estimates of additional manufacturer costs are currently translated into price changes for use in TREMOVE runs is a gross simplification. TREMOVE results with respect to impacts on sales and vehicle use are found to be quite sensitive to price changes in different vehicle segments (size & fuel type). In the current modelling approach these only depend on the details of the way in which the CO_2 target is implemented (e.g. target level and slope of limit function). The observed sensitivity of TREMOVE suggests that manufacturer pricing strategies may have impacts of equal magnitude, so that the translation of manufacturer cost changes to price changes used as input for TREMOVE deserves more attention.

14.3 Conclusion

In response to CO_2 regulation, cars need to be made more efficient. This involves application of additional technologies or more complex technologies relative to a situation without regulation and this leads to finite additional manufacturer costs. How these additional costs affect prices and as a consequence the cost to consumers depends on the ways in which manufacturers are able to pass through these costs. Whether pass through of costs leads to a net increase in real car prices depends on the baseline price development upon which these increases are superimposed.

The fact that since at least 2003 average car prices appear to have been decreasing at the same time as CO_2 reduction technology has been developed and added to new cars, accompanied by the lower cost of use as a result of the new cars being more fuel efficient, means that consumers will not have noticed any adverse effect from the Regulation. In the absence of regulation car prices might have reduced even more, but consumers would probably not have been better off as the additional costs of making cars more fuel efficient are earned back through fuel cost savings well within the lifetime of the vehicle. This is already the case for the additional costs as estimated in the Impact Assessment and support studies underlying Regulation (EC) No 443/2009 and will certainly be the case if these costs ex post turn out to be lower than estimated ex ante.

It is concluded that the fact that average car prices appear to have declined in real terms over the last years does not provide evidence that ex ante assessments overestimated the costs for meeting the 130 g/km target. At the same time there is also no proof of the contrary. Because of this, and due to the lack of detailed insight in ex post cost developments, there is at this point in time neither a need nor a real possibility to derive recommendations for improvements in the methodology of ex ante assessments of the cost implications of CO_2 regulation and other related policy instruments. However, some consideration could be given to the way in which changes in manufacturers costs are translated into changes in price within existing assessment models.

15 Consequences of additional provisions in the definition of the 2020 target

15.1 Introduction

Article 9 of Regulation (EC) No. 443/2009 of the European Parliament and of the Council states that if a manufacturer's specific CO_2 emissions average exceeds its specific emissions target in that year the Commission shall impose an excess emissions premium on the manufacturer or, in the case of a pool, the pool manager. From 2019 onwards the excess emissions premium is set at € 95 per gCO_2/km of average excess emissions for each new registered passenger car. Between 2015 and 2020 the excess emission, for which manufacturer groups have to pay a penalty, is determined relative to their 2015 target, determined per manufacturer group using the mass-based limit function.

Additional provisions, such as a trajectory of declining annual targets between 2015-2020, possibly combined with a banking and borrowing scheme, might be of assistance in reaching the 2020 target in a cost-effective and more controlled manner. A trajectory of declining annual targets provides more certainty that the 2020 target is met by all manufacturer groups and may improve the net GHG emission reduction compared to a possible situation in which progress towards the 2020 targets is mainly made in the last years before the target year. Such a provision would then involve excess emission premiums relative to the annual targets rather than to the 2015 target.

As such a trajectory of declining annual targets reduces the flexibility for manufacturers with respect to the approach routes for meeting the 2020 target. Combining the stepwise approach with banking and borrowing, allows manufacturers to more flexibly deal with the approach to the 2020 target and to avoid payment of excess emissions premiums while still providing an increased incentive for aiming to reach the 2020 target.

This task explores the implications of:

- establishing a trajectory of declining annual targets between 2015 and 2020,
- introducing a banking and borrowing scheme in combination with a trajectory of declining targets, in which:
  - either the CO_2 credit balance has to be neutralised before the target year and one, or
  - the CO_2 credit balance can to be neutralised beyond the target year.

15.2 Consequences of establishing a trajectory of declining annual target values

15.2.1 Introduction

To increase the likelihood that the 2020 specific emissions targets are met by the manufacturer groups, a trajectory of declining annual targets can be proposed. Such a trajectory defines annual targets for each manufacturer group separately. Since a 130 gCO_2/km target is already in place for 2015 and the 95 gCO_2/km target is set for 2020, the period in which such a trajectory could be applied is 2015-2020.

The effort needed to implement such a trajectory is limited since in the post 2015 period the Monitoring Mechanism and the administrative system to determine and collect excess emission premiums on an annual basis will already be in place. The only adaption to be made is that excess emissions are to be determined relative to a different target.

Manufacturers might perceive such a trajectory as detrimental, as they lose flexibility in the CO_2 reduction pace that they would otherwise freely choose between 2015 and 2020. In this period certain manufacturers might prefer a less than linear decrease while they expect certain technologies to become cheaper towards the end of this period or if e.g. a faster reduction is not considered compatible with the manufacturer's timing of model cycles.

An alternative legislative incentive for achieving more control over the way in which the target is approached is a periodic increase of the sales share per manufacturer that has to comply with the specific manufacturer's target. This mechanism is currently applied in R443/2009 for the 130 g/km target. It has turned out, however, that with the percentages as set in the legislation manufacturers do no have to make a strong effort to reach the target percentages in the first years of the 2012-2015 period. Furthermore it is likely with this approach that the vehicles within the manufacturer's portfolio for which the highest costs are involved for reducing CO_2 emissions to the required levels will be taken on lastly. This might lead to an inability of certain manufacturers to meet their target while the problem would only arise very late in the process. Because of these reasons, the remainder of this task focussing on assessment of the alternative option of setting intermediate (2015-2020) CO_2 targets that have to be met by the average new vehicle fleet.

15.2.2 The effects of establishing a trajectory of declining annual target values on the excess emissions

A possible way to introduce stepwise annual targets between 2015 and 2020 is a linear interpolation between the targets for 2015 and 2020 (with constant yearly reductions), as depicted in blue Figure 84. As stated in section 15.2.1, a reason to implement such a scheme is to avoid a scenario as depicted in red in Figure 84. In this exaggerated – but in principle feasible – scenario, manufacturers do not improve on CO2 emissions until the next target year 2020, since there are no incentives in the years between both targets. They could then implement radical portfolio management strategies to avoid sales of high CO_2 vehicles and promote sales of low CO_2 vehicles. As a result, the emissions are relatively high in this period. It should however be mentioned that based on current trends such a CO_2 reduction path is not expected. According to the Commission's projections (Figure 93), manufacturers are currently over-achieving relative to the 130 gCO_2/km target and are right on track for the 95 gCO_2/km target in 2020. This reduction pace, depicted in green in Figure 84, is actually below the stepwise reduced target depicted by the blue line in Figure 84. It is not to be expected that manufacturers will intentionally lower their effort to reduce CO_2 emissions because of over-achieving in the first part of the 2015-2020 period, but market trends may cause a slow down of the reduction pace, especially when the economy improves again in the coming years or when existing strong fiscal incentives for efficient cars would be reduced by Member State governments.

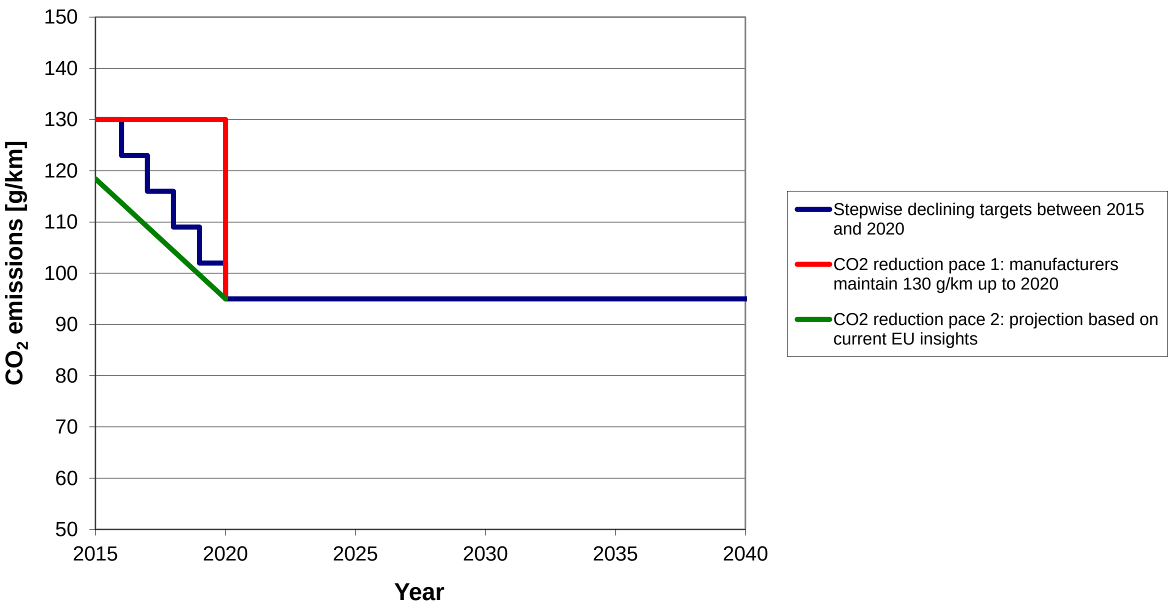


Figure 84 A possible trajectory of declining annual target values (blue line) and two possible CO_2 fleet average scenarios between 2015 (in which a target is set at 130 gCO_2/km) and 2020 (in which a target is set at 95 gCO_2/km).

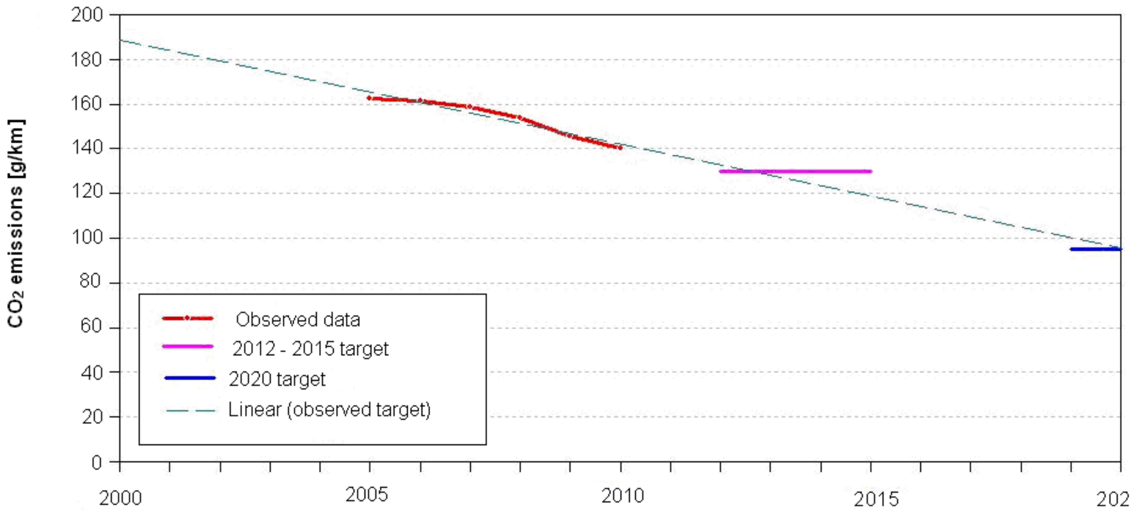


Figure 85 EU CO_2 reduction projections based on observed 2005 – 2010 Monitoring System data[112].

The pace at which the fleet average CO_2 emissions are reduced between 2015 and 2020 influences the emissions from the transport sector far beyond 2020 as new vehicles sold between 2015 and 2020 remain in the fleet for around 15 years. Different trajectories by which the new vehicle average CO_2 emissions approach the 2020 target therefore lead to different total fleet compositions with different total fleet average CO_2 emissions in subsequent years. This is quantified in Figure 86.

Figure 86 is based on a simplified cohort model for vehicle fleet of the EU27 countries, that uses vehicle numbers and annual mileages per age category derived from the TREMOVE model for the period up to 2030. Data beyond 2030 is estimated by extrapolation of TREMOVE data. For the calculation of total emitted CO_2, vehicles up to 20 years old are taken into account. The average new vehicle CO_2 emissions up to 2015 are determined using the Commission's projections depicted in Figure 85. The blue line represents the total CO_2 emissions in case the suggested stepped targets are followed exactly. The red and green lines represented the – more extreme – scenarios described above.

The upward trend of total annual CO_2 emissions from by passenger cars from 2032 onwards is the result of two phenomena. Firstly, all three depicted scenarios are based on the assumption that the emissions of newly registered vehicles do not decrease below 95 g/km beyond 2020. As a result the fleet average CO_2 emissions asymptotically reach 95 g/km after 2032. As the demand for passenger car mobility (Figure 87) still increases after 2032 (about 21% between 2015 and 2040), total CO_2 emissions increase as well.

The total CO_2 emissions over the 2015-2040 period in 'CO_2 reduction pace 1' are about 2.5% (approximately 250 Mtonnes CO_2) higher than for the scenario in which the suggested step targets are exactly followed. In case of over achievement by the manufacturers ('CO_2 reduction pace 2'), total CO_2 emissions in the period between 2015 and 2040 are about 1.9% (approximately 200 Mtonnes CO_2) lower compared to the scenario in which the suggested step targets are exactly followed.

The higher amount of CO_2 emissions potentially arising from not implementing the declining targets, is similar to the effect of an approximately 2.8 g/km higher fleet average CO_2 level over the period between 2015 and 2040 (2.9% of the 95 gCO_2/km target). This indicates that the effect of the declining targets – or of the absence thereof – is potentially significant, and hence that the declining targets are worth for consideration as an additional provision in particular as a risk management measure.

[112] EU monitoring system: Decision 1753/2000/EC and Regulation (EC) 443/2009. Targets are from Regulation (EC) 443/2009. Source: European Commission, DG Climate Action.

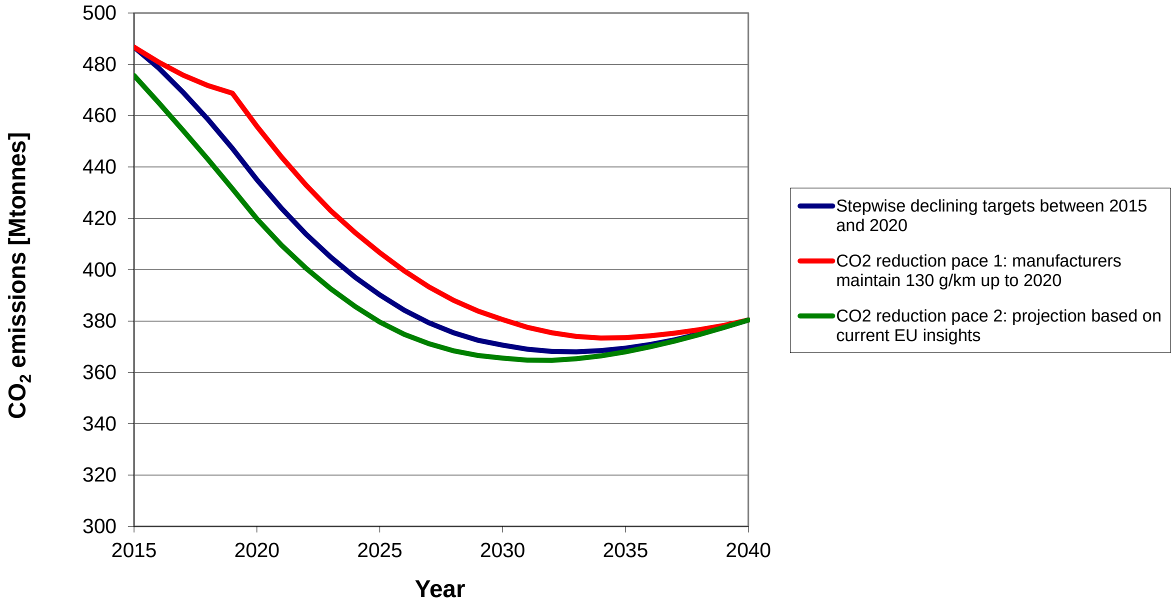


Figure 86 Estimation of total annual CO_2 emissions from passenger vehicles in the EU27 as a result of various CO_2 emission reduction trajectories for new vehicles between 2015 and 2020.

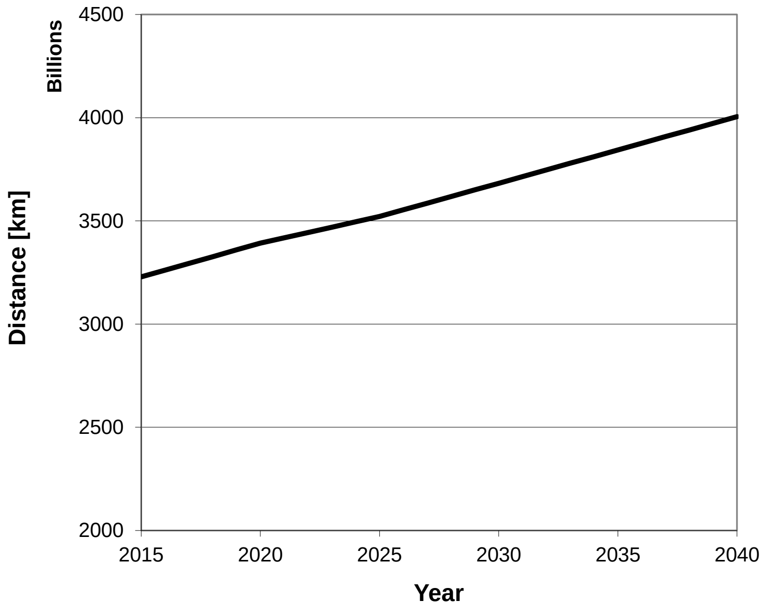


Figure 87 Estimation of annual distance travelled by passenger cars within the EU27 (Source: TREMOVE).

15.3 Consequences of introducing provisions for banking and borrowing

15.3.1 Introduction

If a banking and borrowing scheme is in place, manufacturers have more flexibility in the compliance with a specific emissions target for a specific year. When the average CO_2 emission of the new vehicle sales is below the specific emission target for that year, the manufacturer or group of manufacturers can bank these emissions as emission allowances. When the average CO_2 emission value exceeds the specific emissions target in another year, the manufacturer can offset these excess emissions with 'banked' emission allowances from preceding year(s) or 'borrow' emission allowances, which have to 'paid back' in subsequent years. This mechanism allows manufacturers to flexibly deal with the introduction of new technologies, decreasing the risk of paying excess emissions premiums, while maintaining the overall reduction trajectory. Such a scheme can thus be used to complement the trajectory of declining annual targets, as discussed in section 15.2, to provide manufacturers more flexibility in complying with the annual targets.

The main advantage of banking and borrowing is the flexibility it provides for manufacturers to react to changing circumstances. For manufacturers it could also increase the cost-effectiveness of implementing the necessary technologies for reducing the emissions as well as providing flexibility with respect to the development and implementation cycles of new models. Investigation of Task 1.3 (see sections 5.4 and 5.5) leads to the insight that of the nine vehicle models analysed, three models are planned to have platform changes in the 2016/2017 timeframe. For three other models changes are planned in for 2019/2020 and for the final three 2021 is the modification year. As a result some manufacturers may not be able to reach the 2020 target in time (partly) due to lower CO_2 emitting models not being introduced until 2021. This also reduces their ability to reach possible intermediate targets set by stepwise reduced annual targets between 2015 and 2020. This would lead to the payment of excess emissions premiums. Alternatively, manufacturers may have to change their development cycles to be able to introduce lower CO_2 emitting vehicle models planned for e.g. 2021 already before the 2020 target year. This change might result in extra costs. Banking and borrowing might therefore provide the flexibility needed for reaching the target in a more cost-effective way.

Negative impacts of allowing banking and borrowing include an increased risk of 'carbon leakage', due to the possibility of borrowed emission allowances that may not be neutralised, or paid back, by manufacturers at the end of the scheme's duration. Additionally, if manufacturers are allowed to borrow emission allowances before they have banked, and the duration of the scheme extends beyond 2020, the specific fleet average emissions target of 95 g/km in 2020 might not be met. From a perspective of the underlying intentions of the regulation, such a scheme might also be perceived as allowing manufacturers to delay developments and rollout of CO_2 reduction technologies for their passenger vehicles.

15.4 The effects of banking and borrowing on excess emissions

For banking in borrowing, two possible configurations can be proposed. In the first configuration manufacturers are only allowed to bank and borrow during the annual step targets period (2015-2020), while in the second manufactures have a period beyond the target year (2020) to neutralise their banked or borrowed 'emission credits'.

15.4.1 Banking and borrowing during the annual step targets period (2015-2020)

If banking and borrowing is only allowed during the annual step targets period, the fleet average CO_2 emissions will be 95 g/km from 2020 onwards. Two modelled scenarios for banking and borrowing during this period are depicted in Figure 88. The total emitted CO_2 emissions as a result of these banking and borrowing scenarios are shown in Figure 89.

In a similar fashion to Figure 86, the increase of emissions beyond 2032 in Figure 89 can be explained by increased travelled distance, while the fleet average CO_2 emissions converge to 95 g/km. Compared to Figure 86, the emissions of scenario 1 and 2 are even closer to the annual fleet wide CO_2 emissions produced in case the step targets are followed exactly.

The total CO_2 emissions between 2015 and 2040 in scenario 1 are only slightly higher (<0.01%) than in the scenario in which the suggested step targets are exactly followed. However, since manufacturers have borrowed in the first half of the banking and borrowing period, they will have to reduce their CO_2 emissions at a quicker rate in the second half of this period. For scenario 2 the CO_2 emitted is approximately 0.7% (about 54 Mtonnes of CO_2) lower compared to the scenario in which the suggested step targets are exactly followed.

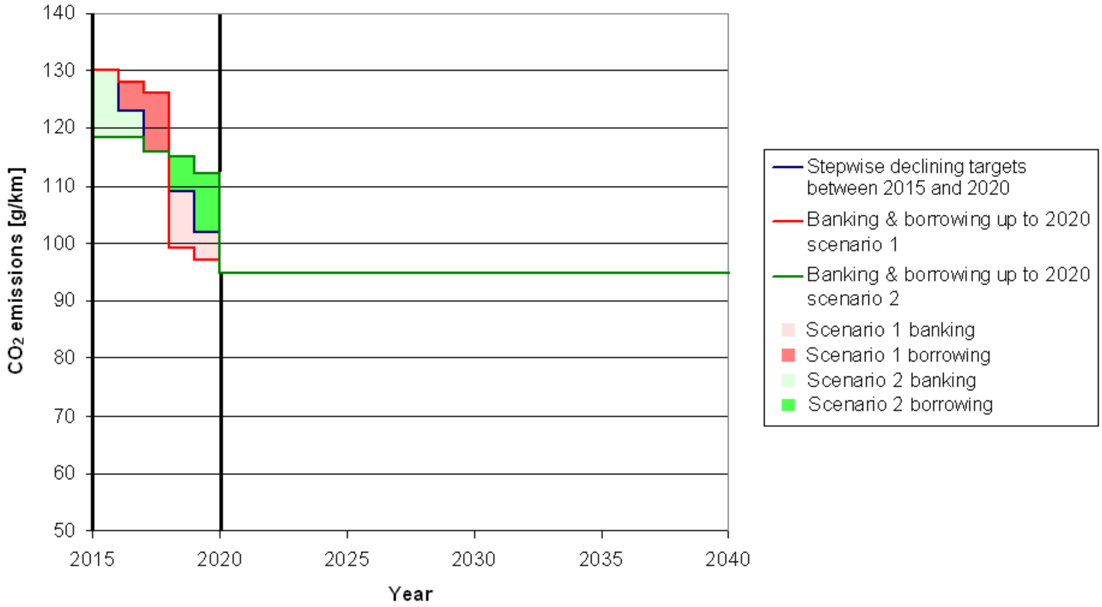


Figure 88 Possible banking and borrowing scenarios when banking and borrowing is only allowed during the annual step targets period (2015-2020).

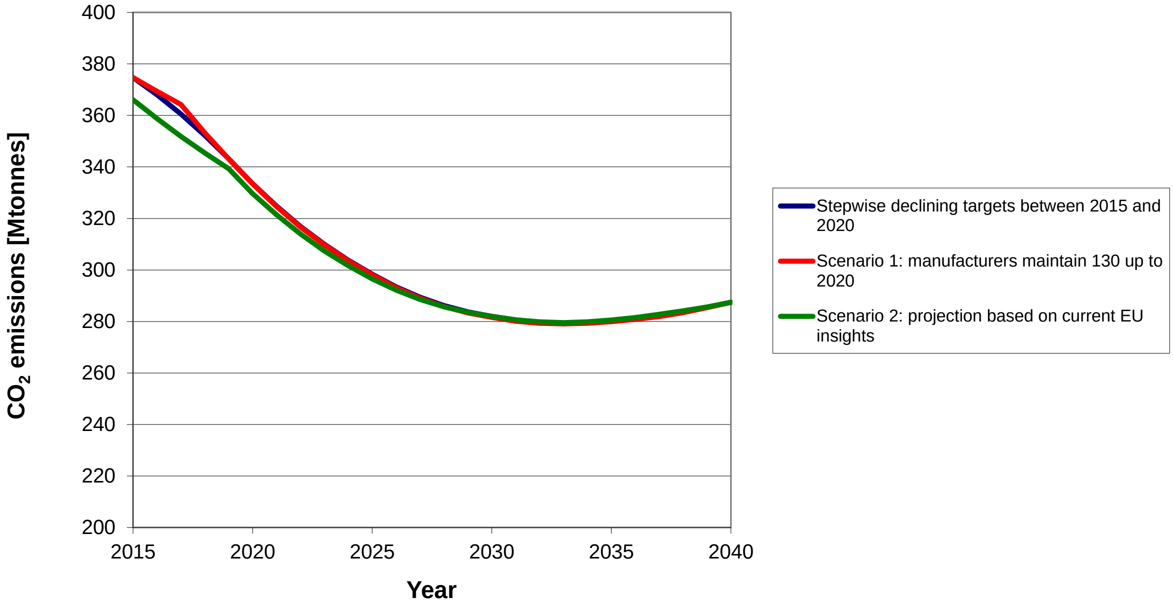


Figure 89 Estimation of total annual CO_2 emissions by passenger vehicles in the EU27 as a result of various banking and borrowing scenarios between 2015 and 2020.

The overall average annual additional manufacturer costs for mass and footprint between 2015 and 2020 are depicted in Table 95 and Table 96 respectively. As can be seen in both tables, it is cost effective to bank CO_2 emission credits early in the banking and borrowing period (scenario 2). The first gCO_2/km reduction is the cheapest to realise as it can be achieved with the cheapest available technologies. In case this relatively cheap gCO_2/km is banked, it can later be used to offset a gCO_2/km reduction that is more expensive to realise.

Table 95 Overview of average additional manufacturer costs for the two scenarios in which the banking and borrowing balance has to be neutralised before the target year 2020 (mass as utility parameter).

mass-based limit function		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	*average cost*
Baseline scenario without banking and borrowing	average CO_2 [g/km]	130	123	116	109	102	95	95	95	95	95	95	
	additional manufacturer costs [€]	403	642	915	1238	1639	2188	2188	2188	2188	2188	2188	**1633**
Banking & borrowing up to 2020 scenario 1	average CO_2 [g/km]	130	128	126	99	97	95	95	95	95	95	95	
	additional manufacturer costs [€]	403	468	536	1851	2010	2188	2188	2188	2188	2188	2188	**1672**
Banking & borrowing up to 2020 scenario 2	average CO_2 [g/km]	118	118	116	115	112	95	95	95	95	95	95	
	additional manufacturer costs [€]	832	832	915	957	1092	2188	2188	2188	2188	2188	2188	**1614**

Table 96 Overview of average additional manufacturer costs for the two scenarios in which the banking and borrowing balance to be neutralised before the target year 2020 (footprint as utility parameter).

footprint-based limit function		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	*average cost*
Baseline scenario without banking and borrowing	average CO_2 [g/km]	130	123	116	109	102	95	95	95	95	95	95	
	additional manufacturer costs [€]	414	653	926	1250	1654	2197	2197	2197	2197	2197	2197	**1644**
Banking & borrowing up to 2020 scenario 1	average CO_2 [g/km]	130	128	126	99	97	95	95	95	95	95	95	
	additional manufacturer costs [€]	414	480	547	1864	2022	2197	2197	2197	2197	2197	2197	**1683**
Banking & borrowing up to 2020 scenario 2	average CO_2 [g/km]	118	118	116	115	112	95	95	95	95	95	95	
	additional manufacturer costs [€]	844	844	926	969	1103	2197	2197	2197	2197	2197	2197	**1625**

15.4.2 Banking and borrowing beyond the annual step targets period (2015-2025)

If banking and borrowing is allowed beyond the 2015-2020 period, the total new sales average CO_2 emissions will not necessarily equal 95 g/km in 2020. Figure 90 depicts two examples of possible schemes in which the banked or borrowed amount are allowed to be neutralised up to five years beyond the target year. The total CO_2 emissions as a result of these banking and borrowing scenarios are shown in Figure 91.

In the following example it is assumed that CO_2 reduction credits have to be neutralised before 2025. For Figure 90's scenario 1, the average CO_2 emissions level in 2020 is higher than 95g/km because some manufacturers have borrowed more than they have banked until then. Therefore these manufacturers will have to neutralise their balances after 2020. To achieve this, some manufacturers will have to reduce so much that the fleet average CO_2 emissions will drop below 95 g/km at some point. Some manufacturers might not be able to achieve this by implementing CO_2 reducing technologies and even for the ones that could, costs would (at least temporarily) rise quite significantly, since the costs for realising reductions increases more then linearly with the achieved reduction level, as can be seen in the cost curves developed in Task 1.1. Instead of borrowing manufacturers may this be likely to look for more cost effective options, such as sales portfolio management, to stimulate the sales of cars with relatively low CO_2 emissions. Obviously the latter also comes at a cost as it would imply selling such cars for relatively low prices, which may also reduce revenues or even profits. When both implementing CO_2 reducing technologies and stimulating sales of low CO_2 emission vehicles are more expensive than paying the excess premium, manufacturers may opt for paying the excess premium, which would result in "CO_2 leakage" as the target is not met.

In Figure 90's scenario 2, the fleet average CO_2 emissions would be allowed to lie above 95 g/km in 2020, as manufacturers have banked more than they have borrowed in the period before the target year. As a result the manufacturers would have more time to lower their emissions to 95 gCO_2/km.

The total CO_2 emissions between 2015 and 2040 in scenario 1 are slightly higher (<0.1%) than in the scenario in which the suggested step targets are exactly followed. However, since manufacturers have a negative emission credit balance in 2020, they will temporarily have to sell vehicles with an average below 95 gCO_2/km. For scenario 2 the CO_2 emitted is approximately 0.8% (about 67 Mtonnes of CO_2) lower than the scenario in which the suggested step targets are exactly followed.

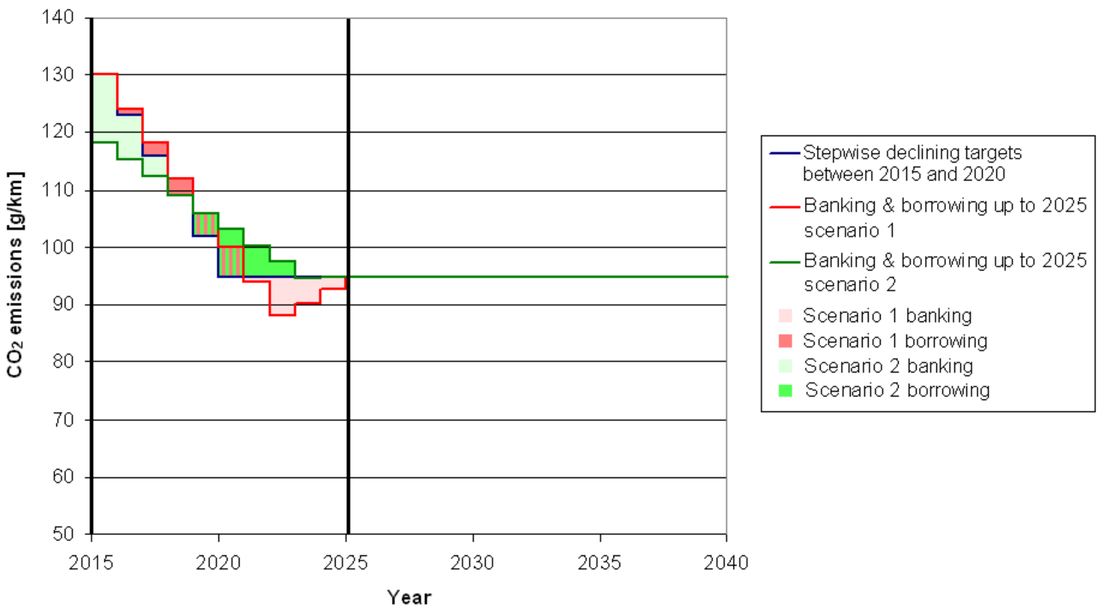


Figure 90 Possible banking and borrowing scenarios when banking and borrowing is allowed until five years beyond the annual step targets period (2015-2020).

The overall average annual additional manufacturer costs for mass and footprint between 2015 and 2020 are depicted in Table 97 and Table 98 respectively. As can be seen in both tables, it is also in this case cost effective to bank CO_2 emission credits early in the banking and borrowing period (scenario 2). The first gCO_2/km reduction is the cheapest to realise as it can be achieved with the cheapest available technologies. In case this relatively cheap gCO_2/km is banked, it can later be used to offset a gCO_2/km reduction that is more expensive to realise.

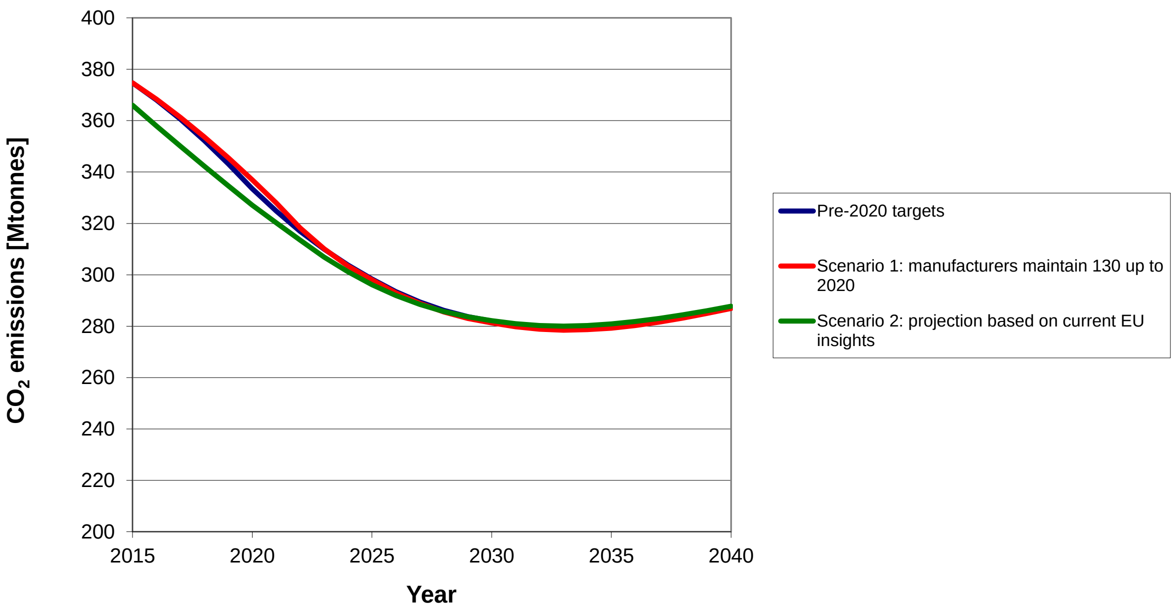


Figure 91 Estimation of total annual CO_2 emissions by passenger vehicles in the EU27 as a result of various banking and borrowing scenarios between 2015 and 2025.

Table 97 Overview of average additional manufacturer costs for the two scenarios in which the banking and borrowing balance has to be neutralised within 5 years after the target year 2020 (mass as utility parameter)

mass-based limit function		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	*average cost*
Baseline scenario without banking and borrowing	average CO_2 [g/km]	130	123	116	109	102	95	95	95	95	95	95	
	additional manufacturer costs [€]	403	642	915	1238	1639	2188	2188	2188	2188	2188	2188	**1633**
Banking & borrowing up to 2020 scenario 1	average CO_2 [g/km]	130	124	118	112	106	100	94	88	90	93	95	
	additional manufacturer costs [€]	403	606	832	1092	1398	1777	2284	3001	2691	2422	2188	**1699**
Banking & borrowing up to 2020 scenario 2	average CO_2 [g/km]	118	115	112	109	106	103	100	97	95	95	95	
	additional manufacturer costs [€]	832	951	1078	1238	1398	1566	1755	1973	2226	2188	2188	**1581**

Table 98 Overview of average additional manufacturer costs for the two scenarios in which the banking and borrowing balance to be neutralised within 5 years after the target year 2020 (footprint as utility parameter)

footprint-based limit function		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	*average cost*
Baseline scenario without banking and borrowing	average CO_2 [g/km]	130	123	116	109	102	95	95	95	95	95	95	
	additional manufacturer costs [€]	414	653	926	1250	1654	2197	2197	2197	2197	2197	2197	**1644**
Banking & borrowing up to 2020 scenario 1	average CO_2 [g/km]	130	124	118	112	106	100	94	88	90	93	95	
	additional manufacturer costs [€]	414	617	844	1103	1411	1790	2293	3000	2695	2429	2197	**1708**
Banking & borrowing up to 2020 scenario 2	average CO_2 [g/km]	118	115	112	109	106	103	100	97	95	95	95	
	additional manufacturer costs [€]	844	962	1090	1250	1411	1581	1769	1985	2235	2197	2197	**1593**

15.5 Overall conclusions on the consequences of additional provisions in the definition of the 2020 target

A trajectory of declining annual targets, setting intermediate steps with constant yearly reductions between the 2015 target and the target level set for 2020, can be proposed for two different reasons. First of all it avoids that manufacturers postpone the introduction of fuel efficient technologies to the last years before the target has to be met. Such behaviour would lead to higher fleet-wide CO_2 emissions in the last years than the situation in which efficient cars are introduced earlier in anticipation of the target year. Secondly a trajectory of declining annual targets may increase the likelihood that manufacturer groups actually meet their 2020 specific emissions targets.

Concerning the first motivation it is found that the impact of stepwise targets on the total annual CO_2 emissions from passenger vehicles in the 2015-2040 period is limited to a few percent relative to a worst case scenario without the step-wise approach in which manufacturer only implement the required reductions close to the 2020 target year. Still, the higher amount of CO_2 emissions potentially arising from not implementing the declining targets is similar to an approximately 2.8 g/km higher fleet average CO_2 level over the period between 2015 and 2040 (2.9% of the 95 gCO_2/km target). This indicates that the effect of the declining targets – or of the absence thereof – can be significant, and hence that they should be considered as an additional provision and in particular as a risk management measure.

Further, current production plans of some manufacturers indicate that they have planned the introduction of new or improved versions of existing vehicles, with lower CO_2 emissions, just beyond the target year of 2020, making the target incompatible with their model cycles. As a result these manufacturers have two options: either to pay the excess emissions premium, because the introduction of these vehicles occurs too late to meet the manufacturer's target, or advance the development and implementation of the new or improved versions so that they can be marketed before 2020. Both options could involve significant costs. If manufacturers were to meet stepwise declining intermediate targets, the chance that manufacturers with incompatible model cycles opt for

paying excess premiums, rather than adapting their model cycles to meet the 2020 target, could be greatly reduced.
However, setting annually declining targets without additional measures could reduce the flexibility for manufacturers to cost-effectively adapt their R&D, manufacturing and marketing activities with the target timing to a level that could not be reasonably demanded or is even practically impossible. This is not only related to the possibilities that manufacturers have to align their model cycles, but also to relatively unpredictable market developments that affect the average achieved by manufacturers in a given year. Combining the declining annual targets with the possibility of banking and borrowing, allows manufacturers to more flexibly deal with the approach to the 2020 target and to avoid payment of excess emissions premiums while still providing an increased incentive for aiming to reach the 2020 target with a more linear approach pathway.

From the different banking and borrowing scenarios assessed, it becomes clear that the total impact on the CO_2 emitted by passenger vehicles over a period of 25 years (2015-2040) is small, as long as the banked or borrowed emission allowances balance are neutralised by the end of a banking and borrowing period with sufficiently limited duration (5 to 10 years).

Although the impact of banking and borrowing on the total CO_2 emissions was found to be small, its effect on the additional manufacturer costs can be significant. Banking in the first half of the banking and borrowing period followed by borrowing in the second part reduces the net costs of meeting the targets (averaged over a longer time) compared to the situation in which the stepwise approach is exactly followed. Alternatively borrowing first, followed by banking later in the period, leads to an increase in the average costs per car for meeting the targets. The cost difference is higher if banking and borrowing is allowed before and after the 2020 target year compared to when it is only allowed before the 2020 target year. The reason for these cost impacts lies in the strong non-linearity of the cost curves, which implies that the costs per g/km reduced are lower at low reduction levels than at high reduction levels. If a manufacturer starts by banking, the relatively inexpensive g/km's banked in the first period can be offset by avoiding more expensive reductions later. The other way around, borrowing in an early stage has to be compensated by overachieving the target in later years at much higher costs per g/km.

Finally, the analysis presented in this work leads to the following main conclusions:

- A trajectory of declining annual CO_2 targets for manufacturers prior to the 2020 target year can prevent extra CO_2 emissions from the fleet over a longer time period;
- Banking and borrowing is a recommendable flexibility mechanism in addition to such a trajectory since such short periods between targets leave relatively little headroom for manufacturers to steer for these annual targets. This relates to their possibilities to adjust R&D programmes and model development cycles, but also to exterior developments (e.g. unexpected changes in sales distribution) that can influence a manufacturer's average CO_2 emission levels. Allowing banking and borrowing offers manufacturers the opportunity to compensate for possible overshooting or undershooting the targets in certain years as a result of these control limitations.
- The possible effect on fleetwide CO_2 emissions of the introduction of banking in borrowing in addition to annual decreasing targets is small as long as the banked or borrowed emission allowances balance is neutralised by the end of the banking and borrowing period.
- Banking and borrowing does not provide an incentive for manufacturers to postpone the application of CO_2 reducing technologies. Borrowing CO_2 credits prior to banking increases the net costs of meeting the target averaged over a longer time period. Therefore manufacturers will only delay their CO_2 emissions reduction if the costs of changing their model cycles are higher than the additional costs of compensating for their borrowed CO_2 credits. Hence it is safe to allow banking and borrowing;
- In order to manage the risk of manufacturers not being able to balance out a negative amount of CO_2 credits, a maximum amount of borrowed CO_2 credits can be considered.

16 Consequences of mileage weighting

16.1 Introduction

European emission regulation has historically always revolved around specific vehicle emissions, expressed in g/vkm. While this is very much in line with commercial definitions of fuel consumption (typically expressed in l/100km), it lacks a strong connection to the total amount of fuel that is actually consumed, and the environmental impact the purchase of a new vehicle entails.

Indeed, different consumers buy a vehicle for diverse purposes, and usually, a car is chosen based on the intended usage. Therefore, it is possible to link a vehicle's specific emissions with its total emissions in first order, given that the average usage patterns (mileage) are broadly known for all vehicle types. More detailed, 2nd order estimates of a vehicle's total emissions would require additional information on usage patterns (e.g. distribution over road types or speed-time profiles) in combination with knowledge of how these affect real-world fuel emissions.

As using more detailed estimates of real-world emissions would certainly not be feasible in a legislative context, this task limits itself to making a first exploration of the possibility for and consequences of using a mileage weighted emission target in a regulatory approach to reducing CO_2 emissions from passenger cars.

The main questions to be answered in this study are:
- In which way can mileage weighting be included in the overall CO_2 target and the specific targets for individual manufacturer groups?
- Is mileage weighting effective in making the net achieved CO_2 emission reduction (total fleet emissions) less sensitive to choices by manufacturers with regard to the way they distribute CO_2 reduction efforts over different models and market segments?
- Does mileage weighting have implications for the costs of meeting the target and the cost-effectiveness of the overall achieved CO_2 emission reduction?

In the next section, a discussion will outline the main issues related to overall and manufacturer- and utility-specific mileage weighted targets. Then, the results on vehicle mileages will be presented as derived from the FLEETS project, one of the latest to deal with the topic on a European scale. After that, the relation between mileage and the selected utility parameter will be analysed. The conclusion of this subtask will be the development of an alternative CO_2 emission target which takes lifetime mileage into account, and the impact this may have on total costs and CO_2 emissions.

16.2 Defining overall and manufacturer- and utility-specific mileage weighted targets

16.2.1 Do mileage estimates need to be utility-specific?

As the whole purpose of introducing mileage weighting is to take account of the fact that cars in different market segments tend to be driven differently (the "mileage values"), it is necessary to be able to attribute a specific mileage to every vehicle model on the basis of an objectively verifiable characteristic of the vehicle. The simplest and for the moment most consistent option would be to resort to the utility parameter, and hence the modelling of mileage as a continuous function of utility would be needed.

Furthermore, because currently observed mileages for petrol and diesel vehicles are quite different, two separate functions would need to be proposed. In the future, increased knowledge on usage patterns and mileages of EVs and other alternative energy vehicles may show that they are substantially different from those of conventional cars, which would require separate relations for mileage as function of utility parameter for these vehicles as well.

In practical terms, mileage as function of utility can be indicatively modelled on the basis of the FLEETS data (see also section 16.3). An average utility value would need to be established for each segment. After that a linear or non-linear fit could be made through the 3 points per fuel type.

However, a more detailed mileage survey would be preferable if mileage functions are to be derived for the purpose of inclusion in legislation.

16.2.2 Do mileage estimates need to be manufacturer-specific?

In the context of this project, and in line with current European CO_2 emissions legislation, g/km targets need to be set for each individual manufacturer such that a certain fleet average is achieved. Hence, if mileage weighting is to be applied in legislation, each manufacturer will get its own mileage-weighted emissions target.

Furthermore, since vehicles see an evolution of their usage pattern over their lifetime, namely by progressively reducing their annual mileage, lifetime mileages would be needed to reflect a vehicle's contribution to total emissions.

However, mileage weighting does not imply the need to determine and work with manufacturer-specific mileages. In fact, the lifetime mileage value to be attributed at the vehicle level to establish this target can be determined on different levels of detail, and at least as a first-order approach, it would suffice to work with manufacturer-independent, fleet average values. This would make it easier to establish sufficiently representative values as it does not require monitoring the use of all cars.

It should be noted that working with fleet averages may be found to do injustice to some specific manufacturers, and it may make it more difficult to get them accepted. At the same time, using manufacturer-specific functions does require monitoring nearly all vehicles, and establishing lifetime mileages using this approach would imply around 15 years of data collection. This is further discussed in section 16.5.

16.2.3 Which limit function to use for mileage-weighted manufacturer-specific targets?

Mileage weighted targets per manufacturer can be defined on the basis of the existing utility-based limit function, which has been derived relative to the sales-weighted least squares fit through the 2009 database. Multiplying each vehicle model's specific target with the sales and the specific mileage value, summing that over all vehicle models and dividing that by the sumprodruct of sales and mileages over all models will yield a mileage and sales weighted target per manufacturer.

With this approach most manufacturers will get a mileage-weighted target that is different from the sales-weighted target. This is not true, however, for manufacturers which sell vehicles in a very narrow utility bandwidth.

However, the limit function could also be determined in a way that takes account of mileages. This could be done by determining a sales plus mileage-weighted fit through the vehicle sales database, instead of a sales-weighted fit, and by deriving the 100% slope limit function for the 2020 target by constant reduction percentages relative to this line. The advantage of this would be that targets would also change for manufacturers that only sell vehicles in a small utility bandwidth. Given its increased complexity and the task's limited budget, this path was not explored further. A more detailed investigation should establish the added value of this approach and identify any potential consistency issues, e.g. double-counting.

As this task is a first exploration of feasibility and impacts, the modelling carried out in this task relied on the original utility-based limit function. Hence, targets per manufacturer were defined by sales- and mileage-weighting of the targets per model set by the 100% slope limit function based on the sales-weighted fit through the 2009 data.

16.2.4 Generic advantages of mileage weighting

If each manufacturer meets its specific target as defined on the basis of mileage and sales weighting of the targets per vehicle which are set by a utility-based limit function, the overall lifetime emissions of all new vehicles sold in a given year become independent from the way in which manufacturers distribute the required reduction efforts among the different models / segments. This has been established on the basis of parameter variation in a dedicated spreadsheet model, but can also be proven mathematically.

Numeric values of the mileage plus sales weighted target are generally higher than the sales weighted target for manufacturers selling a spectrum of vehicles spread over a wider range of utility values / different segments. But this has no real implications as this target can be reached in different ways without affecting the net lifetime CO_2 emissions, including the case in which each car meets its specific target set by the utility based limit function. The latter is also one of the ways in which a manufacturer can reach its sales weighted target.

For manufacturers that sell a narrow product portfolio (small bandwidth of utility values) the mileage plus sales weighted target is identical to the sales weighted target, if both are based on the same limit function. This would change if the mileage weighted target would be based on a utility-based limit function that would be derived from a sales plus mileage weighted fit.

16.2.5 In practice, which compromises were made for this study?

As discussed above, it is not possible to use actual real world mileage of every sold vehicle. Other intermediate levels of detail are in principle feasible but would fall outside of the scope of this task. Hence, the chosen approximation for a first order correction was to work with fleet average figures, although obviously differentiated according to vehicle size and fuel

This still leaves the issue of the practical collection of data on mileages. This is unfortunately not done systematically by national authorities, let alone allocated to manufacturers. The FLEETS project, which will be discussed and from which data will be used in the next section, made an attempt to communicate with administrations from all over Europe to obtain insight into average mileage per vehicle. The level of detail that was produced was chosen so as to be in line with modelling tools as used in the European context. The result was averages per vehicle size (3 segments) and fuel type (gasoline and diesel). With these data, and using the projected 2020 sales split over the same 6 segments, it is possible to calculate the targeted total lifetime emission volume for all cars sold in 2020, since estimates are available for the emissions in g/km and the total amount of kms driven.

Therefore, although lifetime mileages per model or as function of utility would be desirable, currently available data does not allow for this kind of detail. Therefore, it was chosen to attribute the average mileage per segment for all vehicles of that segment, regardless of their utility value and obviously also manufacturer.

16.3 Vehicle mileages

The TREMOVE model has always included annual mileage and mileage evolution patterns in its source data and model structure. The recent versions 3.3 and 3.4 include the mileages from the FLEETS project[113].

The first subsection deals with the assumed annual mileages of new vehicles. The assumption was made that there is a decrease of annual mileage as a car ages (for various reasons such as that it is used by vehicle owners with smaller mobility budgets, because it is replaced in its function as the primary vehicle of a household, because it spends more time being maintained in the garage, etc.). Estimates exist for this mileage degradation as well, which is dealt with in a second subsection.

16.3.1 Mileage of new vehicles

Table 99 below reflects the FLEETS results for the mileage of new vehicles (split by vehicle size and fuel type) for 2005 for all countries in the EU27. FLEETS did not distinguish between small and medium-sized diesel cars, hence the identical values for these types.

[113] See http://www.e3mlab.ntua.gr/reports/Fleets_Final_Report.pdf

Table 99 FLEETS values for mileage of new vehicles in 2005, EU27.

Country	PCDL	PCDM	PCDS	PCGL	PCGM	PCGS
AT	38,799	36,494	36,494	20,603	20,714	20,564
BE	36,751	36,507	36,507	11,953	14,286	14,043
BG	18,545	17,444	17,444	5,160	4,705	4,258
CY	35,787	33,661	33,661	16,963	15,467	13,998
CZ	50,909	47,886	47,886	15,165	13,827	12,515
DE	22,771	23,179	23,179	15,689	15,453	14,763
DK	40,279	39,420	39,420	22,480	22,134	22,134
EE	23,109	21,736	21,736	17,343	15,813	14,312
ES	38,957	27,603	27,603	14,543	14,689	14,671
FI	40,627	35,392	35,392	13,846	15,501	15,456
FR	21,013	20,491	20,491	19,939	18,762	15,886
GR	70,466	70,466	70,466	14,186	13,452	9,908
HU	37,534	35,304	35,304	18,171	16,568	14,995
IE	37,770	36,649	36,649	26,571	26,443	24,119
IT	19,193	19,140	19,140	15,270	15,167	12,027
LT	22,154	20,838	20,838	8,064	7,353	6,655
LU	90,712	85,324	85,324	37,902	34,559	31,278
LV	21,537	20,258	20,258	11,853	10,808	9,782
MT	17,793	16,736	16,736	11,840	10,795	9,770
NL	36,740	35,203	35,203	14,306	14,282	14,238
PL	12,637	19,290	19,290	9,620	8,772	7,939
PT	30,908	29,072	29,072	18,791	17,134	15,507
RO	21,797	20,502	20,502	12,339	11,251	10,183
SE	69,439	60,801	60,801	18,430	16,148	12,021
SI	47,459	44,640	44,640	22,315	20,347	18,415
SK	43,982	41,370	41,370	15,867	14,467	13,094
UK	21,400	21,685	21,685	19,576	20,898	20,231

PC= Passenger car, D= Diesel, G= Gasoline, L= Large, M= Medium, S= Small.

When we weight these values with FLEETS reported sales in 2005, we obtain the average values that will be used for further evaluation in this study. These are shown in Table 100.

Table 100 Average mileages per vehicle type, FLEETS.

Vehicle type	Total
PCDL	26,318
PCDM	24,574
PCDS	23,041
PCGL	16,839
PCGM	16,772
PCGS	14,438

The very first thing that stands out is the difference between fuel types: average mileage for new diesel cars is significantly higher than that for gasoline cars. Equally striking are the relatively minor differences between size classes. As it appears, drivers looking to use their cars intensively are more inclined to buy diesel cars, which have higher purchase costs but typically lower driving costs per km.

16.3.2 Mileage degradation and lifetime mileage

Two other factors play a role in the total impact of the car purchase decision on lifetime CO_2 emissions: the expected lifetime of a vehicle, and the evolution of the usage pattern over its lifetime.

TREMOVE also accounts for these factors through the survival parameters, which were also taken from FLEETS. The following table gives the median total lifetime mileage of all vehicle types, weighted with the fleet composition of 2005. More detail about the calculations in the model can be found in the TREMOVE manual and other reports on www.tremove.org.

Table 101 Total lifetime mileages per vehicle type, based on FLEETS.

Vehicle type	Lifetime mileage
PCDL	444,662
PCDM	362,316
PCDS	379,465
PCGL	300,347
PCGM	285,222
PCGS	250,952

16.3.3 Electric vehicles

In the coming decades new propulsion technologies may enter the market in significant quantities. The usage of these vehicles may differ from the conventional petrol and diesel cars. In the case of e.g. electric vehicles (EVs), which have a limited driving range on a single battery charge, it may be expected that they will mainly be used in applications with relatively short trip distances and possibly also below-average annual mileages.

In CE Delft's 2011 study on the impacts of EVs[114], a number of rough assumptions were made on vehicle lifetime and annual mileage, which mainly implied the assumption of equal annual mileage for EVs and ICEVs. As these were taken from TREMOVE 3.3.1 (and thus FLEETS), this is the same information used in the present study. No dedicated research into the specificities of electric driving behaviour was performed.

For the purpose of that study, those assumptions were sufficient. For a detailed review of implications of mileage weighting on manufacturers of EVs, more specific projections should be performed. Since insufficient information is currently available, one can put forward two - mutually exclusive - hypothetical scenarios:

- Average lifetime mileage of EVs is lower than that of ICEVs: the limited range of the batteries, combined with long charging times and limited number of charging points, would indicate that consumers that drive a lot are not likely candidates for EVs.
- Average lifetime mileage of EVs is higher than that of ICEVs: as long as EVs have high purchase cost and relatively low cost/km, one might expect that they are most likely to be bought by people/companies with high annual mileages.

In the former case, mileage weighting would decrease the weight of the zero-counting of EVs for the fleet averages. Lower than average mileage would thus decrease the incentive for manufacturers to push EVs to the market if mileage weighting was to be included in target setting.

This effect could be reinforced if the lower than average mileage of the electric part of the fleet would require the conventional vehicles to drive more or take a larger share of the fleet (through higher

[114] http://www.ce.nl/publicatie/impact_of_electric_vehicles/1152, D5

sales), so as to reach the same total annual mileage for the entire fleet. If their mileage or number goes up even more, it would further dilute the weight of the zero-counting of EVs.

Naturally, the opposite would be valid in the latter situation with higher than average mileages for EVs.

The present study's scope does not include an attempt at determining which hypothesis is more likely; further research is needed on the expected usage and survival parameters of electric vehicles.

It should be noted that the reasoning above is focussed on full EVs, and does not apply to Plug-in Hybrid EVs (PHEVs) or EVs with range extenders (EREVs). Contrary to full EVs, both could be expected to have a significant market share by 2020. However, in this case it is again very difficult to project the actual impact on emissions (via the ratio of electric versus ICE driving in real life – which is unknown). Ergo, it is impossible in the present study to predict the impact mileage weighting will have on target setting for these vehicle types.

In any case the above makes clear that mileage weighting of a CO_2 target for passenger cars does require a priori assumptions on the annual of lifetime mileage of vehicles with alternative powertrains. Such assumptions are difficult to make. In principle such mileage data would need to be derived from proper monitoring of the use of alternative vehicles.

16.3.4 Link with utility parameter

Mileages that were used in TREMOVE are categorised according to the model's vehicle classification system, which is based on engine sizes (small = below 1400cc, medium = between 1400cc and 2000cc, large = 2000cc and above). Naturally, the most elegant categorisation of mileages if this element is to be introduced in legislation would be to base them on the same utility parameter that is used to define the target per vehicle.

For the purpose of the illustrative exercise carried out in this task it was necessary – and deemed a good enough proxy – to create a simple coupling between the 6 segments as used in TREMOVE and those of the TNO cost assessment model (which are based on grouping of marketing classes instead of engine size).

If mileage weighting were to be included in the target setting, relations between mileage and utility parameter value would need to be defined first. This would need to be done separately for different fuel types or propulsion system types. This issue was discussed at length in the previous chapter.

16.4 Implications of mileage weighting

16.4.1 Impacts on net CO2 reductions

The basic principle of the approach followed for the quantitative assessment made in this task is that the total sales- and lifetime mileage-weighted CO_2 emissions (= total lifetime emissions of new vehicle sales in grams), achieved under a mileage weighted target, is set equal to the sales- and mileage-weighted CO_2 emissions (in grams) achieved under the existing non-mileage-weighted target.

This means that under this approach, mileage-based redistribution of the reduction effort (between segments) occurs only **within** the fleet of each manufacturer rather than between manufacturers. A more general approach could possibly allow for the latter option as well, but within the scope of this task it was not possible to devise a modelling approach to test this.

Therefore, for the purpose of the assessment carried out here, the individual manufacturers' sales- and mileage-weighted CO_2 emission targets are calculated as the sumproduct of the average CO_2 emissions (in grams per kilometre) per manufacturer per segment resulting from cost optimising under the (non-mileage weighted) target, the sales (per manufacturer per segment), and the lifetime mileage specific for each segment (Table 101). This results in a maximum amount of CO_2 emissions per manufacturer in grams per year. Since under a mileage-weighted target every manufacturer is simply obliged to reduce a certain amount of total lifetime CO_2 emissions, the distribution of this reduction over the segments can be determined by the manufacturer in such a way that the additional costs are minimised. This cost optimum is determined using an adapted version of the TNO cost assessment model.

It should be noted that this approach is slightly different from the one initially suggested (in the Inception Report), which proposed to assume a constant expenditure by manufacturers to reach the target in an unweighted versus a mileage-weighted case, and thereafter estimate the additional avoided emissions that could be achieved using mileage weighting. It was decided to move away from this approach and instead assume a constant projected total emissions volume, thus trying to estimate the potential cost savings generated by mileage weighting. The essential reason for this is that the 95g/km target that was decided upon by the EU already assumes goals for total emissions and climate change effects. Using the approach from the present study, that target for total CO_2 emissions is preserved. Still, the used approach does show that a mileage-weighted target makes the CO_2 emissions insensitive to the distribution of reduction efforts, which is also an impact on emissions.

16.4.2 Impacts on costs

Mileage weighting implies that the values in Table 101 were taken into account for the calculation of the sales- and mileage weighted targets per manufacturer.

Under the current legislation (which uses only sales to weight emission targets), if mileages are different for different vehicle models / segments, the net impact of the legislation on total CO_2 emissions (in Mton) depends on the way in which manufacturers distribute their reduction efforts over different models / segments. In this explorative task, the purpose is to make sure that the net Mton CO_2 emissions become insensitive to (annual) vehicle mileages. This is achieved by defining the target per manufacturer using a sales- and mileage-weighted average of the individual vehicle targets based on the limit function. Each manufacturer will then still try to reach that new target with minimal costs. The parameter to be minimised is, therefore, still the total manufacturer costs, and the approach thus tries to estimate the potential cost savings generated by mileage weighting.

As described in the previous section, this approach starts with the assumption that the total CO_2 emissions (in grams) should be equal under the existing non-mileage-weighted target and a sales- **and** mileage-weighted target. The maximum amount of CO_2 emissions per manufacturer is then used as a target per manufacturer to cost-optimise the distribution of CO_2 reductions over different segments for meeting the mileage-weighted target. As a result of this method the total fleetwide CO_2 emissions (in grams) remain equal to the case of the non-mileage weighted CO_2 target.

Following these steps produced the results in Table 102 and Table 103:

Table 102 Mileage-weighted achieved average emissions per segment[115], mass-based limit function.

Mass-based limit function	PCGS	PCGM	PCGL	PCDS	PCDM	PCDL	Average
2020 achieved average CO_2 emissions without mileage weighing [g/km]	82.8	98.1	122.3	88.4	105.3	128.1	95.0
2020 achieved average CO_2 emissions including mileage weighing [g/km*]	91.1	106.5	140.5	80.0	98.2	122.5	96.4
additional manufacturer costs without mileage weighing [€]	2994	3242	5874	2369	2710	4188	2947
additional manufacturer costs including mileage weighing [€]	2325	2826	5386	2907	3001	5300	2817

* g/km equivalent

115 Based on modelled efforts by individual manufacturer groups to meet their specific targets at minimal additional manufacturer costs.

Table 103 Mileage-weighted achieved average emissions per segment[116], footprint-based limit function.

Footprint-based limit function	PCGS	PCGM	PCGL	PCDS	PCDM	PCDL	Average
2020 achieved average CO_2 emissions without mileage weighing [g/km]	84.3	100.4	112.7	88.3	103.4	118.7	95.0
2020 achieved average CO_2 emissions including mileage weighing [g/km*]	91.4	106.2	137.4	80.5	97.8	118.8	96.2
additional manufacturer costs without mileage weighing [€]	2909	3259	6208	2283	2739	4831	2943
additional manufacturer costs including mileage weighing [€]	2288	2875	5793	2842	3067	5935	2849

* g/km equivalent

A first observation is that because a number of relatively high emitting vehicles drive relatively longer distances (i.e. large diesels), the 'weight' of these vehicles in the average CO_2 emissions per kilometre becomes relatively higher under a mileage weighted target, increasing the average emissions per vehicle with about 0.8 g/km.

It can be observed that mileage weighting would reduce the cost of reaching the CO_2 target. In the unweighted case, a large effort is required from gasoline cars. Given that their lifetime mileages are 20%-35% lower on average than their diesel equivalents, those efforts yield lower total CO_2 savings. Not surprisingly, the largest relative changes in incremental costs occur for the types with the lowest and highest average mileages: small gasoline (-20.5%) and large diesel (+28%) vehicles. These are also the vehicles with the largest and smallest share of sales volume. Ergo, in the unweighted case, the contribution of emissions of gasoline cars, especially small ones, to the net fleetwide emission reduction is smaller than their contribution to meeting the sales weighted target. Under a mileage-weighted target vehicle segments with high mileages will also contribute more to meeting the average emissions target.

The lifetime emissions total (based on test cycle emissions[117]) in the unweighted case for all cars sold in 2020 is 303.725 million tonnes of CO_2. In order to reach that target, 29.813 billion € will be spent on technical improvements. To reach the same total emissions with mileage weighting, the incremental cost drops to 29.211 billion € - saving just under 2%.

16.5 Additional practical considerations

In addition to the discussion in section 16.2, it should be pointed out that while mileage weighting can contribute to a more efficient path in reaching an emission target, there are a number of practical issues that would need to be resolved before it could be applied, even within the context of the approach followed in this task.

16.5.1 Collecting reliable mileage statistics

Certainly, the most important question is how lifetime mileages can be measured in a clear and generally accepted manner. A minimum level would be to establish overall fleet average relations between the utility parameter and mileage, if necessary separately per fuel / propulsion type. But as for a given utility parameter value different manufacturers may sell very different vehicle types in very different markets, it could also be considered to define mileage functions separately per manufacturer.

It does not seem infeasible to collect reliable information. A first option would be to set up an EU-wide survey, collecting data from sufficiently large samples of vehicles in different Members States. This may be a sufficient basis for generating overall fleet average mileage data.

More detailed information can be obtained by collecting information from vehicle inspections. All cars (should) have to pass a vehicle inspection on a regular basis, at which time mileage statistics can be

[116] Based on modelled efforts by individual manufacturer groups to meet their specific targets at minimal additional manufacturer costs.
[117] As stated, this task is based solely on test cycle emissions. Real world emissions have been demonstrated in literature to be quite (more than 10%) higher than these test cycle emissions.

recorded, and these values can then be used to accurately calculate the desired information. In this way also information per manufacturer could be obtained. The complexity of setting up such a system is limited, assuming all countries have a standard for vehicle inspection with centralised databases in place.

Determining annual mileage can be done in a fairly unambiguous manner. It is however much more difficult to assess the average total lifetime of a vehicle, as it may have a second or third life in another country or even another continent. Through the same central system as for mileages, a vehicle can be tracked and its age can be recorded, as long as it stays within the territory of the EU, which will likely cover a substantial enough share of total fleet to produce a good estimate of total lifetime.

In any case, it is likely that the inclusion of lifetime mileage as a base parameter for emission targets will be a cause for concern with automobile manufacturers.

16.5.2 Updating mileage statistics

Mileage statistics may vary over time, as market segments change due to the arrival of new technologies, or even due to emission legislation itself. From many countries, a lot of knowledge on mileage profiles already exists, allowing for estimates of evolution in mileage statistics over the years. When detailed data from all countries can be obtained and it is updated regularly, trends can be quickly identified.

The update interval depends on the sensitivity of the target to changes in the mileage profile. Thresholds should be defined, in agreement with the sector, for updates of the target.

16.5.3 Coupling of mileage and utility parameter

As explained above, TREMOVE-sourced mileages are based on engine sizes. While for the purpose of the illustrative exercise carried out in this task it was not necessary to define this coupling, if mileage weighting is to be used in legislation, one needs to be able to attribute a lifetime mileage value to each newly sold car based on an easily verifiable characteristic of that car.

This can not be engine size, as engine sizes are expected to decrease due to downsizing without affecting vehicles' usage patterns. Also for hybrid and electric vehicles engine size is not a practical parameter. The most elegant categorisation of mileages would be to base them on the same utility parameter that is used to define the target per vehicle.

This implies that yearly and lifetime mileages would need to be recorded together with the technical information which is feasible to be used as utility parameter, e.g. mass and footprint.

16.6 Conclusion

In this subtask, estimates for lifetime mileage of all vehicle classes were retrieved from FLEETS via TREMOVE. Per vehicle type, the mileage at the median age of leaving the vehicle fleet was derived.

These values were used to estimate total lifetime emissions (g/km x lifetime km) per manufacturer per segment. The cost model was then run, for each of the utility parameters (mass and footprint), with the objective of reaching the same amount of total CO_2 emissions as in the non-mileage-weighted case, per manufacturer, at minimal cost. The distribution of reduction effort between segments thus becomes dependent on the corresponding lifetime mileages.

It was shown that the lifetime emissions total for all vehicles sold in 2020 can be achieved 2% less expensively (equivalent to € 600 million) when mileage is taken on board as one of the weighting parameters (in addition to sales). This is due to the fact that vehicles with higher emissions generally cover longer distances, thus increasing the emission reductions that can be captured with CO_2 reduction technologies applied to these vehicles.

Since this task could only consider mileage-based redistribution of the reduction effort (between segments) **within** the fleet of each manufacturer rather than between manufacturers, potential further cost savings may have been left out. Applying mileage weighting also leads to a different distribution of the contributions of different manufacturers to reaching the overall target. This may have additional cost impacts.

In any case, this task concluded that including mileage as a weighting parameter:

- **can** contribute to a greater efficiency in reaching EU GHG emission targets;
- makes the achieved net GHG emission reduction insensitive to the way in which manufacturers choose to distribute their reduction efforts over different market segments / models;
- will help to reach the intended overall GHG emission reduction in a more cost-effective manner by taking account of the fact that CO_2 emission reduction technologies have more impact in cars that drive more.

A major concern that needs to be addressed is the establishment of robust and accepted mileage values, which at least should be recorded in function of an appropriate utility parameter and the fuel type, but possibly also specific for each manufacturer. This can be done through surveys or improved inspection/reporting procedures, for which discussions with the relevant sectors will be needed.

Unfortunately, for electric vehicles, the existing projections of lifetime mileage were not sufficient to reach any conclusions with regard to the effects of mileage weighting.

Recommendations for further analysis include:

- determining an alternative utility based limit function on the basis of a sales plus mileage weighted fit through the 2009 data and using this in the cost assessment model;
- more detailed assessment of the difference in GHG emission and cost impacts between the sales weighted and the sales plus mileage weighted target definition as a consequence of the fact that mileage weighting also leads to a different distribution of the contributions of different manufacturers to reaching the overall target;
- further exploration of the possibilities to establish functional relationships between mileage and utility parameters.

17 GHG emissions of various life-cycle aspects

17.1 Introduction

The relevance of lifecycle emissions in passenger vehicle transport is increasing, since vehicles are required to have lower GHG emissions in use. The recently agreed legislation (Regulation (EC) No 443/2009) reduces the amount of GHGs emitted during vehicle use. This implies that without measures, the relative impact of vehicle material generation, component production, vehicle assembly and the end-of-life phase may increase. Measures for these life cycle phases are already in place e.g. as part of the EU Emission Trading Scheme (ETS).

The lifecycle of a vehicle can be divided into three main stages: production (vehicle and fuels), use phase and end-of-life vehicle treatment. See Figure 92 for an illustrative overview of the different phases identified in the vehicle life cycle.

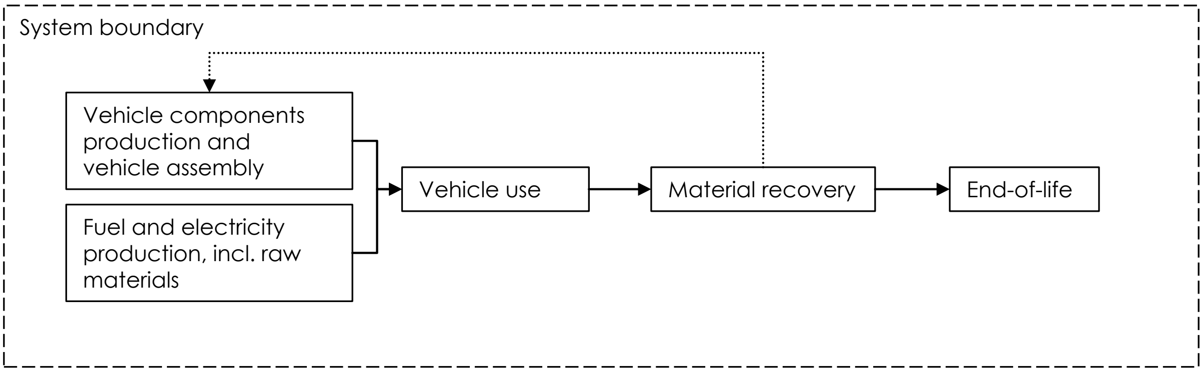


Figure 92 Different phases in the vehicle life cycle.

The GHG intensity of fuel production is covered by Directive 2009/30. The Directive sets targets to reduce the life cycle greenhouse gas emissions of fuels. It places the responsibility for reducing greenhouse gas emissions during the life cycle of fuels on the fuel suppliers. Oil industry will have to gradually reduce fuel greenhouse gas emissions by 6-10% between 2010 and 2020.

Vehicle end-of-life disposal has also been regulated, albeit not the GHG emissions or energy use of this phase: Directive 2000/53 sets targets for recycling (incl. re-use) and recovery of vehicles. Producers, distributors, insurance companies, ELV collectors and treatment operators in the EU all share responsibility for meeting these targets:

- Effective January 1, 2006, 80% of ELV by weight must be reused or recycled, with a total recovery of 85%.
- Effective January 1, 2015, 85% of ELV by weight must be reused or recycled, with a total recovery of 95%.

New vehicles must be 85% reusable or recyclable (by mass) and 95% recoverable, effective 2008, to receive type-approval in the European Union.

This paper will focus on the parts in the vehicle lifecycle chain where no direct GHG product regulations exist: vehicle production and end-of-life disposal.

17.1.1 Objectives

The objective of this paper is to:

- Assess the order of magnitude of GHG emissions caused by the manufacture, usage and disposal of several types of cars;
- Assess their evolution in the future, as function of various technological options for reducing GHG emissions;

- Outline possible ways of taking into account the GHG emissions caused by the manufacture and disposal of cars.

17.1.2 Approach

Generally, several studies illustrate the contribution of vehicle production and disposal as the share per kilometre driven over the entire lifecycle. However, assumptions like lifetime mileage, vehicle mass, material use, material emission factors, use of recycled materials, and engine type and size influence the outcome. To limit the effects of differences in data, we will normalise a number of figures (see Table 104), as follows:

- Use a vehicle lifetime that is estimated to be around 238,000 km on average (based on the TREMOVE model version 3.3 dataset).
- Fuel well-to-wheel emissions have been taken from JEC (2008). Upstream process emissions amount 12 and 14 grams of CO_2 eq. per MJ of fuel produced for petrol and diesel respectively.
- Use a standardised set of fuel consumption reference figures and fuel well-to-wheel emissions, as given in Table 105. A factor that corrects for the difference in fuel consumption over the NEDC driving cycle and real world use has been applied.

Table 104 Normalised reference values used in this study.

	Petrol			diesel		
	small	medium	large	small	medium	large
sales weighted CO_2 NEDC (g/km)	133	160	195	118	139	170
RW/TA correction factor	1.2	1.2	1.2	1.2	1.2	1.2
sales weighted kerb mass (kg)	958	1212	1434	1091	1292	1515
Lifetime mileage (*1000 km)	138	173	199	226	304	344

Notes:

- *The RW/TA correction factor represents the ratio of real world GHG emissions and GHG emissions as measured on the type approval test. These averages are based on sales data per market segment. However, recent TNO data suggests that the RW/TA correction factors are higher for small vehicles*
- *The CO_2 emissions of the same class diesel and petrol vehicles cannot be compared therefore, since the vehicles are not necessarily comparable and have different mileage.*

Source: Polk 2009 sales data; TNO (2006) ; TREMOVE 3.3

The mass of the vehicle strongly influences the energy consumption during vehicle production; however, this is only directionally correct if the share of material stays constant over the different weight classes. In these cases the GHG emissions during vehicle production could be taken into account as function of the vehicle mass. In case of different material composition energy consumption can vary depending on the types of materials used. For example, light weighing cars can be reached by materials with high, but also with low CO_2 emissions. Therefore light weighing does not necessarily lead to a decrease in production related GHG emissions.
The per kilometre impact of manufacturing will be estimated on the basis of the normalised data presented above and fuel consumption and vehicle production emissions depending on the vehicle size.

17.2 Conventional vehicles: material use and vehicle manufacture

Material production and vehicle assembly generate GHG emissions. The amount depends on the vehicle mass and factors like the mix of energy and materials used. A number of available studies have assessed the lifecycle emissions of conventional vehicles (CVs) in recent years. The table below provides information on the amount of GHGs that is accompanied with vehicle production.

Table 105 Overview of GHG emissions of vehicle production.

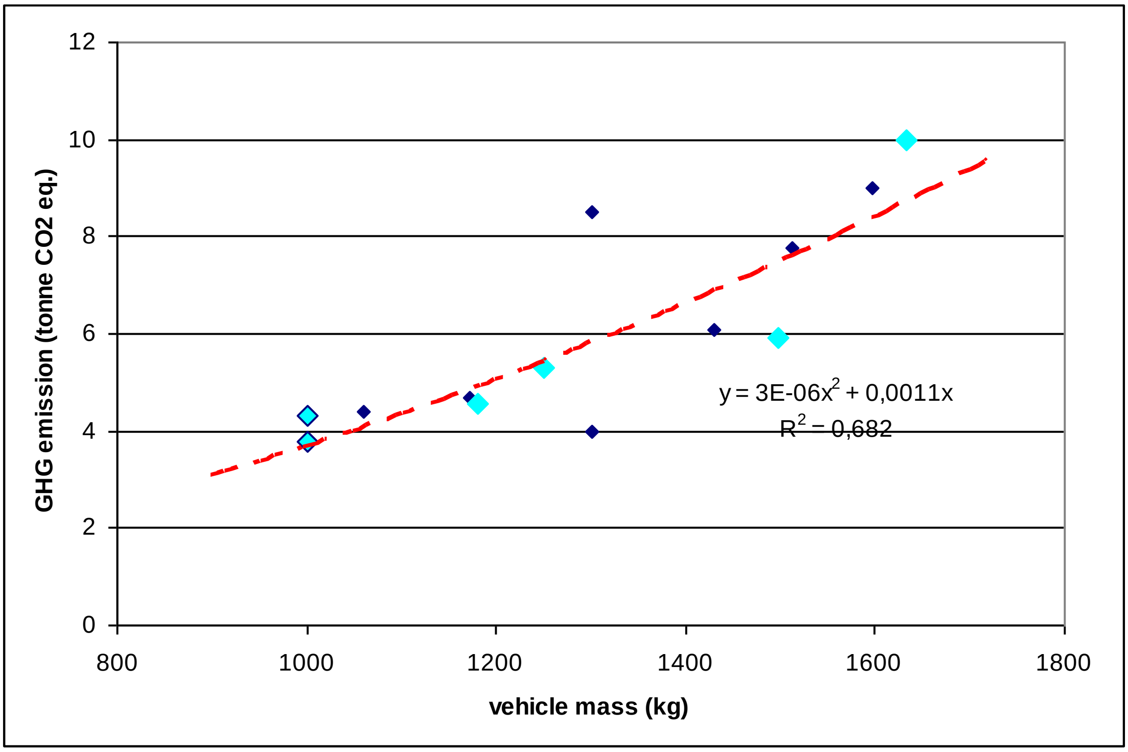
Source	GHG emission (tonne CO_2 eq.)	Comments
GREET 2.7 model (2009)[118]	7.8	Vehicle mass 1513 kg
Ford (2007)	9-10	The values represent a petrol and diesel vehicle respectively of around 1500 kg (Galaxy, S-Max).
Schweimer (2000)	4.5 - 5	The values represent a petrol and diesel vehicle respectively of around 1000 kg (Golf A4). Taking the lower weight into account, this estimate is at the lower end.
Samaras (2009)	8.5	The value represents a petrol vehicle with a weight of 1300 kg (Toyota Corolla).
Lane (2006)	4.3	Vehicle mass 1000 kg value valid for both petrol and diesel vehicle
AEA (2007)	3.8	1000 kg vehicle. Composition figures used from Lane (2006).
Helms (2010)	4.0	Average vehicle, assuming to represent 1300 kg.
VW (2009a)	5.8	Golf V 1.9 TDI. vehicle mass 1251 kg
VW (2009a)	4.9	Golf V 1.6 MPI. vehicle mass 1173 kg
VW (2009b)	6.1	VW Passat, 1429 kg petrol
VW (2009b)	5.9	VW Passat, 1479 kg diesel

When we plot the GHG emissions figures from Table 104 against the weight of the vehicle, the pattern displayed in Figure 93 can be found. The difference in GHG emissions can be explained for 68%[119] by the difference in vehicle mass. In addition to mass, the difference in GHG emission can be explained by the following factors:

- Differences in material composition
- Difference is engine volume/power
- Differences in material emission factors (LCA database)
- Differences in the LCA approach of allocating recycling
- Differences in electricity mix
- Differences in the system boundaries

More studies and the possibility of taking into account the other variables playing a role in estimating vehicle production emissions would facilitate the definition of a better trend line. An analysis with the SimaPro LCA software tool showed for example that using the composition figures from Scheimer (2000) and Lane (2006), material composition differences result in a difference of about 300 kg CO_2 eq.

[118] http://www.transportation.anl.gov/modeling_simulation/GREET/
[119] If we delete the two outlying points (1300 kg), R2 increases to 0.88.



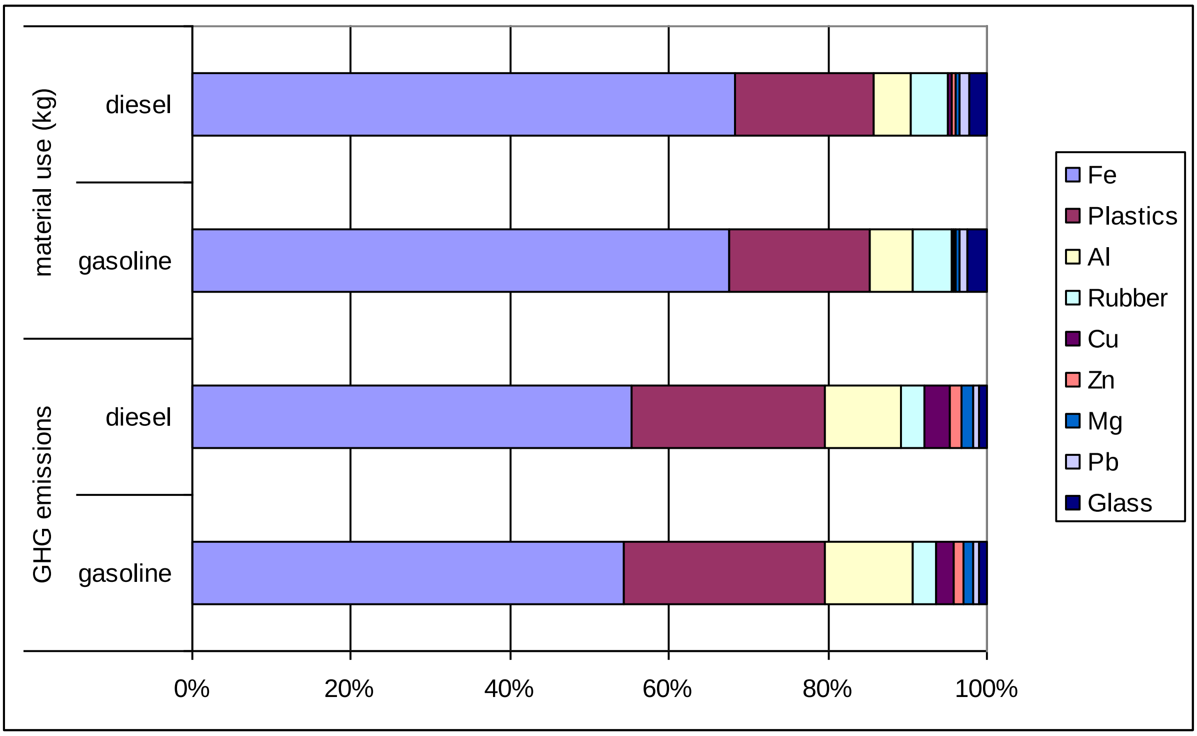
Note: the turquoise dots represent diesel vehicles, while the blue dots represent petrol vehicles.

Figure 93 Relation between vehicle mass and GHG emission for diesel and petrol vehicles.

The individual studies comparing petrol and diesel vehicles show on average higher GHG impact during the vehicle production stage for diesel vehicles, although the studies investigated show quite large variations in the results. However, the lower GHG emissions during the use-phase of a diesel vehicle more than compensate for the higher energy consumption during vehicle production in all studies investigated.

17.2.1 Breakdown of raw material production GHG emissions

Lane (2006) provides the following figures on GHG emissions breakdown of the production of a vehicle of 1000 kg.



Source: Lane, 2006.

Figure 94 Breakdown of raw material use and GHG emissions per vehicle.

The data show that steel, plastics and aluminium are the dominant material source in vehicle production and their production is associated with more than 90% of all emissions. Lane (2006) also shows that the impact of CH4 and N2O emissions is very limited compared to the impact of CO_2.

17.2.2 Breakdown of energy consumption in material and vehicle production

Production of metals is very energy intensive because the ore must be mined, concentrated, and subjected to endothermic chemical reactions to yield the metal product. Schweimer (2000) shows that material production is associated with the greatest use of energy, around 57-58% emissions. Lane (2006) estimates the material use at 60% of total production emissions. The remainder CO_2 emission is associated with the assembly of vehicles and vehicle parts. Burnham et al. (2007) found that the painting process accounts for a big part of the process emissions from a vehicle assembly plant. However, the assembly plant has only a very small share of the production phase (cradle-to-gate). Specifically, the energy use from the painting process (curing ovens) accounts for about 20% of the vehicle assembly plant's total energy use, the production of vehicle components not taken into account.

17.2.3 Material recycling

The use of recycled materials is common in the automotive sector, part of the iron and aluminium used are scrap metals. The figures depicted in Table 106 represent the recycling rate of different materials applied in the calculations in the GREET 2.7 model.

Table 106 Share of use of virgin and recycled material.

	Virgin Material	**Recycled Material**
Steel	30%	70%
Wrought Aluminium	89%	11%
Cast Aluminium	41%	59%

Source: Burnham et al., 2007.

The energy consumption concerning the use of recycled materials is lower than the use of virgin materials, because the basic material only needs to be re-melted. Using recycled cast and wrought aluminium instead of virgin aluminium saves 70 and 73% of GHG emissions respectively. Recycling of steel saves 60% of the GHG emissions compared to the use of virgin materials. If the use of recycled steel can be increased to 90% instead of 70%, the vehicle emissions of the conventional vehicle reduce by around 11%, compared to the figures from Table 105 / Figure 93 (GREET 2.7 model).

17.2.4 End-of-life

The studies differ in the method of emission allocation. Most studies calculate with the use of recycled materials (Burnham et al., 2007; Samaras, 2009; Schweimer, 2000) and apply production emissions of recycled materials. These studies allocate emissions benefits to the recycled products. Other studies (AEA, 2007) calculate with virgin materials and the corresponding production emissions and apply a recycling stage in the end, with allocation of recycling credits to the vehicle.

If the studies assume recycled materials to be used, end-of-life processing emissions seem to be very small (Burnham et al., 2007; Samaras, 2009; Schweimer, 2000). Some studies neglect these emissions because its share is deemed to be too small.

17.3 Impact of vehicle production on lifecycle emissions

Using the fuel consumption data presented in Section 17.1.2, the share of vehicle production in the total lifecycle can be estimated on the basis of data from Figure 96 for different classes of vehicles. The figures below present the absolute and relative contribution to the lifecycle GHG emissions.

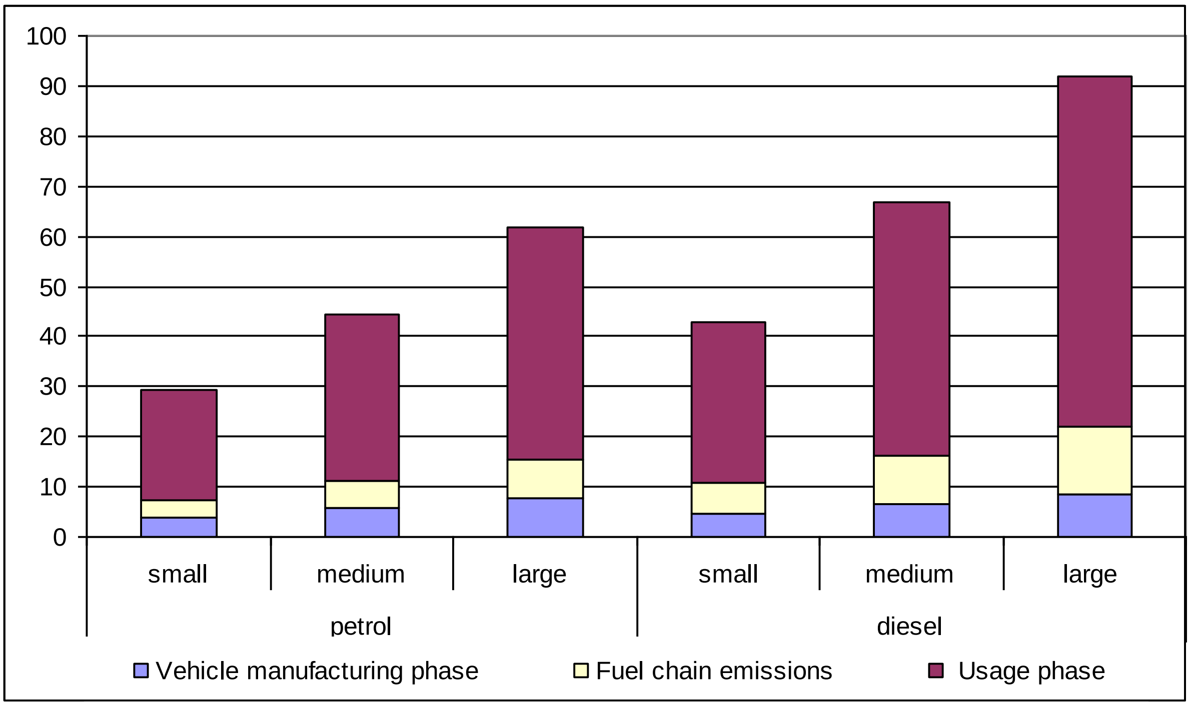


Figure 95 Contribution of different life cycle phases to the total life cycle GHG emissions (tonne CO_2 eq./vehicle).

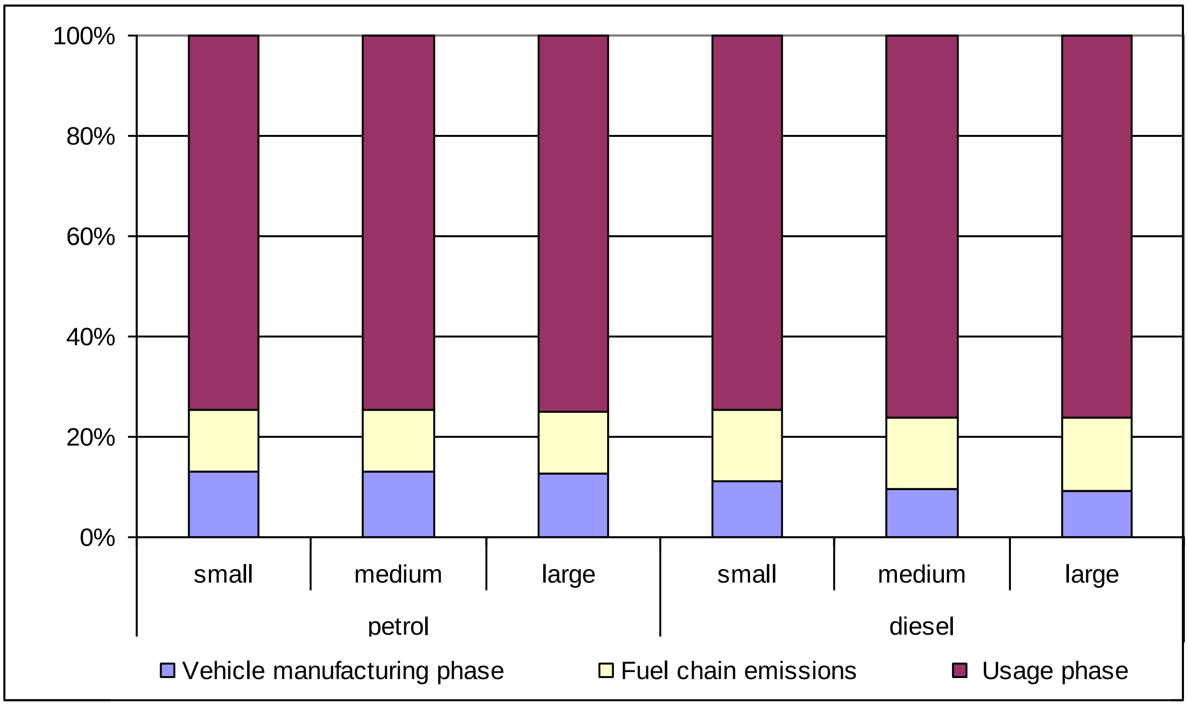


Figure 96 Contribution of different stages in the life cycle to total GHG emissions.

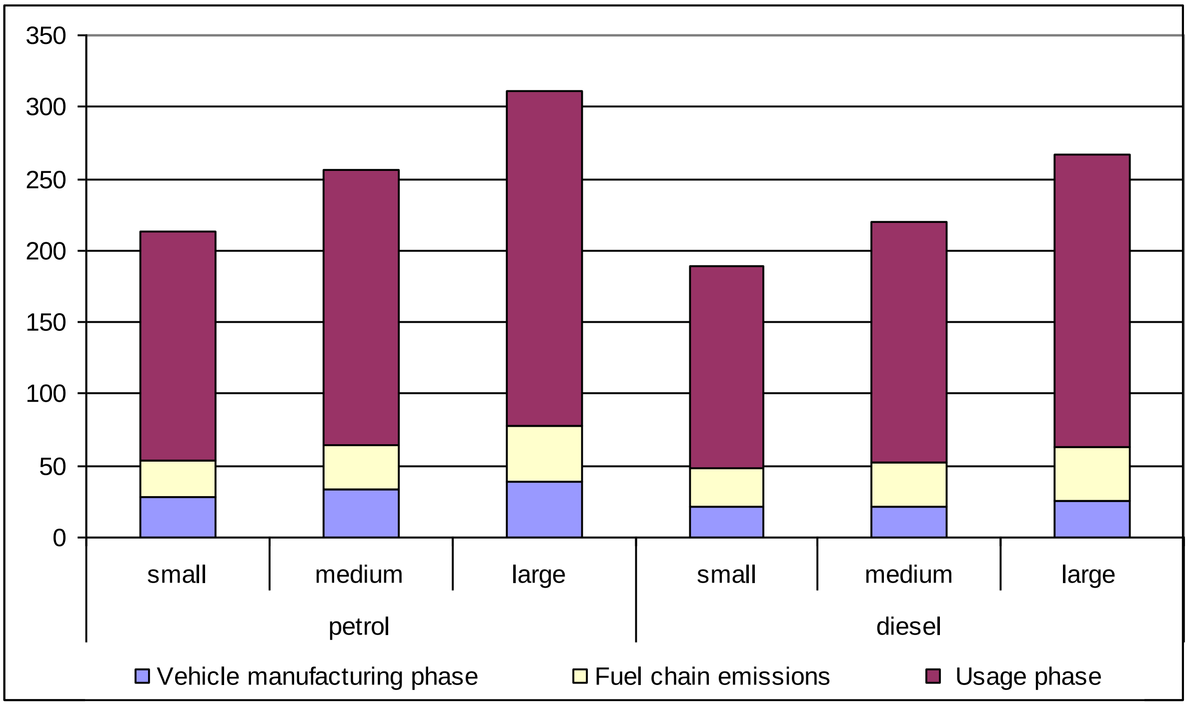


Figure 97 Contribution of different stages in the life cycle to total GHG emissions (g CO_2 eq. /km).

The absolute and relative production cycle emissions are depicted in Table 107.

Table 107 Absolute and relative emissions of the vehicle production stage (g CO_2eq./km).

	petrol		diesel	
	g/km	%	g/km	%
Small	28	13%	21	11%
Medium	33	13%	21	10%
Large	39	13%	25	9%

For conventional vehicles, the GHG emissions related to vehicle production range from 21 to 39 (g CO_2eq./km) depending on the vehicle size and engine type.

17.3.1 Uncertainty analysis

If we assume all vehicles to drive 180,000 kilometres over the entire lifetime, the situation is very different, see Annex L. In such a scenario, the difference between small vehicles and large vehicles is much bigger. Furthermore, the share of production in the total life cycle is significantly higher.

17.4 Impact of short term fuel efficiency measures

Under the EU regulation 443/2009 on vehicle CO_2 emissions in force, vehicle emissions are needed to decrease in the next five years. On average, car makers will need to reduce fuel consumption by 10-15%. Several technologies can be applied to reduce vehicle fuel consumption. Depending on the mass and materials needed, these technologies will increase or decrease the vehicle mass and CO_2 emissions associated with manufacturing. An overview of technologies available and their impacts on vehicle mass is depicted in Table 108. The following scale was used for the impact on vehicle kerb mass (column 2):

-5	=	very high mass reduction (>-10%)
-4	=	high mass reduction (circa -5-10%)
-3	=	medium mass reduction (circa -3-5%)
-2	=	medium low mass reduction (circa -1-3%)
-1	=	low mass reduction (< -1%)
0	=	none/negligible change in mass
+1	=	low mass increase (< +1%)
+2	=	medium-low mass increase (circa +1-3%)
+3	=	medium mass increase (circa >+3 – 5%)
+4	=	high mass increase (circa +5-10%)
+5	=	very high mass increase (>+10%)

Table 108 High-level assessment of impact of technology on overall vehicle mass and materials, assuming medium vehicle.

Technology	**Impact on overall vehicle mass**	**Materials**	**Comments**
Gas-wall heat transfer reduction	+1	New actuator – steel/aluminium	Will vary depending on approach taken. Assume charge motion system (swirl control valves / tumble flaps)
DI, homogeneous	+1	Injectors typically steel (varying grades), seals etc., fuel pump body aluminium or stainless steel	Assuming solenoid injectors plus fuel pump
DI, stratified charge	+1	Injectors typically steel (varying grades), seals etc., fuel pump body aluminium or stainless steel	Assuming solenoid injectors plus fuel pump
Mild downsizing (15% reduction)	-1	Reduction in engine block/head material (e.g. aluminium) plus material in turbo: aluminium, cast iron, nickel based alloy, copper/Brass and steel	Reduction in mass due to downsizing plus additional mass of turbocharger (assume FGT)
Medium downsizing (30% reduction)	-1	Reduction in engine block/head material (e.g. aluminium) plus material in turbo: aluminium, cast iron, nickel based alloy, copper/Brass and steel	Reduction in mass due to downsizing plus additional mass of turbocharger (assume FGT)
Strong downsizing (>45% reduction)	-1	Reduction in engine block/head material (e.g. aluminium) plus material in turbo: aluminium, cast iron, nickel based alloy, copper/Brass and steel [1,2]	Assume architecture scale-down (e.g. I4 to I3) to achieve downsizing plus additional mass of turbocharger (assume 2-stage e.g. FGT+ e-boost)

Technology	Impact on overall vehicle mass	Materials	Comments
Cam phasing	+1	Cam phasers typically steel	Assuming twin phasers (intake and exhaust)
Variable valve actuation and lift	+1	Addition of steel, aluminium	Assuming BMW "Valvetronic" type system
Low friction design & materials	0	Addition of a coating material (e.g. DLC, MoS_2)	Low friction coatings, improved lubricants will have negligible impact on mass
Diesel Combustion improvements	0 - +1	No significant change	Depends on technology utilised. Assume HCCI for this analysis
Diesel Mild downsizing (15% reduction)	-1	Reduction in engine block/head material (e.g. iron or aluminium)	Reduction in mass due to downsizing
Diesel Medium downsizing (30% reduction)	0	Reduction in engine block/head material	Reduction in mass due to downsizing
Diesel Strong downsizing (>45% reduction)	-1	Reduction in engine block/head material (e.g. iron or aluminium) plus material in turbochargers: aluminium, cast iron, nickel based alloy, copper/Brass, steel [1,2]	Assume architecture scale-down (e.g. I4 to I3) to achieve downsizing plus additional mass of turbocharger (assume 2-stage e.g. FGT+ e-boost)
Optimising gearbox ratios	0	No change	Assuming a manual transmission
AMT	+1	Actuator: either hydraulic or electric motor (like a windscreen motor (worm gear) plus extra electronics - Transmission Control unit	Assuming substitution for manual transmission. AMT is very similar to manual with the addition of actuators plus control. Typically steel for gears, aluminium for casing
DCT	+2	Additional clutch compared to manual, control: electro-hydraulic or electro-mechanical Different transmission fluid for wet clutch compared to manual. Addition of park brake mechanism	Assuming substitution for manual transmission. DCT is similar to manual transmission with two clutches. Can use wet or dry clutch technology, assume wet clutch. Typically steel for gears, aluminium for casing
CVT	+2	Planetary gears, traction fluid, addition of park brake mechanism	Assuming substitution for manual transmission. Assuming push-belt CVT – more like an automatic transmission than a manual. Typically steel for gears, aluminium for casing
Start-stop	+1	No change in type of material used	Assume super-starter plus advanced lead-acid battery
Micro hybrid	+1	Addition of power electronics, belt starter generator	Assume belt starter generator
Mild hybrid	+3	Addition of power electronics (invertors for motor, DC-DC converters for 14v supply, controller), e-motor[2], NiMH battery, cables	Excluding any benefits from engine downsizing
Full hybrid	+4	Addition of power electronics (inverters for motors, DC-DC converters for battery interface, DC-DC converters (isolating) for 14v supply, and system controller), e-motor[2], NiMH battery, electric brakes & steering	Components depend on hybrid layout. Parallel hybrid assumed (excluding any benefits from engine downsizing)
Mild weight reduction (~10% red. in BIW)	-2	For example: use of AHSS (Advanced high strength steels), Aluminium	Impact on materials depends how weight reduction achieved
Medium weight reduction (~25% red. in BIW)	-4	For example: use of AHSS (Advanced high strength steels), Aluminium	Impact on materials depends how weight reduction achieved
Strong weight reduction (~40% red. in BIW)	-5	For example: use of AHSS (Advanced high strength steels), Aluminium	Impact on materials depends how weight reduction achieved
Lightweight components other than BIW	Assume -1	For example: aluminium, plastics, composites replacing traditional materials	Will vary significantly dependent on components addressed by light-weighting
Aerodynamics improvement	0	No change	Assume aerodynamics improvement from improved initial design
Tyres: low rolling resistance	0	Change in tread compound (typically silica replacing carbon black)	

Technology	Impact on overall vehicle mass	Materials	Comments
Reduced driveline friction	0 to +1	No significant change	Assume replacing transmission lubricant, reducing oil levels and implementing a partitioned sump
Secondary heat recovery cycle	+2	Add turbine plus heat exchangers & fluid for refrigerant circuit	Assume Rankine cycle
Auxiliary systems efficiency improvement	0 to +1	Replacement of FEAD driven oil and water pumps with electrical pumps (typically addition of hydraulics, canned motor[2], electronics)	Depends on the components used. Assuming electrification of various pumps e.g. (water pump, oil pump, vacuum pump Saving of FEAD mass – removal of pulley etc.
Thermal management	0 to +1		Depends on approach. Assume advanced coolant control via electric thermostat and advanced lubricant circuit control via controlled hydraulic valve

1 *Note electric motor replaces the Fe end of the turbocharger for an e-boost system.*
2 *Electric motor construction varies widely dependent on size and usage. Typically they consist of Copper windings, soft iron cores, high carbon steel bearings, permanent magnets, resin/plastics for insulation/encapsulation, brass/steel for contacts/connectors, steel or plastic casing.*

The table shows that the technologies available to reduce vehicle fuel consumption can both result in a decrease or increase of the vehicle mass. We can state that apart from hybridization and weight reduction, the impact on vehicle mass of the technologies assessed is limited and the materials used do not differ much from current materials used. Hybridization has the biggest negative impact on vehicle mass and weight reduction has the highest positive impact on vehicle mass. The impact of other measures is limited. The impact on mass should, however, be evaluated together with the impact on fuel efficiency, since it is the overall impact that counts.

In chapter 2, an analysis was made of the technologies that could be used by vehicle manufacturers in the next years to meet a 95 g/km target. The technologies with the best cost/benefit ratio will be applied most frequently due to economics. Table 109 provides an overview of the technologies with the best cost/benefit ratio and the impact on overall vehicle mass (see above Table 108 for definition).

Table 109 Fuel consumption reducing technologies for medium sized cars, with the best cost/benefit ratio.

diesel	**Fuel consumption reduction (%)**	**Costs (€)**	**Cost per % fuel consumption reduction (€)**	**Impact on overall vehicle mass**
tyres: low rolling resistance	3	30	10	0
mild downsizing (15% cylinder content reduction)	4	50	13	-1
optimising gearbox ratios / downspeeding	3	60	20	0
combustion improvements	2	50	25	0
aerodynamics improvement	2	50	25	0
strong downsizing (>=45% cylinder content reduction)	15	500	33	-1
auxiliary systems improvement	11	420	38	0 to +1
start-stop	4	175	44	1
medium downsizing (30% cylinder content reduction)	7	450	64	-1
thermal management	2,5	150	60	0 to +1
micro hybrid - regenerative breaking	6	375	63	+1
automated manual transmission	4	300	75	+1
medium (~ 25% reduction on body in white)	5	320	64	-4
strong (~40% reduction on body in white)	11	800	73	-5
lightweight components other than biw	1,5	120	80	-1
petrol				
tyres: low rolling resistance	3	35	12	0
optimising gearbox ratios / downspeeding	4	60	15	0

gas-wall heat transfer reduction	3	50	17	+1
low friction design and materials	2	35	18	0
cam-phasing	4	80	20	+1
aerodynamics improvement	2	50	25	0
variable valve actuation and lift	10	280	28	+1
strong downsizing (>=45% cylinder content reduction)	17	600	35	-1
start-stop hybridisation	5	200	40	+1
auxiliary systems efficiency improvement	12	440	37	0 to +1
thermodynamic cycle improvements e.g. split cycle, pcci/hcci, cai	14	475	34	0 to +1
direct injection, homogeneous	5	180	36	+1
micro hybrid - regenerative breaking	7	375	54	+1
direct injection, stratified charge	9	500	56	+1
mild downsizing (15% cylinder content reduction)	5	250	50	-1

Note: all data refers to a medium size car. Source: chapter 2.

Table 108 shows that the impact on weight of the technologies with the best cost/benefit ratio is rather limited. Furthermore, the fuel consumption decrease outweighs the additional GHG emission generated during production in all cases. If we, for example assume that a technology that increase the vehicle mass with 1% reduces the fuel consumption with 5% (e.g. petrol direct injection), the GHG savings outweigh the additional vehicle production emissions with factor 15.

Hybridisation is not included in the table above. However, arguments other than cost effectiveness, like their emission reduction potential and the visibility for consumers, will influence vehicle manufacturers' choices. Below, we elaborate on the technologies with the most significant impact on emissions: light weight and battery and hybrid electric vehicles.

17.4.1 Light weight vehicles

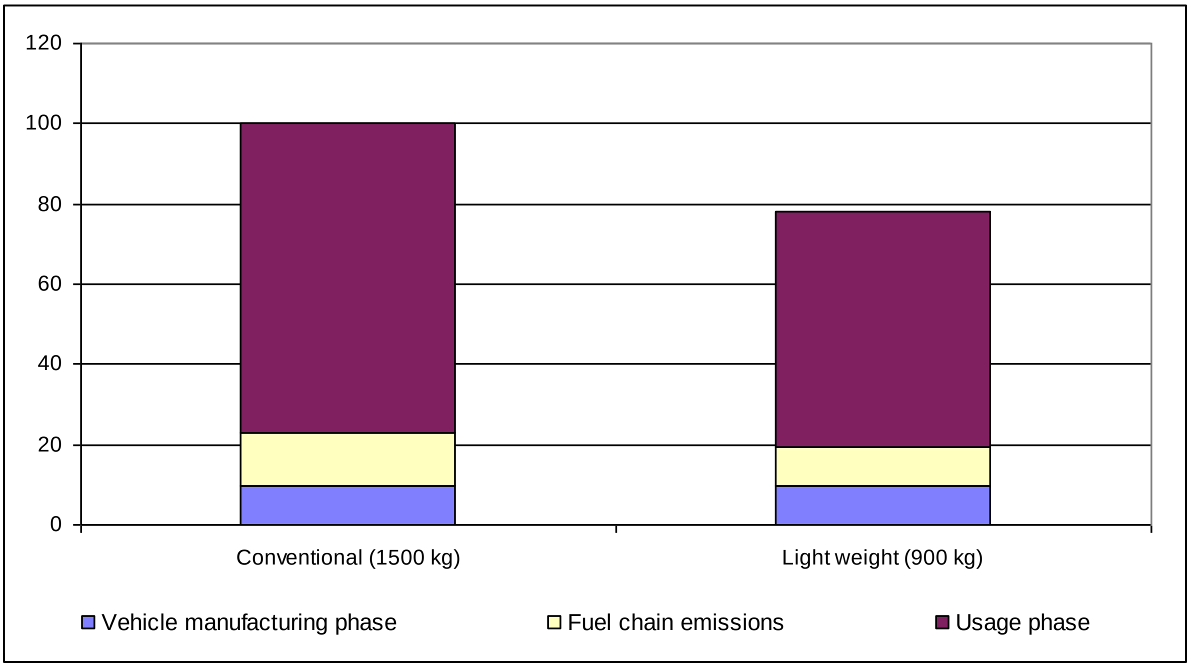
The GREET 2.7 (based on a US passenger car) model contains a conventional and a light weight vehicle. The light weight vehicle is 25% more fuel efficient than the conventional vehicle, due to its lower weight. The lower weight has been achieved by a more limited use of steel and increased use of carbon fibre-reinforced plastic and aluminium. Table 110 depicts the differences in the conventional vehicle and the light weight vehicle with respect to material use.

Table 110 Contribution of main materials to total weight of vehicle.

	Conventional (%)	**Light weight (%)**	**Product GHG emission factor (tonne CO2 eq./tonne material)**
Steel	62	32	2-2.2
Cast iron	11	4	0.5-1.5
Wrought aluminium	2	7	8.5-11
Cast aluminium	5	15	8-10
Carbon fibre-reinforced plastic	0	16	10.4
Copper	2	5	1.7-7.7

Source: Burnham et al., 2007; the range in material CO_2 impacts is based on the GREET 2.7 model and Eco-invent database.

While the emissions per kg of material are higher for the light weight vehicle, the GREET 2.7 model shows that the energy consumption during the vehicle production stage does not increase due to the use of light weight materials. This can be explained by the lower combined weight of light weight vehicle parts in a vehicle versus the conventional equivalent (i.e. emissions per tonne material are higher, but the total tonne material used is lower). The greenhouse gas emissions from the production of the lightweight vehicle are slightly lower (7.8 tonne CO_2 eq. (conventional) vs. 7.6 tonne CO_2 eq. (light weight)). This implies that the use of light-weight materials increase the share of vehicle production in the overall life cycle energy consumption (i.e. because the energy consumption of the usage phase is reduced), but there is no increase in absolute terms.



Source: GREET model 2.7,

Figure 98 US example of emissions of conventional vehicle versus light weight vehicle (conventional=100).

17.5 Batteries and electrically powered vehicles

The successful deployment of PHEVs (Plug-in Hybrid Electric Vehicles) and BEVs (Battery Electric Vehicles, also called pure EVs, full EVs or simply EVs) will depend on the battery technology development and government policies. Most current HEVs (Hybrid Electric Vehicles) utilize NiMH batteries. However, the most likely alternative battery chemistry for the use in PHEVs and BEVs is Lithium-ion (Li-ion). Li-ion batteries have the advantage of higher energy densities (per unit volume and per unit mass). All current battery types have considerably lower energy density compared to petrol and diesel and thus add to the weight of the vehicle.

A number of studies have assessed the lifecycle emissions of hybrid and electric vehicles compared to conventional vehicles (CVs) in recent years. The results of such analyses have been somewhat mixed depending primarily on a number of key assumptions, including:

a) The battery capacity (in kWh), which depends on the overall vehicle energy consumption (in kWh/km) and the desired electrically powered range;
b) The emissions resulting from production (and disposal) of batteries per kWh capacity;
c) The vehicle usage and charging regime:
    - the relative efficiencies of conventional, hybrid and electric vehicles are markedly different for different operational cycles (e.g. proportion of urban, extra-urban, highway driving);
    - for PHEVs the proportion of the total km that will be electrically powered will also depend on the daily usage pattern (e.g. lots of shorter journeys vs fewer longer ones) and the battery capacity of the vehicle
d) The greenhouse gas intensity of the electricity used in BEVs and PHEVs;

e) Whether the battery needs to be replaced during the lifetime of the vehicle.

17.5.1 Approach

The results of a number of recent studies has been analysed below. These estimates all assume that no replacement of the battery is needed during the lifetime of the vehicle. If the battery needs to be replaced, the impact of battery production would increase depending on the lifetime of the battery in relation to the vehicle lifetime. It was attempted to make these figures comparable by applying the following assumptions:

- Electricity GHG intensity of the 2010 EU average mix (467 gCO_2e/kWh from JEC, 2008). To illustrate the effect of different electricity sources, electricity produced from coal is also used (the marginal electricity source in some cases (CE Delft, 2010)).
- Li-ion battery packs for PHEVs and BEVs and NiMH battery packs for regular HEVs;
- A lifetime of the vehicle of 238,000 km.

Furthermore, the fuel consumption of the HEVs and BEVs is linked to the fuel consumption of conventional vehicles in the selected studies.

Despite normalisation of certain key assumptions the studies still show significant differences in the overall assessment of conventional, hybrid and electric vehicles. Most of these differences can be put down to differences in the assumed relative efficiencies of the different vehicle types. In particular the energy efficiency of BEVs relative to conventional petrol vehicles is significantly lower for Torchio (2010) and to a lesser extent Helms et al (2010), compared to other studies. This large range in assumptions can on the one hand be explained by the differences within types of batteries. For example not all Li-Ion batteries have the same composition. On the other hand, the large range in assumptions can be explained by the current lack of information on the real-world performance of electric vehicles. Comparing different vehicles using standard test cycles is useful in making real-world comparisons. However, conventional vehicles and electric vehicles have optimum efficiencies at very different parts of their speed range – BEVs are most efficient in urban conditions and conventional ICE (internal combustion engine) powered vehicles are most efficient at higher speeds. Such comparisons may therefore differ significantly depending on the actual usage of the vehicle. Helms et al (2010) attempts to factor in such considerations into its assessment (see Table 111).

Table 111 Fuel and Electricity consumption values used in LCA (reproduced from Table 2 of Helms et al, 2010).

Vehicle	**Units**	**Urban areas**	**Extra urban areas**	**Motorway**	**Average Use (Germany)**
Urban Use	%	70%	20%	10%	
Average Use (Germany)	%	29%	39%	32%	
Petrol Car	l/100km	7.5	5.2	6.7	6.35
Diesel Car	l/100km	5.6	4	5.3	4.88
BEV	kWh/100km	20.4	20.8	24.9	22.00
E-drive_PHEV	%	90%	50%	10%	
PHEV_Electricity	kWh/100km	17.8	10.6	3.3	10.35
PHEV_Fuel	l/100km	0.3	2.3	6	2.90
** PHEV in urban area assumed to have 20% lower fuel consumption than conventional vehicle*					
The assumed battery capacity is 25 kWh for the BEV and 12.5 kWh for the PHEV-50.					

Note: In comparison with other sources (e.g. Notter, 2010) the BEV has a relatively high energy consumption. The fuel consumption of the PHEV vehicle reflects the overall fuel consumption over a mix of electric and ICE-mode driving.

The GHG emissions associated with battery production have been studied by different researchers. The emissions that can be allocated to the battery of the vehicle are strongly linked with the size and type of the battery. In Figure 99, battery production emission data from different studies is documented. In general it appears that new Li-ion battery packs likely to be used in PHEVs and

BEVs have lower lifecycle GHG emissions per unit capacity than the NiMH battery packs currently used in today's HEVs.

The production of the battery is dominated by the production of the cathode, anode and the battery pack (steel box, printed wiring board and cables). Their contribution to the overall impact of the battery is some 80% (Notter, 2010).

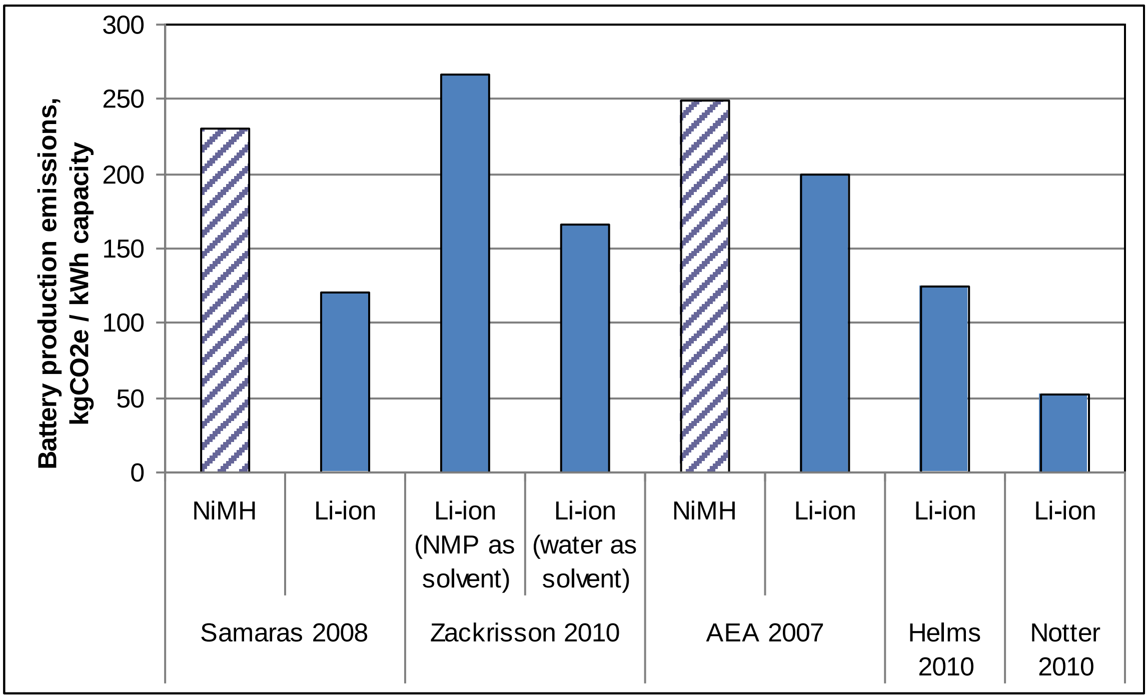
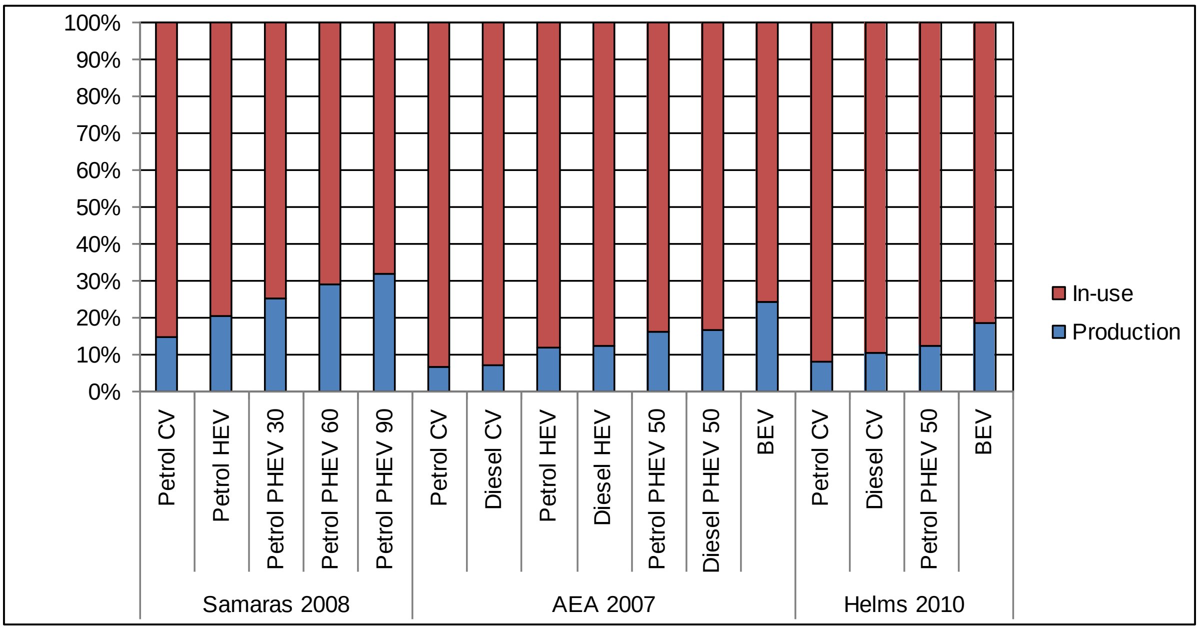


Figure 99 Battery production emissions (kg CO_2 eq. per kWh capacity).

Not only differences between battery types, but also differences within the same battery types can be observed. This can be explained by:

- Limited industry experience and ongoing improvements,
- different production processes,
- different original data sources with different calculation methodologies / system boundaries
- battery size,
- energy density,
- type of solvent used,
- weight per kWh of capacity
- differences in product emission factors
- electricity mix used
- Type of battery materials/alloys.

The results of this analysis show that emissions from the production of a BEV could be 60-80% higher than that of a conventional equivalent vehicle, representing a significantly larger part of the total lifecycle emissions (depending on the GHG intensity of the electricity), see Figure 100.



Notes: Use data has been normalised from original sources to the GHG intensity of the EU electricity mix (based on JEC, 2008) and an assumed average EU vehicle lifetime of 238,000 km (based on data from TREMOVE). It includes fuel production emissions. Based on battery production GHG emissions for Li-ion batteries for PHEVs and NiMH for HEVs.

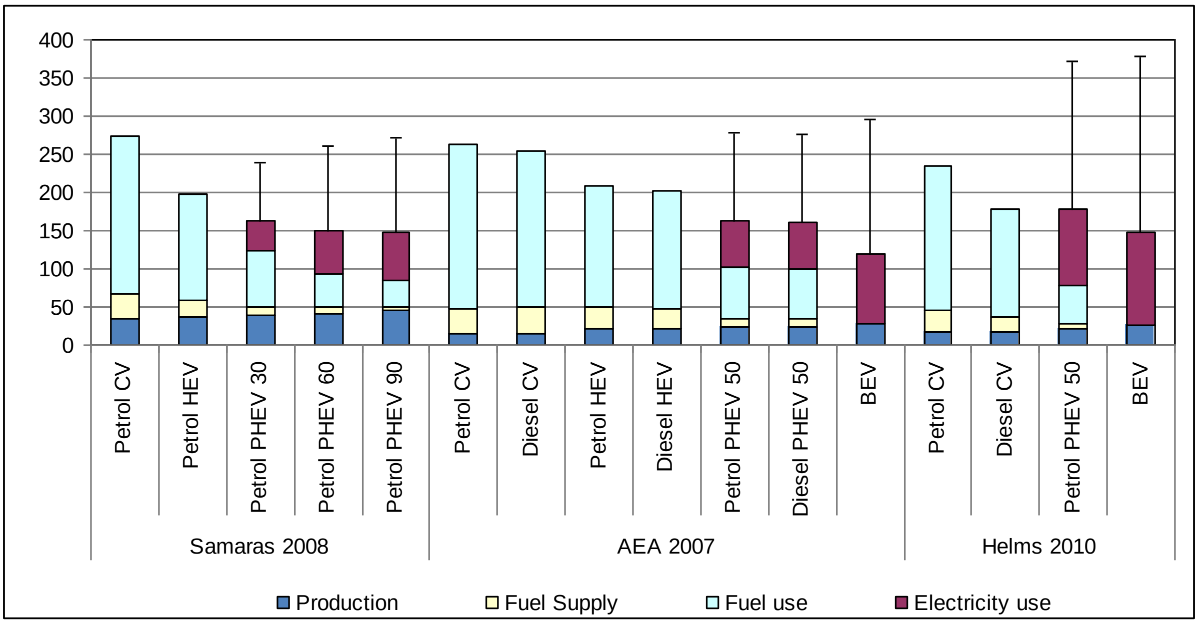
Figure 100 Estimated proportion of GHG emissions from production and usage phases for hybrid and electric vehicles based on different literature sources.

GHG emissions for production of NiMH batteries (currently used in HEVs) were estimated to be up to double the emissions for Li-ion batteries.

Although the share of vehicle production in the overall lifetime emissions increases, PHEVs and BEVs still have the potential to significantly reduce the climate impact of passenger vehicles. The absolute life cycle emissions of electric vehicles depend strongly on the source for electricity, as can be seen from Figure 101: the thick bars represent emissions of the average EU electricity mix in 2010, the error bars represent emissions if the electricity is produced with coal fired power plants.

The graph shows that hybrid and electric vehicles have a clear potential to decarbonise transport. The additional production emissions for HEVs are limited, compared to their reduced fuel consumption. In the case of average 2010 EU electricity emissions, conventional vehicles need to significantly reduce their fuel consumption to be competitive from a carbon emissions point of view. BEVs and PHEVs can be even more carbon efficient if electricity is used with a low carbon content. However, if the emissions of electricity production become lower, the emissions of the production of vehicles and batteries become relatively more significant.

The battery can be associated with between 5 and 20 grams CO_2 eq. per vehicle kilometre for a full electric vehicle, taking the best and worst estimates from Figure 99into account. The big difference may be the result of uncertainties and limited availability of real world figures, but battery size and energy density also play a role.



Notes: Use data has been normalised from original sources to the GHG intensity of the EU electricity mix (based on JEC, 2008) and an assumed average EU vehicle lifetime of 238,000 km (based on data from TREMOVE). Based on battery production GHG emissions for Li-ion batteries for PHEVs and NiMH for HEVs. The error bar represents coal fired power (900 g/kWh).

Figure 101 Absolute lifecycle GHG emissions allocated to use and production (g CO_2 eq./km).

17.6 The 2020 perspective

In this section, we provide a view on the 2020 production emissions, assuming vehicle fuel efficiency will develop in line with the current EU Directive. For vehicle production, potential developments are not yet clear. Below, we discuss the relevant climate policies and the possibility to set targets for vehicle manufacturers on the basis of the emissions in the vehicle production cycle.

17.6.1 Impacts of generic climate policy

The biggest categories in the GHG emissions of car production are:

- Raw material production (steel, plastics, rubber)
- The use of electricity (however like with electric vehicles, the decarbonisation of the power generation mix in the future may lead to a decrease of impact)
- The use of other energy sources during vehicle assembly (natural gas/heat).

Installations with a heat excess of more than 20MW are subject to the emission trading system. This implies that most part of the vehicle production chain is not subjected to the EU-ETS, except e.g. EU steel, aluminium and electricity production facilities. EU-ETS guarantees cost effective reductions by definition, but not necessarily in the vehicle production chain. Non EU-ETS companies are targeted by the EU Effort Sharing Decision (Decision No. 406/2009/EC), which will deliver an approximately 10% reduction of emissions from the non-ETS sectors in 2020 compared with 2005 levels. More specifically, Eastern European countries are allowed to grow, while Western countries are subjected to reduction targets above 10%. Countries are responsible for national emission reductions. This implies that car manufacturing plants in Eastern Europe will probably not be subjected to emission reduction targets. Various EU countries use their own set of instruments for non EU-ETS companies, ranging from energy management plans and voluntary agreements to energy taxes.

By far most of the passenger vehicles sold in the EU are assembled in the EU. Raw materials, however, do not necessarily originate from the EU. If raw materials are produced outside the EU, the emissions associated are generally not covered by any reduction target[120].

[120] This may, of course, change in the future, if global climate negotiations are successful.

However, there are examples of car manufacturers which are voluntarily improving the sustainability of vehicle production. The eco-factory Tsutsumi where Toyota builds the Toyota Prius is an example of an environmental best practice. (McCarthy, 2009) Another example is the factory of Volvo in Belgium, which is carbon neutral. The factory makes use of onsite generated renewable energy or of imported hydroelectricity. (Ryan, 2010) Those voluntary initiatives can contribute to the sustainability of vehicle production, but results are uncertain. By setting binding targets for the industry, also stragglers are enforced to improve behaviour.

An option to improve the carbon footprint of vehicle production is to set targets for the carbon footprint of vehicle production or depicting the carbon footprint on the energy label, to inform the general public. This might change the behaviour of the automotive industry, but does not change the necessity for GHG legislation for the supplying industry sectors (e.g. steel industry, chemical industry).

17.6.2 Setting specific targets

Setting a target for the CO_2 footprint of a car including raw material production is not easy, especially not in the short term. There are many suppliers to the EU automotive industry, ranging from tyre manufacturers to suppliers of engine parts and electrical devices. It might therefore be difficult to hold vehicle manufacturers accountable for the GHG emissions concerned with vehicle production. Furthermore, being all part of the global commodity market, the automotive industry is not necessarily bound to specific suppliers. Changes can occur within a year. In addition, allocation of plant emissions of suppliers to specific products is still a significant issue of debate which makes it difficult to calculate the amount of GHG associated with one single product. Furthermore, monitoring of progress by the industry would be a significant task.

However, it is not yet clear if manufacturers are able to provide information for the purpose of setting targets. To make an adequate assessment of time series across the majority of the principle manufacturers, temporally isolated studies for their operations with different system boundaries / assumptions will not be able to inform the development of any kind of regulation in a robust way. Therefore, industry consultation would help to understand the availability of data that is needed to develop regulation that takes vehicle production emissions into account.

Setting legislation would be easier if a common set of product emission factors will be agreed. Difference in material use will be shown in the figures then, but not the emissions associated with specific production processes. Last but not least, it was shown earlier that for example the use of light-weight materials may increase emissions during production of the vehicle, but reduce overall LCA emissions due to the fuel efficiency improvements they can achieve.

By using a set of key assumptions, demonstration of improvement in reducing the main manufacturing emissions and using lower GHG source materials might be required as an effort from industry. There is currently limited and inconsistent public reporting on energy/emissions from vehicle production. A requirement to report on energy consumption / emissions resulting from vehicle manufacture would help to improve the current information source/understanding and monitor the current situation. To be able to track production emissions per vehicle, a simplified model and agreement on system boundaries and key assumptions would be required for reporting. By doing so, the situation could be monitored which would allow for the possibility for inclusion of targets at a later date if then deemed appropriate. The advantage of such an approach is that also the emissions of materials produced outside the EU could be covered.

Setting a standard for the energy consumption in the production chain is not a very common policy approach in the EU, but might be applied in the future. In the recent renewable fuel quality directive targets have been defined for the fuel chain of both conventional fuels and renewable fuels. In the case of vehicle production, the number of actors (suppliers) is, however, much higher. Therefore, starting from a simplified approach, setting CO_2 targets for vehicle production on the longer term should be further explored in order to assess its feasibility.

Reducing the carbon intensity of vehicle manufacturing and raw material production could also be achieved by generic climate policy. The European Commission has been considering whether to revise the Energy Tax Directive and introduce common minimum energy and CO_2 tax rates for energy carriers, depending on the energy and carbon intensity of the fuel. This would reduce energy consumption in the vehicle production chain via the price mechanism. In addition energy consumption criteria, in line with consumer electronics, could be applied to major installations (e.g. curing ovens) used in the vehicle production chain. But again, this should be part of more generic industry policy and not only to the automotive industry and its suppliers.

As illustrated, it is not clear if production emissions will decrease in the next decade. If vehicle emissions will be reduced to 95 g/km (NEDC cycle) on average with vehicle weight and production emissions remaining the same, production emissions might increase to 15-23% on average of the entire lifecycle. However, this depends on the technologies used to lower the tailpipe CO_2 emissions.

17.7 Conclusions

The share of total GHG emissions resulting from vehicle production in the life cycle emissions and energy consumption of a vehicle strongly depends on assumptions about fuel consumption and on the vehicle lifetime assumed. Reviewing available studies, we estimate that vehicle production is associated with 21 to 39 g CO_2 eq. /km, depending on the size and engine type of the vehicle[121]. This represents 9-13 % of the entire vehicle life cycle. On the basis of higher weights of diesel vehicles, we roughly estimate production emissions for diesels to be 10-20% higher than for equivalent petrol vehicles. However, due to higher lifetime mileages, production emissions of diesel vehicle are lower than petrol in absolute and relative terms if expressed per vehicle kilometre.

The above implies that the use phase is much more important in the life cycle at the moment than the production phase. However, there are clear indications that use phase emissions will decrease in the next decade, whereas production phase emissions are expected to remain constant or increase due to technological improvements of the vehicles. On the other hand, examples presented show increasing sustainability of the automotive industry and suppliers (e.g. steel-ETS), including decarbonisation of the power generation. Generic climate policy and regulation addresses emissions in the vehicle production chain mostly indirectly and to a limited extent. EU ETS as an example will result in emissions reduction, but reductions may achieved in other sectors due to lower costs.

The impact of short term conventional fuel efficiency improving technologies on the vehicle production emissions is limited. Most technologies influence vehicle weight in only a very limited way, apart from weight reduction, hybridization and electrification. Furthermore conventional materials are used generally for the technologies with limited impact. The CO_2 savings during vehicle use by far outweigh the additional production emissions in all cases.

Hybrid vehicles have slightly higher production emissions. The additional production emissions for HEVs are limited, compared to their reduced fuel consumption. Electrification of vehicles increases emissions in the production phase, although the extent remains unclear. Emissions can be expected to increase with 5 to 20 g CO_2 eq./km for BEVs. The extent varies with battery size, type and energy density. However, there is quite a large variation in the literature on this issue, and differences between studies can not always be explained by these factors.
Also, for electric vehicles, the use phase is the most important contributor to climate change based on the current average electricity mix. This depends, however, on the type of electricity production - i.e emissions can be very low if the electricity is produced form renewable sources such as wind and hydropower (or higher for coal powered generation). As the carbon emissions of electricity production will reduce over time due to the renewable energy directive (RED) and the ETS, the emissions of electric vehicle use can also be expected to reduce over time. Same applies to the future production emissions that are to a certain extent equally a function of the electricity consumed.

Thus the share of vehicle production emissions might increase due to GHG policies in the other parts of the lifecycle chain and more carbon intensive production of HEVs and BEVs, Therefore, vehicle production emissions might need more attention in the future. This can be done by setting targets for the emissions associated with vehicle production, using the carbon footprint for a vehicle for consumer information, or generic climate policy.

[121] Also the lifetime mileages significantly influence the outcome, see section 17.1.2.

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18 Rebound effects of improved fuel efficiency

18.1 Introduction

New CO_2 regulation has an impact on the purchase price of a new vehicle, as well as on the cost of driving. While the focus in the first three tasks is on the technology and its expected improvement in fuel efficiency, this subtask reviews the expected impact on (driving) behaviour as a response to the decrease in driving costs (higher fuel efficiency) and increase in purchase costs (technology). The initial hypothesis, which requires confirmation and quantification, is that lower driving costs will increase mileage, cause people to drive with less attention to their fuel consumption, and thus cause extra CO_2 emissions.

First order assessments are presented below:
- on the basis of using elasticities and other applicable economic methodologies, found in literature.
- on the basis of a detailed analysis of results from previous TREMOVE calculations carried out in relation to the Cars & CO_2 legislation (runs by TML in 2005/2006), and runs with fuel cost variations (in this case the 3.3 sensitivity runs done by TML in 2010)

18.2 Elasticity approach: literature review

The first phase consists of a review of available literature on elasticities of (passenger) transport. An elasticity is an economic indicator to measure price sensitivity, defined as the percentage change in consumption of a good caused by a one-percent change in its price (or other characteristics).

Different kinds of elasticities exist, and with each, it is important to always keep in mind the assumptions that were made to measure them. Elasticities are always measured in a given set of circumstances, and are in theory only applicable under the same circumstances. For example, the mileage elasticity with regard to fuel price measured in the US can not be applied in Europe without caution, given how different the share of fuel costs is in Total Cost of Ownership (TCO) of the vehicle. For that reason, a range of elasticities is presented in most cases. All but one (0) of the studies below deal with Europe however - albeit in different decades.

Another caveat that should be mentioned is that elasticities often represent a combination of effects, which are not always measurable on their own. For example, the elasticity of fuel consumption with regard to fuel price combines driving behaviour and vehicle choice; if a car becomes cheaper to drive, it will likely be driven more; customers might also decide to buy bigger cars, if they feel the extra comfort outweighs the higher driving cost (which is still lower than it was before the fuel price decrease).

In short, it should be clear that elasticities are a rather crude approach to estimate the effects of evolutions in market circumstances. Nonetheless, since literature provides data from varying backgrounds, a range of values can be used to calculate upper and lower bounds of likely effects.

The following subsections contain summaries of some of the most relevant publications on this topic. Elasticities are presented as “the elasticity of x with regard to y”, which means that the relative change of x is compared as a reaction to the initial change in parameter y. For example, the elasticity of fuel consumption with regard to fuel price is the % change in fuel consumption as a result of a % change of fuel price.

Phil Goodwin, “Review of New Demand Elasticities With Special Reference to Short and Long Run Effects of Price Changes,” Journal of Transport Economics, Vol. 26, No. 2, May 1992, pp. 155-171.

In the introduction to this paper, a short historical overview is presented with the evolution of elasticity observations (of fuel consumption) w.r.t. petrol price since 1980. Apparently, these have been going upward (from -0.1/-0.4 to -0.48). Also, it is remarked that LT elasticities are in general 2 to 3 times higher than the ST values.
With regard to traffic levels, the values are quite a bit lower than for fuel consumption, due to changes in the drivers’ behaviour. For ST, it would around -0.16, while the LT elasticity was estimated at -0.33.

The rest of the study covers public transport, which is of lower interest for this evaluation.

TRACE (1999), Cost of private road travel and their effects on demand, including short and long term elasticities. Elasticity Handbook: Elasticities for prototypical contexts, The Hague

Based on an extensive literature study TRACE (1999) provides estimates on different kinds of elasticities. Elasticities with respect to fuel costs, travel time and parking charges are presented. In this review we will only discuss the fuel cost elasticities.

This study provides fuel cost elasticities with regard to vehicle kilometres and number of trips. To estimate the rebound effects of vehicle emission regulation especially the former kind of fuel price elasticity is relevant. The following ranges of long term elasticity estimates with regard to vehicle kilometres are found by TRACE (1999): -0.20 to -0.35 (commuting), -0.37 to -0.48 (business/education), -0.46 to -0.52 (shopping/other), -0.28 to -0.35 (total).

Jong, G. de and Gunn, H. (2001), “Recent evidence on car cost and time elasticities of travel demand in Europe”, Journal of Transport Economics and Policy, 35, pp. 137–160.

This paper further describes the work that was done in the TRACE project mentioned above. It tried to provide estimates of transport elasticities for policy work, when no empirical base for such estimates was available in the region in question. The focus is on changes of (stimuli):

- Car transport cost
- Car transport time

And their impact on (response):

- Car trips and vkm
- Car pkm
- Other modes

As most other studies, this paper starts off with a review of elasticities available in earlier research. It covers Europe only. The most relevant relation for this review is that between car transport cost and car vkm (Table 2 of the publication is cited in Table 112).

Table 112 Summary of elasticities found in the TRACE project.

Fuel Price Elasticities of the Number of Car Kilometres

Term/purpose	*Literature EU*	*The Netherlands' national model system (NMS)*	*Italian national model*	*Model for Brussels*
Short term:				
Commuting	−0.12	−0.10	−0.79	−0.22
Home-based business	−0.02	−0.03	−1.58	
Non-home-based business	−0.02	−0.02		
Education	−0.09	−0.04	−1.09	
Other	−0.20	−0.24	−0.87	
Total	−0.16	−0.13		
Long term:				
Commuting	−0.23	−0.22	−1.22	−0.31
Home-based business	−0.20	−0.25	−1.73	
Non-home-based business	−0.26	−0.16		
Education	−0.41	−0.35	−1.41	
Other	−0.29	−0.65	−1.03	
Total	−0.26	−0.36		

Elasticities in the short term are all below -0.2, except for the ones in the Italian model, which is apparently due to this model’s orientation towards longer distance trips. In general, it can be concluded that the short term elasticity is around -0.15, while the long term value is closer to -0.3. Also, short distance transport has a higher elasticity (ε) than long distance (more options available).

Hanly et al. (2002), Review of income and price elasticities in the demand for road traffic, ESRC TSU publication 2002/13

In this project a literature review of income and price elasticities in the demand for road traffic is performed. Therefore 69 different elasticity studies were studied, presenting 491 elasticity estimates.

The mean vehicle kilometres elasticity with regard to fuel price is estimated at -0.1 (-0.14 to -0.06) for the short term and -0.3 (-0.6 to -0.1) for the long term. The impact of fuel prices on car ownership is given by elasticity values of -0.08 (-0.21 to -0.02) for the short term and -0.25 (-0.1 to -0.63) for the long term. Next to these fuel price elasticity values also elasticities for the impact on total fuel demand (-0.25 for the short term and -0.64 for the long term) and fuel consumption per car (-0.08 for the short term and -1.1 for the long term) are given.

The elasticity values discussed above are all estimated by using a dynamic approach. Hanly et al. (2002) also present an overview of elasticity values estimated by static approaches. However, since no difference between short and long term impacts are made for these kinds of elasticities they are less informative. Therefore, we will not discuss these elasticity values here.

In addition to the fuel price elasticities also car purchase cost elasticities are discussed. The mean vehicle ownership elasticity with regard to car purchase cost is equal to -0.24 (-0.03 to -0.41) for the short term and –0.49 (-0.13 to -0.78) for the long run, which is higher than that for fuel price. The impact on fuel consumption is given by elasticity values of -0.12 (0 to -0.26) for the short term and -0.51 (0 to -0.88) for the long term. Finally, car purchase cost elasticities with regard to vehicle kilometres are equal to -0.19 (0.11 to -0.33) for the short term and -0.41 (-0.20 to -0.62) for the long term.

With regard to the elasticity values found, Hanly et al. mention that the number of studies on price elasticities with regard to car ownership is small and hence the uncertainty in the results is rather large. Therefore these values should be considered with care.

Graham and Glaister (2002a), Review of income and price elasticities of demand for road traffic, Centre for Transport Studies

This study provides a review of road traffic-related demand elasticities. Elasticity values included in this study are:

- elasticities of car travel with respect to fuel price and car time;
- elasticities of car ownership with respect to cost price and income;
- elasticities of freight traffic with respect to price;
- elasticities of fuel demand with respect to income and price.

In this review we will especially consider the price and cost elasticities with regard to car travel and car ownership. Additionally, we will briefly present the results with regard to fuel demand.

With respect to fuel price elasticities with regard to vehicle kilometres 34 studies are reviewed. These studies are the same as the studies reviewed by TRACE (1999). For the short term mean elasticity values of -0.15 (-0.01 to -0.24) were estimated. For the long term the mean elasticity value was found to be equal to -0.43 (-0.07 to -1.02).

The study also reviewed some studies which have estimated elasticities of demand for car ownership. One difficulty the authors experienced in drawing together the results of these studies is that the definitions of ‘cost’ and ‘price’ are not consistent across studies and this hinders proper comparability of estimates. Graham and Glaister (2002a) report only one study which has estimated purchase cost elasticity: -0.24 to -0.59. Some more results are presented for elasticity values with respect to fixed car costs, ranging from -0.80 to -2.65. The reported elasticities with respect to variable car costs (or running costs) range from -0.38 to -1.33, while specific fuel price elasticities with regard to car ownership range from -0.02 to 0.12 for the short term and -0.1 to -0.24 for the long term. Finally, based on all elasticity values assessed Graham and Glaister (2002a) conclude that the total car cost/price elasticity of car ownership is equal to -0.90 (range from -0.24 to -2.65), while the short run mean value is -0.20 (range from -0.09 to -0.35).

Finally, with respect to the elasticity values with regard to fuel demand, Graham and Glaister (2002a) come up with the same conclusions as Graham and Glaister (2002b). The long run price elasticity of demand for fuel is between -0.6 and -0.8 and the short run elasticity between -0.2 and -0.3.

Graham & Glaister (2002b), The demand for automobile fuel. A survey of elasticities. Journal of Transport Economics and Policy. Volume 36, Part 1., 1-26

This study provides a survey of the international fuel demand literature, resulting in an assessment of the general magnitude of the relevant elasticities. The study is not a methodological review. It focuses on assessing empirical evidence on the size of fuel price elasticities.

Although the use of specific data or methodological approaches can create crucial differences in the magnitude of elasticity estimates, the overwhelming evidence of the survey suggest that long run fuel consumption elasticities with regard to fuel price fall in the –0.6 to –0.8 range. Additionally, many of the studies reviewed claim to find similarities and not differences between countries in the size of the long run elasticities. Short run price elasticities normally range from –0.2 to –0.3, in other words they tend to be around 60% to 70% lower than the long run elasticities.

More important with respect to the analysis of rebound effects are the gasoline price elasticities with respect to traffic levels. The short term elasticity is about –0.15 and the long term about –0.30. These elasticities are lower than the fuel demand elasticities, which indicates that motorist do find ways of economising on their use of fuel (e.g. by applying a more fuel-efficient driving style or buying a more fuel-efficient vehicle).

Graham and Glaister (2004), Road traffic demand elasticity estimates: a review, Transport Reviews 24, 3, 261-274

This study provides a brief summary of road traffic-related elasticity estimates as reported in the international literature. A variety of elasticity measures is presented, including fuel price elasticities and car cost elasticities.

The study provides some elasticities with regard to the demand for car ownership. However, these elasticities are also presented by Graham and Glaister (2002a). Therefore we will not discuss them here.

Graham and Glaister (2004) also present some evidence on fuel price elasticities, which is based on earlier studies of both authors, e.g. Graham and Glaister (2002a en 2002b), complementing with some more recent studies. However, only elasticities with regard to total fuel demand are presented; vehicle kilometres elasticities with regard to fuel price are not taken into account. Since collecting evidence on fuel price elasticities with regard to fuel demand is not the key aim of this review and since the results are in line with Graham and Glaister (2002a an 2002b), we will not discuss the results on this issue here.

Goodwin,P., Dargay,J. and Hanly, M., “Elasticities of Road Traffic and Fuel Consumption With Respect to Price and Income: A Review,” Transport Reviews (www.tandf.co.uk), Vol. 24, No. 3, May 2004, pp. 275-292.

This publication from 2003 has set as its goal to make a review of research on transport elasticities since 1990. A similar study by Graham and Glaister was carried out in parallel (see 0), though the authors were mutually unaware of the other group’s efforts.

Some important conclusions and generalizations were made in this paper, that greatly help our cause of estimating the impact of greater fuel efficiency on annual mileage.
First of all, it became apparent that the most relevant effects can be derived in a term of 3-5 years after the initial stimulus. Hence, the “long term” stable results should be almost completely evident after 5 years. Secondly, the important remark is made that while most studies assume symmetrical elasticities (same effects for price increases as for decreases), logic shows this can not always be the case. For example, when fuel prices rise, new, more fuel-efficient cars become more attractive. However, when prices would drop again, it is not possible to revert to older, cheaper, less efficient cars.

The main conclusions with regard to the effects of a fuel price increase:

- ε=-0.10 (ST) and -0.30 (LT) for vkm
- ε=-0.25 (ST) and -0.60 (LT) for fuel consumption
- ε=+0.15 (ST) and +0.4 (LT) for fuel efficiency
- 0>ε>-0.10 (ST) and =-0.25 (LT) for vehicle ownership

Furthermore, the study concludes from the income elasticities that as income rises, use per car declines, and fuel efficiency declines as well. Table 3 in the report (Table 113 below) summarises all findings.

Table 113 Summary from the study of Goodwin, Dargay and Hanly, 2004.

Table 3. Overall results: elasticities of various measures of demand with respect to fuel price per litre produced by dynamic estimation using time series data

Dependent variable	Short-term	Long-term
Fuel consumption (total)		
Mean elasticity	–0.25	–0.64
Standard deviation	0.15	0.44
Range	–0.01, –0.57	0, –1.81
Number of estimates	46	51
Fuel consumption (per vehicle)		
Mean elasticity	–0.08	–1.1
Standard deviation	n/a	n/a
Range	–0.08, –0.08	–1.1, –1.1
Number of estimates	1	1
Vehicle-km (total)		
Mean elasticity	–0.10	–0.29
Standard deviation	0.06	0.29
Range	–0.17, –0.05	–0.63, –0.10
Number of estimates	3	3
Vehicle-km (per vehicle)		
Mean elasticity	–0.10	–0.30
Standard deviation	0.06	0.23
Range	–0.14, –0.06	–0.55, –0.11
Number of estimates	2	3
Vehicle stock		
Mean elasticity	–0.08	–0.25
Standard deviation	0.06	0.17
Range	–0.21, –0.02	–0.63, –0.10
Number of estimates	8	8

n/a = Not available

Todd Litman, (2006),"Transportation Elasticities, How Prices and Other Factors Affect Travel Behavior", Victoria Transport Policy Institute.

This Canadian study starts off with an introduction to the concept of elasticities from an economic background.

The author then adds his own review of publications on the matter, the majority of which is covered in the underlying document as well. He also covers how elasticity values may differ between different income classes and different trip types, as well as a number of other factors that may impact driving behaviour, such as parking costs, road tolls and congestions charges. While the results contain a lot of interesting numbers, no new elasticity values are delivered.

Brons et al. (2008), A meta-analysis of the price elasticity of gasoline demand. A SUR approach, Energy Economics 30, 2105-2122

In this study a meta-analytical approach is used to estimate the price elasticity of gasoline demand and decompose this into estimates of the price elasticity of fuel efficiency, mileage per car and car ownership with respect to gasoline price. The meta-analytical estimation approach is based on a Seemingly Unrelated Regression (SUR) model with Cross Equitation Restrictions. Starting point of this approach is the linear relationship between the price elasticities of gasoline demand on the one hand and fuel efficiency, car mileage and car ownership on the other hand. Making use of this relationship this approach enables the researchers to combine information of different types of elasticities and thus increase the sample size and hence the accuracy of the estimates. An additional advantage of this approach is that it enables one to decompose the estimated value of the price elasticity into values of the elasticities of fuel efficiency, mileage per car and car ownership.

In this study an estimated mean short-run price elasticity of gasoline demand of –0.34 is found. This value can be deconstructed into estimates for the price elasticities of fuel efficiency (0.14), mileage per car (-0.12) and car ownership (-0.08). These results show that, in the short run, the response in demand resulting from a change in gasoline price is driven mainly by changes in fuel efficiency and mileage per car and to a lesser degree by a change in car ownership.

For the long run a price elasticity of gasoline of –0.84 is estimated, which is, as expected, higher than the short–run estimate. This value can be decomposed into estimates for the price elasticities of fuel efficiency (0.31), mileage per car (-0.29) and car ownership (-0.24). So, also on the long run the response in demand resulting from a change in gasoline price is driven to similar degrees by responses in fuel efficiency, mileage per car and (to a lesser degree) by a response in car ownership.

18.2.1 Summary

A lot of research has been done over the years, yet some of the findings seem to be a constant:

- The fuel price elasticity with regard to fuel demand is greater than that for mileage, due to changes in driving style and (in the long term) fleet evolution.
- Short term elasticities are lower than long term elasticities.
- While some studies made mention of the elasticity of fuel consumption with regard to vehicle price, they are unable to reach firm conclusions on this matter, and hence, we will not retain them for this study, as the case could be made that these are second order effects rather than first order.

Therefore, we will use the following values in the rest of this study:

- The range that was found in literature for elasticities of vehicle kilometers driven with regard to fuel price goes from -0.01 to -0.24 for the short term, and from -0.07 to -1.02 for the long term. **Cautious averages are set at -0.15 (ST) and -0.30 (LT).**
- For the elasticity of fuel consumption with regard to changes in fuel price, they range from -0.1 to -0.34 for the short term, and from -0.3 to -0.84 for the long term. **As average values, we will take -0.25 and -0.6 for further use in the underlying study.**

Since the eventual target of the study is to determine the effects on CO_2 emissions, it is best to work with the elasticity of fuel consumption, rather than that for vehicle kilometres.

It should also be noted that all of the reviewed documents refer to an increase in fuel price, whereas our study deals with a decrease in (fuel) cost per vkm (ceteris paribus). While the effects are fairly similar, special attention needs to be paid to the subtle differences. For example, when fuel prices increase, people may be more inclined to buy a new, more efficient but more expensive car. If prices would decrease again, they can not revert to their cheap(er), old car (that uses more fuel), which has probably left the fleet at that moment.

18.3 Past TREMOVE runs

In this part, we will make a detailed review of past projects in which TREMOVE was run to evaluate decreases in fuel costs, no matter the origin. This can be in the form of:

- efficiency improvements (like the 2006 runs that also dealt with CO_2 in cars);
- fuel price scenarios (like the 2010 sensitivity runs in the TREMOVE update project for DG ENV);

The review considers the importance of purchase costs and fuel costs in TCO (without calculating it explicitly), for all vehicle classes present in the TREMOVE model, and how the evolution in these values affects purchase decisions and driving behaviour.

18.3.1 CO_2 & Cars, 2006, runs by TML for DG ENV

In 2006, TREMOVE 2.43b[122] was used to evaluate the proposed evolution of a 140g/km target in 2009 (and equal thereafter), which was part of the basecase scenario, to a lower target by 2012 (and equal thereafter).

We will focus the analysis on 4 of the main runs, all of which are based on TNO's final report (2006)[123]:

- D20: target of 135g by 2012
- D21: target of 130g by 2012
- D22: target of 125g by 2012
- D23: target of 120g by 2012

Detailed information on these runs, as well as on the TREMOVE model itself, can be found on www.TREMOVE.org. In the following subsections, we will go into the assumptions made for these runs, as well as the effects on mileage, fleet turnover and emissions.

The assumptions for the scenario runs (SIM) were as follows:

- 2010-2012 decrease in fuel consumption and CO_2 emissions of new sold cars up to average of 120/125/130/135g CO_2.
  - % fuel efficiency improvements per car type (6 conventional types) are derived from the TNO report.
  - Stable fuel efficiency in 2012-2020 period
- 2010-2012 Increase in car retail cost related to the fuel efficiency improvements
  - Relative (% compared to basecase) cost increases per car type (6 conventional types) are derived from the TNO report. Identical percentages are applied in each country. As TREMOVE calculates annual maintenance cost as a fraction of initial purchase price, this is also affected.
  - The 2012 % cost increase is maintained in the simulation scenario up to 2020.

The slope of the weight/emission reduction curve, which is a measure for the distribution of the emission reduction effort over vehicle types, is set at 100% for these runs. This implies that the same relative effort is required from lighter and heavier vehicles.

D20: 135g

Input

The values for fuel consumption in the table below indicate the relative amount of fuel consumed per vkm, in comparison to the basecase. The values for purchase price increase are also relative to TREMOVE basecase data. It is reminded that the target in TREMOVE basecase is 140g by 2009, and constant thereafter.

[122] This version covered 21 countries: AT BE CH CZ DE DK ES FI FR GR HU IE IT LU NL NO PL PT SE SI UK.

[123] TNO, IEEP, LAT [TNO, 2006]. Review and analysis of the reduction potential and costs of technical and other measures to reduce CO_2 emissions from passenger cars. Final Report to European Commission, DG Entreprise.

2012 values were maintained until the end of the period (for this TREMOVE version: 2020).

Table 114 Cost assumptions in TREMOVE 2.43b run D20, 2006.

Fuel consumption	**2009**	**2010**	**2011**	**2012**
Diesel Small	100%	99.02%	98.04%	97.05%
Diesel Medium	100%	99.42%	98.83%	98.25%
Diesel Big	100%	99.33%	98.67%	98.00%
Gasoline Small	100%	98.10%	96.21%	94.31%
Gasoline Medium	100%	98.53%	97.05%	95.58%
Gasoline Big	100%	98.19%	96.39%	94.58%
Relative purchase price increase				
Diesel Small	0%	0.79%	1.62%	2.47%
Diesel Medium	0%	0.64%	1.28%	1.93%
Diesel Big	0%	0.59%	1.20%	1.81%
Gasoline Small	0%	1.52%	3.10%	4.77%
Gasoline Medium	0%	0.80%	1.62%	2.48%
Gasoline Big	0%	0.65%	1.32%	2.03%

Both the price increase and the fuel saving is the highest for small gasoline powered cars. The improvement in fuel efficiency is about the same for big gasoline cars, but comes at a much lower price, likely because they are much easier to obtain than would be the case for smaller vehicles.

<u>Results</u>

Table 115 Results of TREMOVE 2.43b run D20, 2006, for newly sold cars (age 0).

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	0
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicl	BC	D20	BC	D20	BC	D20	BC	D20	BC	D20
Sum of vehicles	PCDS	1,077,168	1,074,213	1,083,167	1,081,564	1,098,259	1,095,325	1,135,444	1,132,139	1,286,816	1,280,608
	PCDM	5,515,140	5,512,593	5,565,842	5,554,720	5,597,931	5,588,645	5,673,984	5,667,845	5,919,178	5,908,259
	PCDB	1,620,561	1,619,548	1,669,851	1,667,345	1,721,602	1,718,256	1,884,077	1,881,259	2,232,996	2,228,256
	PCGS	4,763,396	4,761,740	4,754,597	4,758,806	4,827,652	4,833,218	5,149,784	5,148,441	6,011,303	6,006,994
	PCGM	3,488,482	3,494,080	3,525,031	3,538,893	3,578,643	3,592,742	3,713,904	3,726,198	4,035,697	4,048,608
	PCGB	836,698	838,455	874,427	877,761	913,294	917,849	1,032,315	1,036,713	1,259,361	1,264,377
Sum of vkm	PCDS	14,576	14,540	15,133	15,117	15,618	15,589	16,774	16,741	19,072	19,010
	PCDM	107,798	107,756	109,621	109,428	110,732	110,580	113,392	113,304	118,518	118,353
	PCDB	32,960	32,941	34,035	33,989	35,125	35,065	38,549	38,502	45,623	45,542
	PCGS	77,076	77,044	78,238	78,322	79,276	79,403	82,849	82,883	90,969	90,977
	PCGM	56,652	56,738	57,321	57,533	57,935	58,147	59,102	59,278	61,498	61,681
	PCGB	17,629	17,664	18,280	18,345	18,955	19,043	20,961	21,041	24,865	24,957
Sum of CO2	PCDS	1,864,129	1,842,433	1,936,328	1,898,951	1,995,092	1,938,782	2,136,253	2,076,063	2,405,997	2,335,345
	PCDM	16,895,501	16,730,480	17,231,315	16,897,423	17,445,642	16,952,810	17,808,926	17,317,057	18,461,454	17,941,574
	PCDB	6,705,398	6,635,678	6,941,724	6,796,378	7,176,646	6,954,264	7,834,288	7,595,726	9,157,881	8,874,435
	PCGS	11,202,138	11,026,066	11,349,069	11,026,098	11,460,431	10,950,007	11,920,748	11,377,717	12,947,887	12,355,424
	PCGM	9,613,571	9,501,240	9,750,906	9,517,445	9,831,344	9,465,891	9,978,320	9,601,777	10,282,251	9,894,883
	PCGB	3,212,197	3,170,247	3,327,634	3,239,257	3,441,483	3,297,428	3,783,869	3,622,924	4,446,509	4,257,250
Total Sum of vehicles		17,301,446	17,300,630	17,472,916	17,479,089	17,737,381	17,746,034	18,589,508	18,592,595	20,745,351	20,737,101
Total Sum of vkm		306,692	306,683	312,628	312,734	317,641	317,827	331,625	331,750	360,544	360,521
Total Sum of CO2		49,492,934	48,906,145	50,536,976	49,375,552	51,350,637	49,559,183	53,462,404	51,591,264	57,701,979	55,658,911

Table 116 Results of TREMOVE 2.43b run D20, 2006, for all cars in the fleet.

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	(All)
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicle	BC	D20	BC	D20	BC	D20	BC	D20	BC	D20
Sum of vehicles	PCDS	8,146,308	8,143,518	9,067,654	9,063,268	9,958,445	9,951,140	12,357,034	12,340,635	15,305,152	15,265,619
	PCDM	59,783,095	59,783,093	62,509,228	62,498,093	65,010,032	64,989,637	71,120,208	71,081,436	77,343,270	77,262,067
	PCDB	16,149,747	16,148,589	16,969,221	16,965,562	17,790,706	17,783,724	20,235,983	20,221,114	24,326,009	24,293,159
	PCGS	75,171,074	75,169,252	74,483,909	74,486,308	73,952,068	73,960,043	73,367,858	73,379,739	75,309,164	75,309,731
	PCGM	53,701,493	53,704,435	53,098,059	53,114,861	52,607,173	52,638,016	51,801,622	51,871,997	52,414,247	52,539,933
	PCGB	10,575,258	10,577,269	10,675,913	10,681,248	10,815,943	10,825,800	11,477,075	11,500,380	13,381,356	13,425,177
Sum of vkm	PCDS	95,683	95,652	106,925	106,881	117,820	117,750	147,219	147,076	182,972	182,640
	PCDM	941,035	941,041	980,487	980,350	1,016,584	1,016,335	1,104,411	1,103,967	1,193,628	1,192,681
	PCDB	265,882	265,864	278,665	278,613	291,522	291,423	329,969	329,763	394,644	394,185
	PCGS	916,630	916,603	905,525	905,561	896,416	896,548	883,030	883,355	900,767	901,186
	PCGM	661,434	661,470	651,697	651,908	643,609	643,997	628,301	629,179	627,608	629,141
	PCGB	171,355	171,386	172,596	172,682	174,518	174,677	184,262	184,638	213,056	213,753
Sum of CO2	PCDS	12,054,159	12,038,579	13,504,575	13,451,616	14,902,060	14,792,889	18,665,288	18,393,027	23,163,464	22,651,340
	PCDM	151,295,576	151,086,033	156,995,982	156,462,605	162,186,858	161,176,394	174,626,328	172,318,852	186,558,300	182,606,143
	PCDB	56,940,793	56,857,275	59,153,817	58,928,418	61,405,293	60,964,643	68,235,670	67,181,217	79,848,064	77,902,711
	PCGS	158,207,168	158,057,619	153,204,113	152,728,844	148,682,296	147,697,981	138,967,634	136,563,441	133,464,420	129,148,083
	PCGM	133,246,773	133,125,859	128,743,108	128,382,982	124,692,510	123,967,133	115,543,702	113,828,464	108,647,922	105,694,593
	PCGB	37,518,858	37,468,479	36,864,211	36,724,179	36,394,068	36,110,757	36,156,001	35,462,246	39,196,854	37,903,951
Total Sum of vehicles		223,526,977	223,526,157	226,803,985	226,809,340	230,134,367	230,148,360	240,359,781	240,395,301	258,079,198	258,095,687
Total Sum of vkm		3,052,017	3,052,016	3,095,895	3,095,995	3,140,468	3,140,731	3,277,192	3,277,979	3,512,674	3,513,586
Total Sum of CO2		549,263,327	548,633,844	548,465,806	546,678,643	548,263,084	544,709,796	552,194,624	543,747,247	570,879,025	555,906,821

The two tables above show the amount of vehicles in the fleet, the number of vkm they drive, and the CO_2 that is emitted as a result, for the years 2010-2012, 2015 and 2020. Table 115 contains only new vehicles (i.e. the sales of that year), whereas Table 116 shows the results for the entire fleet.
The first conclusion is that overall CO_2 goes down, both for newly sold vehicles and for the entire fleet. The feared rebound effect – that new vehicles would start driving a lot more, since it has become cheaper for them to do so – does not appear to happen: the increase in average annual mileage for new vehicles is less than 1‰, and their total mileage goes down (albeit marginally as well). For the total fleet on the other hand, a minimal increase in total mileage is observed.
Another observation is a shift in sales from diesel to gasoline, which can be explained by the fact that the ratio purchase price increase to efficiency increase is a lot higher for diesel. As their relative total cost goes up, the reverse happens for their marketability.

The decrease in total CO_2 emissions is about 15 million tonnes in 2020. The vehicles with the new technology represent an improvement of about 2 millions tonnes per vintage year.

The projected decrease in annual CO_2 emissions for new cars is 3.54% in 2020. This is calculated as 1- (55,658,911/57,701,979), the values of BC and SIM for CO_2 in 2020 in Table 115. The expected improvement in emission level was 3.57%, which is equal to 1 - (135/140). The underlying cause for the difference is the shift away from relatively efficient diesel cars towards gasoline cars. The increase in purchase price does cause a slight drop in sales in longer term. In the first years the new legislation is in force, total sales actually increase. The same split between fuel types occurs here: fewer diesel cars are sold, but this is more than compensated by the sales of gasoline cars. The rebound effect on annual mileage does not really appear to happen: the average is 17,379 km/year without the new regulation, and 17,385 km/year with it, in 2020.

D21: 130g

<u>Input</u>

Table 117 Cost assumptions in TREMOVE 2.43b run D21, 2006.

Fuel consumption	2009	2010	2011	2012
Diesel Small	100%	98.06%	96.12%	94.18%
Diesel Medium	100%	98.47%	96.95%	95.42%
Diesel Big	100%	98.32%	96.65%	94.97%
Gasoline Small	100%	96.55%	93.09%	89.64%
Gasoline Medium	100%	97.15%	94.29%	91.44%
Gasoline Big	100%	96.62%	93.23%	89.85%

Relative purchase price increase				
Diesel Small	0%	1.28%	2.69%	4.24%
Diesel Medium	0%	1.03%	2.12%	3.27%
Diesel Big	0%	0.96%	1.98%	3.06%
Gasoline Small	0%	2.37%	4.98%	7.86%
Gasoline Medium	0%	1.26%	2.63%	4.13%
Gasoline Big	0%	1.02%	2.15%	3.39%

Results

Table 118 Results of TREMOVE 2.43b run D21, 2006, for new cars (age 0).

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	0
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicle	BC	D21	BC	D21	BC	D21	BC	D21	BC	D21
Sum of vehicles	PCDS s	1,077,168	1,073,103	1,083,167	1,079,665	1,098,259	1,094,924	1,135,444	1,130,385	1,286,816	1,276,193
	PCDM	5,515,140	5,508,283	5,565,842	5,547,317	5,597,931	5,575,851	5,673,984	5,654,681	5,919,178	5,890,362
	PCDB b	1,620,561	1,617,988	1,669,851	1,664,817	1,721,602	1,714,641	1,884,077	1,877,046	2,232,996	2,221,937
	PCGS s	4,763,396	4,762,850	4,754,597	4,760,059	4,827,652	4,829,685	5,149,784	5,132,177	6,011,303	5,985,771
	PCGM	3,488,482	3,498,613	3,525,031	3,547,842	3,578,643	3,608,698	3,713,904	3,738,606	4,035,697	4,061,640
	PCGB b	836,698	839,793	874,427	880,027	913,294	921,378	1,032,315	1,039,490	1,259,361	1,267,524
Sum of vkm	PCDS s	14,576	14,528	15,133	15,098	15,618	15,593	16,774	16,729	19,072	18,971
	PCDM	107,798	107,681	109,621	109,301	110,732	110,362	113,392	113,089	118,518	118,066
	PCDB b	32,960	32,911	34,035	33,942	35,125	34,999	38,549	38,429	45,623	45,433
	PCGS s	77,076	77,058	78,238	78,362	79,276	79,396	82,849	82,707	90,969	90,771
	PCGM	56,652	56,806	57,321	57,669	57,935	58,389	59,102	59,457	61,498	61,865
	PCGB b	17,629	17,690	18,280	18,390	18,955	19,112	20,961	21,093	24,865	25,016
Sum of CO2	PCDS s	1,864,129	1,823,857	1,936,328	1,861,233	1,995,092	1,884,788	2,136,253	2,016,482	2,405,997	2,265,475
	PCDM	16,895,501	16,560,613	17,231,315	16,556,830	17,445,642	16,451,976	17,808,926	16,807,488	18,461,454	17,405,526
	PCDB b	6,705,398	6,563,821	6,941,724	6,651,241	7,176,646	6,731,715	7,834,288	7,352,825	9,157,881	8,586,602
	PCGS s	11,202,138	10,856,596	11,349,069	10,683,193	11,460,431	10,433,848	11,920,748	10,820,904	12,947,887	11,750,421
	PCGM	9,613,571	9,385,632	9,750,906	9,281,778	9,831,344	9,113,816	9,978,320	9,234,989	10,282,251	9,517,428
	PCGB b	3,212,197	3,126,674	3,327,634	3,142,508	3,441,483	3,148,728	3,783,869	3,455,858	4,446,509	4,061,037
Total Sum of vehicles		17,301,446	17,300,630	17,472,916	17,479,725	17,737,381	17,745,177	18,589,508	18,572,385	20,745,351	20,703,428
Total Sum of vkm		306,692	306,675	312,628	312,763	317,641	317,851	331,625	331,504	360,544	360,123
Total Sum of CO2		49,492,934	48,317,192	50,536,976	48,176,782	51,350,637	47,764,871	53,462,404	49,688,546	57,701,979	53,586,489

Table 119 Results of TREMOVE 2.43b run D21, 2006, for all cars.

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	(All)
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicle	BC	D21	BC	D21	BC	D21	BC	D21	BC	D21
Sum of vehicles	PCDS s	8,146,308	8,142,408	9,067,654	9,060,259	9,958,445	9,947,735	12,357,034	12,332,773	15,305,152	15,242,488
	PCDM	59,783,095	59,778,783	62,509,228	62,486,396	65,010,032	64,965,197	71,120,208	71,017,790	77,343,270	77,124,472
	PCDB b	16,149,747	16,147,028	16,969,221	16,961,482	17,790,706	17,776,055	20,235,983	20,201,495	24,326,009	24,248,786
	PCGS s	75,171,074	75,170,363	74,483,909	74,488,670	73,952,068	73,958,874	73,367,858	73,338,767	75,309,164	75,183,010
	PCGM	53,701,493	53,708,968	53,098,059	53,128,326	52,607,173	52,667,381	51,801,622	51,941,189	52,414,247	52,665,162
	PCGB b	10,575,258	10,578,607	10,675,913	10,684,845	10,815,943	10,832,906	11,477,075	11,516,357	13,381,356	13,453,964
Sum of vkm	PCDS s	95,683	95,642	106,925	106,854	117,820	117,727	147,219	147,034	182,972	182,490
	PCDM	941,035	940,985	980,487	980,201	1,016,584	1,016,026	1,104,411	1,103,153	1,193,628	1,190,905
	PCDB b	265,882	265,841	278,665	278,553	291,522	291,312	329,969	329,483	394,644	393,550
	PCGS s	916,630	916,613	905,525	905,602	896,416	896,582	883,030	883,075	900,767	900,188
	PCGM	661,434	661,526	651,697	652,078	643,609	644,367	628,301	630,052	627,608	630,684
	PCGB b	171,355	171,408	172,596	172,741	174,518	174,795	184,262	184,903	213,056	214,223
Sum of CO2	PCDS s	12,054,159	12,020,177	13,504,575	13,395,628	14,902,060	14,682,900	18,665,288	18,122,085	23,163,464	22,144,820
	PCDM	151,295,576	150,919,340	156,995,982	155,961,245	162,186,858	160,189,040	174,626,328	169,985,118	186,558,300	178,557,043
	PCDB b	56,940,793	56,786,837	59,153,817	58,715,635	61,405,293	60,535,808	68,235,670	66,125,533	79,848,064	75,935,913
	PCGS s	158,207,168	157,887,493	153,204,113	152,215,469	148,682,296	146,676,961	138,967,634	134,102,210	133,464,420	124,730,983
	PCGM	133,246,773	133,007,944	128,743,108	128,026,237	124,692,510	123,257,475	115,543,702	112,154,112	108,647,922	102,814,535
	PCGB b	37,518,858	37,423,878	36,864,211	36,581,941	36,394,068	35,820,870	36,156,001	34,746,019	39,196,854	36,563,281
Total Sum of vehicles		223,526,977	223,526,157	226,803,985	226,809,978	230,134,367	230,148,149	240,359,781	240,348,370	258,079,198	257,917,881
Total Sum of vkm		3,052,017	3,052,015	3,095,895	3,096,028	3,140,468	3,140,809	3,277,192	3,277,700	3,512,674	3,512,040
Total Sum of CO2		549,263,327	548,045,669	548,465,806	544,896,156	548,263,084	541,163,054	552,194,624	535,235,077	570,879,025	540,746,575

In the previous run, diesel total vkm for all sizes went down, while gasoline vkm for all sizes went up. This is no longer the case: total mileage goes down for small gasoline vehicles as well. The driving factor is not mileage per vehicle (this goes up), but vehicle purchase price, which increases substantially (in comparison with efficiency improvement) for diesels and small gasoline cars. It is not coincidental these are the vehicles with the lowest improvement potential (in terms of cost per unit of CO_2 reduction).

The desired improvement in fuel efficiency is 7.14% in this case (1 - 130/140), and almost all it is actually achieved: 7.13%. Obviously, as the regulation becomes stricter, the cost to improve efficiency increases. When purchase price goes up faster than driving costs decrease, it becomes more expensive to use a car, and fewer people will buy a new one. This is why the rebound effect has almost completely disappeared.

D22: 125g

Input

Table 120 Cost assumptions in TREMOVE 2.43b run D22, 2006.

Fuel consumption	**2009**	**2010**	**2011**	**2012**
Diesel Small	100%	97.08%	94.15%	91.23%
Diesel Medium	100%	97.52%	95.05%	92.57%
Diesel Big	100%	97.31%	94.61%	91.92%
Gasoline Small	100%	95.01%	90.02%	85.04%
Gasoline Medium	100%	95.78%	91.55%	87.33%
Gasoline Big	100%	95.04%	90.09%	85.13%
Relative purchase price increase				
Diesel Small	0%	1.82%	3.93%	6.36%
Diesel Medium	0%	1.45%	3.06%	4.86%
Diesel Big	0%	1.35%	2.86%	4.55%
Gasoline Small	0%	3.25%	7.03%	11.42%
Gasoline Medium	0%	1.74%	3.75%	6.06%
Gasoline Big	0%	1.42%	3.08%	4.99%

Results

Table 121 Results of TREMOVE 2.43b run D22, 2006, for new cars (age 0).

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	0
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicle	BC	D22	BC	D22	BC	D22	BC	D22	BC	D22
Sum of vehicles	PCDS s	1,077,168	1,071,573	1,083,167	1,078,347	1,098,259	1,093,531	1,135,444	1,126,097	1,286,816	1,269,041
	PCDM	5,515,140	5,500,648	5,565,842	5,539,450	5,597,931	5,565,056	5,673,984	5,644,245	5,919,178	5,875,327
	PCDB b	1,620,561	1,616,943	1,669,851	1,662,223	1,721,602	1,711,221	1,884,077	1,873,248	2,232,996	2,216,103
	PCGS s	4,763,396	4,764,379	4,754,597	4,760,931	4,827,652	4,825,641	5,149,784	5,109,057	6,011,303	5,956,654
	PCGM	3,488,482	3,506,173	3,525,031	3,557,762	3,578,643	3,618,353	3,713,904	3,744,749	4,035,697	4,068,331
	PCGB b	836,698	840,913	874,427	882,793	913,294	923,654	1,032,315	1,040,863	1,259,361	1,269,087
Sum of vkm	PCDS s	14,576	14,511	15,133	15,087	15,618	15,585	16,774	16,683	19,072	18,896
	PCDM	107,798	107,548	109,621	109,169	110,732	110,179	113,392	112,918	118,518	117,819
	PCDB b	32,960	32,892	34,035	33,894	35,125	34,937	38,549	38,363	45,623	45,330
	PCGS s	77,076	77,079	78,238	78,394	79,276	79,380	82,849	82,432	90,969	90,461
	PCGM	56,652	56,920	57,321	57,819	57,935	58,533	59,102	59,546	61,498	61,962
	PCGB b	17,629	17,712	18,280	18,444	18,955	19,156	20,961	21,118	24,865	25,046
Sum of CO2	PCDS s	1,864,129	1,804,638	1,936,328	1,824,486	1,995,092	1,829,258	2,136,253	1,953,008	2,405,997	2,191,652
	PCDM	16,895,501	16,399,608	17,231,315	16,233,705	17,445,642	15,957,609	17,808,926	16,305,549	18,461,454	16,876,664
	PCDB b	6,705,398	6,494,001	6,941,724	6,506,186	7,176,646	6,510,374	7,834,288	7,111,865	9,157,881	8,300,926
	PCGS s	11,202,138	10,701,169	11,349,069	10,352,154	11,460,431	9,930,268	11,920,748	10,267,928	12,947,887	11,150,271
	PCGM	9,613,571	9,277,121	9,750,906	9,047,093	9,831,344	8,744,184	9,978,320	8,852,502	10,282,251	9,124,617
	PCGB b	3,212,197	3,078,235	3,327,634	3,051,066	3,441,483	2,995,078	3,783,869	3,283,925	4,446,509	3,859,348
Total Sum of vehicles		17,301,446	17,300,630	17,472,916	17,481,505	17,737,381	17,737,456	18,589,508	18,538,259	20,745,351	20,654,543
Total Sum of vkm		306,692	306,662	312,628	312,807	317,641	317,771	331,625	331,060	360,544	359,515
Total Sum of CO2		49,492,934	47,754,773	50,536,976	47,014,690	51,350,637	45,966,771	53,462,404	47,774,779	57,701,979	51,503,478

Table 122 Results of TREMOVE 2.43b run D22, 2006, for all cars.

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	(All)
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicle	BC	D22	BC	D22	BC	D22	BC	D22	BC	D22
Sum of vehicles	PCDS s	8,146,308	8,140,878	9,067,654	9,057,415	9,958,445	9,943,505	12,357,034	12,316,613	15,305,152	15,198,723
	PCDM	59,783,095	59,771,148	62,509,228	62,470,923	65,010,032	64,939,008	71,120,208	70,960,604	77,343,270	77,007,154
	PCDB b	16,149,747	16,145,984	16,969,221	16,957,848	17,790,706	17,769,022	20,235,983	20,183,652	24,326,009	24,208,258
	PCGS s	75,171,074	75,171,892	74,483,909	74,491,070	73,952,068	73,957,229	73,367,858	73,276,945	75,309,164	75,000,352
	PCGM	53,701,493	53,716,528	53,098,059	53,145,778	52,607,173	52,694,406	51,801,622	51,989,224	52,414,247	52,740,042
	PCGB b	10,575,258	10,579,727	10,675,913	10,688,726	10,815,943	10,839,042	11,477,075	11,527,309	13,381,356	13,470,881
Sum of vkm	PCDS s	95,683	95,626	106,925	106,828	117,820	117,695	147,219	146,895	182,972	182,106
	PCDM	941,035	940,884	980,487	980,001	1,016,584	1,015,686	1,104,411	1,102,405	1,193,628	1,189,352
	PCDB b	265,882	265,827	278,665	278,501	291,522	291,211	329,969	329,225	394,644	392,955
	PCGS s	916,630	916,629	905,525	905,642	896,416	896,608	883,030	882,546	900,767	898,542
	PCGM	661,434	661,621	651,697	652,298	643,609	644,709	628,301	630,661	627,608	631,613
	PCGB b	171,355	171,427	172,596	172,805	174,518	174,897	184,262	185,086	213,056	214,502
Sum of CO2	PCDS s	12,054,159	12,001,149	13,504,575	13,339,904	14,902,060	14,571,811	18,665,288	17,839,788	23,163,464	21,610,984
	PCDM	151,295,576	150,763,150	156,995,982	155,488,255	162,186,858	159,233,712	174,626,328	167,692,035	186,558,300	174,564,452
	PCDB b	56,940,793	56,718,093	59,153,817	58,504,816	61,405,293	60,109,657	68,235,670	65,075,879	79,848,064	73,981,534
	PCGS s	158,207,168	157,731,137	153,204,113	151,728,000	148,682,296	145,694,031	138,967,634	131,689,283	133,464,420	120,366,279
	PCGM	133,246,773	132,895,570	128,743,108	127,675,603	124,692,510	122,539,848	115,543,702	110,431,056	108,647,922	99,825,017
	PCGB b	37,518,858	37,374,731	36,864,211	36,440,100	36,394,068	35,527,351	36,156,001	34,013,569	39,196,854	35,185,715
Total Sum of vehicles		223,526,977	223,526,157	226,803,985	226,811,760	230,134,367	230,142,212	240,359,781	240,254,346	258,079,198	257,625,410
Total Sum of vkm		3,052,017	3,052,014	3,095,895	3,096,075	3,140,468	3,140,806	3,277,192	3,276,818	3,512,674	3,509,070
Total Sum of CO2		549,263,327	547,483,830	548,465,806	543,176,679	548,263,084	537,676,408	552,194,624	526,741,610	570,879,025	525,533,981

Another 2 million tonnes are trimmed off the CO_2 emissions for a total of 6 million. This corresponds to an improvement of 10.74%, while the target would have been just 10.71% (1 – 125/140). This rather surprising result is a consequence of the second order effect, which was already touched upon in the discussion of run D21 above: even though there is a decrease in driving cost per km[124], the increase in vehicle acquisition cost affects sales negatively to the extent that even the shift to less efficient cars (from diesel to gasoline and from small to big) is not significant enough to overcome the lower sales volume. Whether this is desirable from a welfare point of view is disputable, but CO_2 emission levels certainly benefit.

D23: 120g

Input

Table 123 Cost assumptions in TREMOVE 2.43b run D23, 2006.

Fuel consumption	**2009**	**2010**	**2011**	**2012**
Diesel Small	100%	96.07%	92.14%	88.21%
Diesel Medium	100%	96.57%	93.13%	89.70%
Diesel Big	100%	96.28%	92.56%	88.84%
Gasoline Small	100%	93.50%	87.00%	80.50%
Gasoline Medium	100%	94.42%	88.83%	83.25%
Gasoline Big	100%	93.47%	86.94%	80.42%
Relative purchase price increase				
Diesel Small	0%	2.40%	5.35%	8.89%
Diesel Medium	0%	1.89%	4.12%	6.73%
Diesel Big	0%	1.77%	3.85%	6.30%
Gasoline Small	0%	4.17%	9.29%	15.52%
Gasoline Medium	0%	2.25%	4.99%	8.29%
Gasoline Big	0%	1.84%	4.10%	6.84%

[124] This includes fuel cost, fuel tax and VAT, but no other (annualised) costs such as purchase cost, purchase tax or circulation tax.

Results

Table 124 Results of TREMOVE 2.43b run D23, 2006, for new cars (age 0).

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	0
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicle type	BC	D23	BC	D23	BC	D23	BC	D23	BC	D23
Sum of vehicles	PCDS small dies	1,077,168	1,071,022	1,083,167	1,078,292	1,098,259	1,094,210	1,135,444	1,123,681	1,286,816	1,263,889
	PCDM medium	5,515,140	5,494,222	5,565,842	5,531,738	5,597,931	5,556,110	5,673,984	5,632,176	5,919,178	5,858,838
	PCDB big diesel	1,620,561	1,614,682	1,669,851	1,658,872	1,721,602	1,706,760	1,884,077	1,867,180	2,232,996	2,207,788
	PCGS small gas	4,763,396	4,764,930	4,754,597	4,757,076	4,827,652	4,810,950	5,149,784	5,073,980	6,011,303	5,913,569
	PCGM medium	3,488,482	3,512,944	3,525,031	3,566,396	3,578,643	3,628,884	3,713,904	3,749,503	4,035,697	4,073,799
	PCGB big gasoli	836,698	842,829	874,427	885,434	913,294	926,464	1,032,315	1,042,202	1,259,361	1,270,616
Sum of vkm	PCDS small dies	14,576	14,506	15,133	15,091	15,618	15,604	16,774	16,661	19,072	18,846
	PCDM medium	107,798	107,436	109,621	109,037	110,732	110,031	113,392	112,716	118,518	117,546
	PCDB big diesel	32,960	32,849	34,035	33,831	35,125	34,855	38,549	38,255	45,623	45,181
	PCGS small gas	77,076	77,085	78,238	78,358	79,276	79,204	82,849	81,990	90,969	89,971
	PCGM medium	56,652	57,022	57,321	57,950	57,935	58,692	59,102	59,614	61,498	62,041
	PCGB big gasoli	17,629	17,750	18,280	18,496	18,955	19,210	20,961	21,143	24,865	25,075
Sum of CO2	PCDS small dies	1,864,129	1,786,996	1,936,328	1,787,850	1,995,092	1,772,885	2,136,253	1,888,473	2,405,997	2,116,542
	PCDM medium	16,895,501	16,224,810	17,231,315	15,893,996	17,445,642	15,470,089	17,808,926	15,801,481	18,461,454	16,347,367
	PCDB big diesel	6,705,398	6,419,838	6,941,724	6,358,972	7,176,646	6,286,536	7,834,288	6,864,495	9,157,881	8,008,871
	PCGS small gas	11,202,138	10,543,603	11,349,069	10,025,468	11,460,431	9,407,706	11,920,748	9,698,503	12,947,887	10,532,812
	PCGM medium	9,613,571	9,166,242	9,750,906	8,808,125	9,831,344	8,374,565	9,978,320	8,465,918	10,282,251	8,728,006
	PCGB big gasoli	3,212,197	3,036,282	3,327,634	2,954,343	3,441,483	2,846,466	3,783,869	3,116,074	4,446,509	3,662,516
Total Sum of vehicles		17,301,446	17,300,630	17,472,916	17,477,808	17,737,381	17,723,377	18,589,508	18,488,722	20,745,351	20,588,499
Total Sum of vkm		306,692	306,647	312,628	312,764	317,641	317,596	331,625	330,378	360,544	358,660
Total Sum of CO2		49,492,934	47,177,771	50,536,976	45,828,754	51,350,637	44,158,247	53,462,404	45,834,943	57,701,979	49,396,114

Table 125 Results of TREMOVE 2.43b run D23, 2006, for all cars.

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	(All)
vehicle category	(Multiple Items)

		year	run								
		2010		2011		2012		2015		2020	
Data	vehicle type	BC	D23	BC	D23	BC	D23	BC	D23	BC	D23
Sum of vehicles	PCDS small dies	8,146,308	8,140,327	9,067,654	9,056,809	9,958,445	9,943,574	12,357,034	12,310,187	15,305,152	15,173,665
	PCDM medium	59,783,095	59,764,722	62,509,228	62,456,809	65,010,032	64,916,017	71,120,208	70,901,757	77,343,270	76,880,679
	PCDB big diesel	16,149,747	16,143,723	16,969,221	16,952,248	17,790,706	17,758,998	20,235,983	20,156,365	24,326,009	24,147,823
	PCGS small gas	75,171,074	75,172,443	74,483,909	74,487,767	73,952,068	73,939,257	73,367,858	73,163,425	75,309,164	74,706,461
	PCGM medium	53,701,493	53,723,299	53,098,059	53,161,158	52,607,173	52,720,245	51,801,622	52,032,054	52,414,247	52,803,984
	PCGB big gasoli	10,575,258	10,581,643	10,675,913	10,693,274	10,815,943	10,846,373	11,477,075	11,539,320	13,381,356	13,488,425
Sum of vkm	PCDS small dies	95,683	95,622	106,925	106,828	117,820	117,712	147,219	146,869	182,972	181,929
	PCDM medium	941,035	940,800	980,487	979,819	1,016,584	1,015,394	1,104,411	1,101,629	1,193,628	1,187,656
	PCDB big diesel	265,882	265,793	278,665	278,418	291,522	291,062	329,969	328,814	394,644	392,043
	PCGS small gas	916,630	916,633	905,525	905,616	896,416	896,444	883,030	881,415	900,767	895,643
	PCGM medium	661,434	661,707	651,697	652,492	643,609	645,036	628,301	631,210	627,608	632,414
	PCGB big gasoli	171,355	171,458	172,596	172,880	174,518	175,017	184,262	185,285	213,056	214,790
Sum of CO2	PCDS small dies	12,054,159	11,983,635	13,504,575	13,285,651	14,902,060	14,461,037	18,665,288	17,554,245	23,163,464	21,070,178
	PCDM medium	151,295,576	150,593,255	156,995,982	154,985,278	162,186,858	158,255,507	174,626,328	165,379,920	186,558,300	170,558,408
	PCDB big diesel	56,940,793	56,646,057	59,153,817	58,289,094	61,405,293	59,676,949	68,235,670	64,005,003	79,848,064	71,982,975
	PCGS small gas	158,207,168	157,573,274	153,204,113	151,245,958	148,682,296	144,703,149	138,967,634	129,227,234	133,464,420	115,883,425
	PCGM medium	133,246,773	132,781,247	128,743,108	127,319,427	124,692,510	121,816,099	115,543,702	108,691,440	108,647,922	96,804,941
	PCGB big gasoli	37,518,858	37,331,340	36,864,211	36,298,826	36,394,068	35,239,024	36,156,001	33,297,326	39,196,854	33,840,220
Total Sum of vehicles		223,526,977	223,526,157	226,803,985	226,808,065	230,134,367	230,124,464	240,359,781	240,103,108	258,079,198	257,201,037
Total Sum of vkm		3,052,017	3,052,014	3,095,895	3,096,053	3,140,468	3,140,664	3,277,192	3,275,222	3,512,674	3,504,475
Total Sum of CO2		549,263,327	546,908,808	548,465,806	541,424,236	548,263,084	534,151,765	552,194,624	518,155,168	570,879,025	510,140,146

The fuel saving for new vehicles rises to more than 8 million tonnes of CO_2 per vintage year. Again, increased purchase costs cause a drop in total CO_2 that is higher than would be expected: 14.29% versus 14.39% in 2020. This result does take some years to develop, as car sales in 2012 and 2015 are high enough to still generate some negative rebound effect. Likely, the process of replacing old cars by (more expensive and more efficient) new ones is still going on at a higher than usual pace in 2015, but the situation normalises by 2020.
Annual average mileage does increase from 17,379km to 17,420 km/year, yet the lower amount of cars sold more than offsets this increase.

18.3.2 CO2 & Cars, 2008, runs by JRC/IPTS for DG ENV

The JRC/IPTS performed some additional test runs with TREMOVE v2.7, based on the IEEP/CE/TNO 2007 study[125]. The background assumptions differ however. The first relevant difference is that the 140g/km that was put forward as the 2008 target (constant thereafter) was abandoned, and replaced by the assumption of having 160g CO2/km by 2006 and constant thereafter.

[125] [IEEP/CE/TNO 2007]: Service Contract on possible regulatory approaches to reducingCO_2 emissions from cars, DG Environment, contract nr. 070402/2006/452236/MAR/C3.

The second important difference is that the slope of the weight/emission reduction curve was variable for different runs. A lower slope means heavier cars need to improve more than lighter ones.

These runs made additional assumptions on the weight evolution (Autonomous Mass Increase or AMI) of vehicles and the CO_2 reduction effort linked with vehicle mass. For this review, we will consider 2 runs:

- AMI 0%, Slope of 40%
- AMI 0.82%, Slope 40%

The target is set at 130g by 2012, but as it starts in 2007, results are not directly comparably to run D21 above.

AMI 0%, slope 40%

Input

This is a situation in which a larger part of the CO2 reduction effort would be carried by bigger cars, so their cost increase and fuel consumption decrease are higher than in D21.
An important caveat: since the assumptions behind the 2.43b model version used for the runs above, and the 2.7 version used for these runs are different, the tables can not be compared. The 2.7 version used here assumes 160g CO2/km in 2006 and constant thereafter[126].

Table 126 Cost assumptions in TREMOVE 2.7 JRC/IPTS run, AMI 0%, slope 40%, 2008.

Fuel consumption	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Diesel Small	100.00%	98.78%	97.45%	96.23%	94.90%	93.68%	92.46%
Diesel Medium	100.00%	97.86%	95.71%	93.67%	91.53%	89.39%	87.35%
Diesel Big	100.00%	96.93%	93.95%	90.88%	87.81%	84.84%	81.76%
Gasoline Small	100.00%	96.66%	93.31%	89.97%	86.52%	83.18%	79.83%
Gasoline Medium	100.00%	95.95%	91.91%	87.86%	83.82%	79.77%	75.73%
Gasoline Big	100.00%	94.76%	89.52%	84.28%	78.93%	73.69%	68.45%
Relative purchase price increase							
Diesel Small	0.00%	0.40%	0.80%	1.10%	1.50%	1.90%	2.30%
Diesel Medium	0.00%	0.50%	1.10%	1.60%	2.10%	2.60%	3.20%
Diesel Big	0.00%	0.60%	1.30%	1.90%	2.60%	3.20%	3.90%
Gasoline Small	0.00%	1.40%	2.70%	4.10%	5.50%	6.90%	8.20%
Gasoline Medium	0.00%	0.90%	1.90%	2.80%	3.70%	4.60%	5.60%
Gasoline Big	0.00%	1.10%	2.10%	3.20%	4.20%	5.30%	6.30%

[126] "Analysis for the impact assessment and the follow-up of Commission proposals in the area of reducing air pollution and CO_2 emissions from vehicles", IPTS report, Administrative arrangement N 070402/2006/453757/MAR/C5 and amendment 1, June 2009.

Results

The results in the tables below include only the EU15 countries.

Table 127 Results of TREMOVE 2.7 run AMI 0%, slope 40%, 2008, for new cars (age 0).

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	0
vehicle category	(Multiple Items)

		year / run									
		2010		2015		2020		2025		2030	
Data	vehicle type	BC	M40	BC	M40	BC	M40	BC	M40	BC	M40
Sum of vehicles	car <1.4l - diesel	987,421	881,976	950,410	808,440	1,042,249	873,376	987,662	829,451	963,709	810,662
	car 1.4-2.0l - diesel	5,489,356	5,054,137	5,604,779	4,944,005	6,240,632	5,456,122	6,236,815	5,454,141	6,334,085	5,538,132
	car >2.0l - diesel	1,379,198	1,264,555	1,430,376	1,248,569	1,679,101	1,453,345	1,718,422	1,491,822	1,823,362	1,586,721
	car <1.4l - petrol	4,116,659	4,184,225	4,444,544	4,493,641	4,440,269	4,504,278	4,446,228	4,490,074	4,419,538	4,444,620
	car 1.4-2.0l - petrol	2,911,966	3,306,223	3,432,409	4,000,093	3,428,379	4,077,686	3,706,581	4,350,926	3,925,408	4,560,618
	car >2.0l - petrol	662,828	881,292	825,647	1,181,452	826,816	1,234,574	950,353	1,384,967	1,068,094	1,528,853
Sum of vkm	car <1.4l - diesel	12,233	10,956	12,767	10,979	14,422	12,226	13,933	11,814	13,783	11,684
	car 1.4-2.0l - diesel	115,985	107,360	120,528	107,838	134,670	119,554	135,083	119,726	137,767	121,904
	car >2.0l - diesel	30,197	27,892	31,573	28,029	36,940	32,540	37,897	33,392	40,363	35,566
	car <1.4l - petrol	63,064	64,062	67,127	67,934	66,319	67,465	66,327	67,280	66,037	66,776
	car 1.4-2.0l - petrol	53,060	59,828	60,382	69,503	59,201	69,963	63,668	74,707	67,250	78,388
	car >2.0l - petrol	15,041	19,661	18,107	25,089	17,900	26,220	20,531	29,705	22,958	32,861
Sum of CO2	car <1.4l - diesel	1,674,341	1,425,313	1,745,168	1,391,355	1,959,936	1,540,686	1,888,033	1,484,444	1,861,789	1,463,280
	car 1.4-2.0l - diesel	20,175,531	17,155,711	20,886,120	16,418,874	23,221,350	18,117,803	23,196,224	18,069,893	23,539,297	18,307,107
	car >2.0l - diesel	7,372,224	6,003,485	7,673,116	5,606,829	8,921,279	6,469,986	9,109,691	6,608,778	9,652,285	7,002,919
	car <1.4l - petrol	11,269,972	9,968,659	11,961,551	9,769,316	11,754,559	9,654,044	11,704,502	9,586,569	11,604,893	9,476,549
	car 1.4-2.0l - petrol	11,289,186	10,727,542	12,801,823	11,268,420	12,487,057	11,288,440	13,364,701	11,998,854	14,056,264	12,537,402
	car >2.0l - petrol	4,146,993	4,302,030	4,966,831	4,760,627	4,877,409	4,943,149	5,565,851	5,573,422	6,201,174	6,143,060
Total Sum of vehicles		15,547,428	15,572,408	16,688,165	16,676,201	17,657,446	17,599,380	18,046,062	18,001,381	18,534,197	18,469,606
Total Sum of vkm		289,581	289,758	310,485	309,373	329,452	327,969	337,440	336,624	348,158	347,178
Total Sum of CO2		55,928,247	49,582,741	60,034,609	49,215,422	63,221,590	52,014,109	64,829,002	53,321,961	66,915,702	54,930,316

Table 128 Results of TREMOVE 2.7 run AMI 0%, slope 40%, 2008, for all cars.

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	(All)
vehicle category	(Multiple Items)

		year / run									
		2010		2015		2020		2025		2030	
Data	vehicle type	BC	M40	BC	M40	BC	M40	BC	M40	BC	M40
Sum of vehicles	car <1.4l - diesel	6,986,953	6,721,425	10,559,109	9,617,243	12,863,400	11,296,105	13,860,410	11,878,146	14,013,580	11,868,965
	car 1.4-2.0l - diesel	57,364,728	56,296,319	68,756,488	64,674,178	76,705,587	69,696,362	81,821,678	72,787,541	84,896,928	74,824,974
	car >2.0l - diesel	14,675,294	14,408,431	17,237,230	16,146,426	19,531,100	17,595,387	21,419,443	18,855,158	22,922,893	19,998,665
	car <1.4l - petrol	63,213,250	63,386,959	61,042,745	61,539,674	61,475,410	62,180,175	62,111,572	62,920,818	62,438,393	63,170,684
	car 1.4-2.0l - petrol	45,870,724	46,838,399	44,059,875	47,696,666	45,064,737	51,125,355	47,149,544	54,808,006	49,821,145	58,165,530
	car >2.0l - petrol	9,155,186	9,669,925	9,580,076	11,704,849	10,387,797	14,077,504	11,350,672	16,211,004	12,565,524	18,149,333
Sum of vkm	car <1.4l - diesel	76,893	73,970	115,992	105,788	140,696	123,888	150,557	129,487	151,710	129,116
	car 1.4-2.0l - diesel	985,974	968,759	1,162,816	1,098,065	1,287,109	1,176,520	1,367,110	1,225,352	1,415,128	1,257,806
	car >2.0l - diesel	259,340	255,002	300,210	282,555	337,626	306,390	368,608	327,401	393,387	346,568
	car <1.4l - petrol	721,072	723,586	694,061	701,441	699,981	710,637	707,161	719,447	709,684	721,110
	car 1.4-2.0l - petrol	625,272	639,034	595,380	646,238	606,708	690,906	632,647	738,244	666,025	780,207
	car >2.0l - petrol	158,120	167,137	163,964	200,632	177,064	240,443	192,954	276,037	212,985	307,868
Sum of CO2	car <1.4l - diesel	10,453,486	9,870,614	15,821,111	13,776,430	19,182,837	15,881,897	20,484,924	16,418,228	20,560,217	16,247,620
	car 1.4-2.0l - diesel	172,960,424	166,248,604	202,196,362	178,028,734	222,517,809	183,559,539	235,411,495	187,157,161	242,504,277	189,932,440
	car >2.0l - diesel	63,299,422	60,289,352	72,915,615	61,839,074	81,667,465	63,503,155	88,809,264	65,823,433	94,278,424	68,627,452
	car <1.4l - petrol	132,099,304	129,002,246	124,914,984	113,355,086	124,712,214	107,179,050	125,321,342	104,715,074	125,191,425	103,282,254
	car 1.4-2.0l - petrol	134,011,391	132,289,534	126,512,006	119,024,196	128,203,591	117,468,691	133,169,205	120,705,674	139,564,480	125,547,396
	car >2.0l - petrol	42,491,781	42,512,672	44,309,040	43,662,524	48,078,698	47,886,367	52,431,946	52,764,279	57,658,647	57,858,613
Total Sum of vehicles		197,266,134	197,321,458	211,235,524	211,379,037	226,028,031	225,970,887	237,713,319	237,460,672	246,658,463	246,178,151
Total Sum of vkm		2,826,671	2,827,489	3,032,423	3,034,719	3,249,184	3,248,785	3,419,038	3,415,968	3,548,919	3,542,675
Total Sum of CO2		555,315,808	540,213,022	586,669,118	529,686,045	624,362,614	535,478,699	655,628,176	547,583,848	679,757,470	561,495,775

The targeted improvement between basecase and simulation run M40 is 18.75% = 1 - (130g/160g). The actual emission level improvement for new cars is 17.91% or 95.53% of the expected improvement, and a lot lower than in any of the runs discussed above. This is mainly due to two reasons:

1. A relatively larger part of the effort is required from generally heavier diesel cars, causing an even more important shift to gasoline. These cars in turn emit more CO_2 on average.
2. Car sales do not go down as heavily as in the case when efforts are split evenly over all car types and sizes. Contrary to runs D21-23 (100% slope), total mileage and sales of small gasoline cars do not decrease, as the cost increase they have to absorb is relatively smaller. It appears sales of small cars are more elastic with regard to purchase price than bigger cars. As their cost does not increase as much as in D21-D23, they are still sold more, and thus emit more. The same elasticity for bigger vehicles is lower: even though they suffer a high price increase, buyers are willing to absorb that cost to keep their luxury vehicle.

AMI 0.82%, slope 40%

<u>Input</u>

The difference with the previous run is that there is a mass increase – for example for reasons of comfort – that necessitates extra effort to still make the target of 130g/km fleet average by 2012. As such car manufacturers need to move further along the cost curve, making them more expensive.

Table 129 Cost assumptions in TREMOVE 2.7 JRC/IPTS run, AMI 0.82%, Slope 40%, 2008.

Fuel consumption	2006	2007	2008	2009	2010	2011	2012
Diesel Small	100.00%	98.98%	97.86%	96.84%	95.82%	94.70%	93.68%
Diesel Medium	100.00%	97.96%	95.92%	93.88%	91.84%	89.80%	87.76%
Diesel Big	100.00%	97.03%	94.05%	91.08%	88.11%	85.13%	82.26%
Gasoline Small	100.00%	96.55%	93.00%	89.55%	86.00%	82.55%	79.00%
Gasoline Medium	100.00%	95.85%	91.70%	87.55%	83.40%	79.36%	75.21%
Gasoline Big	100.00%	94.55%	89.20%	83.86%	78.41%	73.06%	67.71%
Relative purchase price increase							
Diesel Small	0.00%	0.50%	1.10%	1.60%	2.20%	2.70%	3.30%
Diesel Medium	0.00%	0.70%	1.40%	2.10%	2.90%	3.60%	4.30%
Diesel Big	0.00%	0.80%	1.70%	2.50%	3.30%	4.20%	5.00%
Gasoline Small	0.00%	1.80%	3.70%	5.50%	7.30%	9.20%	11.00%
Gasoline Medium	0.00%	1.20%	2.40%	3.60%	4.70%	5.90%	7.10%
Gasoline Big	0.00%	1.30%	2.60%	3.90%	5.20%	6.50%	7.80%

<u>Results</u>

Table 130 Results of TREMOVE 2.7 run AMI 0.82%, slope 40%, 2008, for new cars (age 0).

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	0
vehicle category	(Multiple Items)

		year	run								
		2010		2015		2020		2025		2030	
Data	vehicle type	BC	M40	BC	M40	BC	M40	BC	M40	BC	M40
Sum of vehicles	car <1.4l - diesel	987,421	879,262	950,410	806,913	1,042,249	871,458	987,662	827,148	963,709	808,406
	car 1.4-2.0l - diesel	5,489,356	5,031,784	5,604,779	4,917,947	6,240,632	5,427,149	6,236,815	5,423,705	6,334,085	5,506,967
	car >2.0l - diesel	1,379,198	1,254,259	1,430,376	1,230,473	1,679,101	1,432,095	1,718,422	1,469,007	1,823,362	1,562,197
	car <1.4l - petrol	4,116,659	4,176,684	4,444,544	4,473,797	4,440,269	4,485,231	4,446,228	4,471,238	4,419,538	4,425,685
	car 1.4-2.0l - petrol	2,911,966	3,322,411	3,432,409	4,010,845	3,428,379	4,090,948	3,706,581	4,365,144	3,925,408	4,575,173
	car >2.0l - petrol	662,828	884,679	825,647	1,184,830	826,816	1,239,489	950,353	1,390,152	1,068,094	1,534,131
Sum of vkm	car <1.4l - diesel	12,233	10,921	12,767	10,959	14,422	12,201	13,933	11,783	13,783	11,653
	car 1.4-2.0l - diesel	115,985	106,907	120,528	107,331	134,670	118,987	135,083	119,116	137,767	121,273
	car >2.0l - diesel	30,197	27,680	31,573	27,659	36,940	32,102	37,897	32,907	40,363	35,037
	car <1.4l - petrol	63,064	63,957	67,127	67,669	66,319	67,214	66,327	67,024	66,037	66,513
	car 1.4-2.0l - petrol	53,060	60,109	60,382	69,682	59,201	70,196	63,668	74,964	67,250	78,656
	car >2.0l - petrol	15,041	19,729	18,107	25,157	17,900	26,327	20,531	29,821	22,958	32,981
Sum of CO2	car <1.4l - diesel	1,674,341	1,433,897	1,745,168	1,406,301	1,959,936	1,556,793	1,888,033	1,499,122	1,861,789	1,477,719
	car 1.4-2.0l - diesel	20,175,531	17,139,716	20,886,120	16,416,745	23,221,350	18,114,500	23,196,224	18,060,159	23,539,297	18,295,534
	car >2.0l - diesel	7,372,224	5,977,997	7,673,116	5,566,196	8,921,279	6,421,291	9,109,691	6,552,258	9,652,285	6,940,381
	car <1.4l - petrol	11,269,972	9,895,106	11,961,551	9,634,742	11,754,559	9,522,760	11,704,502	9,455,371	11,604,893	9,345,674
	car 1.4-2.0l - petrol	11,289,186	10,726,338	12,801,823	11,222,909	12,487,057	11,251,147	13,364,701	11,960,463	14,056,264	12,496,924
	car >2.0l - petrol	4,146,993	4,289,104	4,966,831	4,723,693	4,877,409	4,911,132	5,565,851	5,536,234	6,201,174	6,100,592
Total Sum of vehicles		15,547,428	15,549,080	16,688,165	16,624,805	17,657,446	17,546,371	18,046,062	17,946,394	18,534,197	18,412,559
Total Sum of vkm		289,581	289,304	310,485	308,458	329,452	327,026	337,440	335,616	348,158	346,113
Total Sum of CO2		55,928,247	49,462,157	60,034,609	48,970,586	63,221,590	51,777,623	64,829,002	53,063,606	66,915,702	54,656,825

Table 131 Results of TREMOVE 2.7 run AMI 0.82%, slope 40%, 2008, for all cars.

country	(All)
fuel type	(All)
vehicle technology	(All)
vehicle age	(All)
vehicle category	(Multiple Items)

		year	run								
		2010		2015		2020		2025		2030	
Data	vehicle type	BC	M40	BC	M40	BC	M40	BC	M40	BC	M40
Sum of vehicles	car <1.4l - diesel	6,986,953	6,719,078	10,559,109	9,608,189	12,863,400	11,279,064	13,860,410	11,853,350	14,013,580	11,838,765
	car 1.4-2.0l - diesel	57,364,728	56,256,353	68,756,488	64,514,167	76,705,587	69,426,044	81,821,678	72,439,116	84,896,928	74,432,735
	car >2.0l - diesel	14,675,294	14,378,862	17,237,230	16,035,927	19,531,100	17,406,059	21,419,443	18,605,144	22,922,893	19,708,501
	car <1.4l - petrol	63,213,250	63,367,077	61,042,745	61,434,761	61,475,410	61,996,586	62,111,572	62,689,677	62,438,393	62,919,414
	car 1.4-2.0l - petrol	45,870,724	46,869,631	44,059,875	47,782,253	45,064,737	51,255,744	47,149,544	54,969,091	49,821,145	58,344,309
	car >2.0l - petrol	9,155,186	9,684,212	9,580,076	11,737,557	10,387,797	14,124,841	11,350,672	16,269,580	12,565,524	18,214,776
Sum of vkm	car <1.4l - diesel	76,893	73,944	115,992	105,691	140,696	123,708	150,557	129,230	151,710	128,807
	car 1.4-2.0l - diesel	985,974	968,117	1,162,816	1,095,498	1,287,109	1,172,193	1,367,110	1,219,812	1,415,128	1,251,616
	car >2.0l - diesel	259,340	254,493	300,210	280,659	337,626	303,156	368,608	323,151	393,387	341,655
	car <1.4l - petrol	721,072	723,386	694,061	700,318	699,981	708,655	707,161	716,961	709,684	718,425
	car 1.4-2.0l - petrol	625,272	639,493	595,380	647,497	606,708	692,822	632,647	740,602	666,025	782,811
	car >2.0l - petrol	158,120	167,390	163,964	201,215	177,064	241,293	192,954	277,089	212,985	309,042
Sum of CO2	car <1.4l - diesel	10,453,486	9,897,598	15,821,111	13,868,540	19,182,837	16,020,547	20,484,924	16,577,048	20,560,217	16,407,616
	car 1.4-2.0l - diesel	172,960,424	166,293,119	202,196,362	178,090,504	222,517,809	183,574,352	235,411,495	187,114,906	242,504,277	189,849,645
	car >2.0l - diesel	63,299,422	60,223,765	72,915,615	61,631,364	81,667,465	63,142,345	88,809,264	65,337,679	94,278,424	68,057,342
	car <1.4l - petrol	132,099,304	128,827,919	124,914,984	112,670,390	124,712,214	106,095,960	125,321,342	103,418,285	125,191,425	101,908,817
	car 1.4-2.0l - petrol	134,011,391	132,253,021	126,512,006	118,830,106	128,203,591	117,160,796	133,169,205	120,334,499	139,564,480	125,143,444
	car >2.0l - petrol	42,491,781	42,503,565	44,309,040	43,522,359	48,078,698	47,633,898	52,431,946	52,434,261	57,658,647	57,472,943
Total Sum of vehicles		197,266,134	197,275,214	211,235,524	211,112,854	226,028,031	225,488,338	237,713,319	236,825,958	246,658,463	245,458,500
Total Sum of vkm		2,826,671	2,826,823	3,032,423	3,030,878	3,249,184	3,241,828	3,419,038	3,406,844	3,548,919	3,532,357
Total Sum of CO2		555,315,808	539,998,986	586,669,118	528,613,263	624,362,614	533,627,898	655,628,176	545,216,678	679,757,470	558,839,808

As all cars need to slightly improve their efficiency further, Table 117 shows that cost increases are the highest (in comparison to Table 114) for small gasoline cars, and the situation moves closer the that of runs D20-D23. The result moves in the same direction: a larger part of the potential is realised (18.32% of the desired 18.75%).

18.3.3 Sensitivity runs with TREMOVE 3.3, 2009-2010, runs for DG ENV

In 2009-2010, TML developed a new TREMOVE version for DG ENV/CLIMA, which was to incorporate the results of the FLEETS and EX-TREMIS projects, as well as adopt 2 new baselines, including a number of policies on emissions targets. The selected baselines were constructed in the iTREN-2030 project, and correspond to the “Reference” and “Integrated” scenarios of that project.

As a matter of test, a number of sensitivity runs were made with the new versions, with variations in GDP and crude oil. Precisely those last variations can give us an idea about the change in driving behaviour of newly purchased vehicles (any change in driving style of existing vehicles is not very useful for our purpose). The run that most closely resembles the situation that is being investigated is the one with a decrease in GDP (which mimics the purchase price increase) and a decrease in crude oil price (which mimics the decrease in cost per km). The GDP effect on the sales is a minor one in TREMOVE modeling, so this run could de facto be seen as an evaluation of the effect of lower cost per vkm on driving behaviour (mileage, not fuel consumption).

Table 132 Results of TREMOVE 3.3 alternative sensitivity run GLFL, 2010.

country	(All)
fuel type	(All)
vehicle technolog	(All)
vehicle age	0
vehicle category	(All)

		year / run									
		2010		2015		2020		2025		2030	
Data	vehicle type	BC	FUEL2L	BC	FUEL2L	BC	FUEL2L	BC	FUEL2L	BC	FUEL2L
Sum of vehicles	car >2.0l - diesel	1,013,181	1,620,825	1,342,832	1,418,042	1,150,715	1,228,586	1,036,043	1,108,050	1,116,396	1,200,763
	car 1.4-2.0l - diesel	4,184,761	6,223,688	5,168,166	5,093,632	4,407,889	4,418,696	3,905,672	3,880,976	4,387,357	4,375,773
	car <1.4l - diesel	702,676	1,009,088	858,046	826,869	630,022	614,449	587,420	566,199	651,184	629,569
	car >2.0l - petrol	693,333	1,102,527	972,016	1,026,728	1,105,215	1,202,383	1,001,058	1,087,054	1,075,899	1,167,688
	car 1.4-2.0l - petrol	3,572,350	5,259,331	4,842,654	4,800,103	5,383,343	5,491,843	5,148,782	5,213,997	5,489,951	5,560,214
	car <1.4l - petrol	4,601,077	6,730,956	5,608,039	5,530,544	5,662,504	5,741,200	5,311,456	5,320,750	5,756,200	5,794,990
Sum of vkm	car >2.0l - diesel	31,273	49,560	41,418	43,284	35,550	37,764	33,212	35,429	36,799	39,481
	car 1.4-2.0l - diesel	114,182	167,825	136,988	134,597	116,956	117,413	107,265	106,684	123,849	123,719
	car <1.4l - diesel	16,522	23,638	20,088	19,336	15,237	14,926	14,720	14,233	17,000	16,518
	car >2.0l - petrol	11,655	18,093	15,528	16,199	17,400	18,736	16,181	17,443	18,056	19,477
	car 1.4-2.0l - petrol	53,804	77,378	69,232	68,368	75,472	76,870	74,361	75,230	81,438	82,345
	car <1.4l - petrol	52,289	75,175	62,757	61,586	61,677	62,430	59,509	59,709	65,860	66,275
Sum of CO2	car >2.0l - diesel	6,780,993	10,711,917	8,258,406	8,630,572	5,815,853	6,179,237	5,452,712	5,815,203	6,040,283	6,477,562
	car 1.4-2.0l - diesel	18,761,331	27,498,958	20,781,621	20,418,362	13,940,248	13,993,320	12,832,537	12,757,719	14,821,616	14,797,690
	car <1.4l - diesel	2,132,214	3,044,838	2,374,974	2,285,743	1,433,489	1,403,848	1,383,842	1,337,369	1,597,414	1,551,221
	car >2.0l - petrol	2,737,161	4,234,481	3,301,358	3,454,337	3,174,226	3,426,781	2,989,897	3,230,556	3,340,810	3,611,664
	car 1.4-2.0l - petrol	9,801,396	14,044,824	11,409,312	11,285,538	10,295,716	10,502,400	10,197,749	10,329,888	11,188,196	11,325,379
	car <1.4l - petrol	7,932,694	11,360,217	8,585,831	8,434,230	7,117,792	7,210,541	6,900,815	6,929,115	7,653,490	7,703,861
Total Sum of vehicles		14,767,378	21,946,415	18,791,754	18,695,918	18,339,687	18,697,158	16,990,431	17,177,026	18,476,987	18,728,997
Total Sum of vkm		279,725	411,669	346,010	343,370	322,291	328,138	305,248	308,729	343,001	347,814
Total Sum of CO2		48,145,790	70,895,235	54,711,501	54,508,782	41,777,324	42,716,128	39,757,551	40,399,850	44,641,809	45,467,378

The oil price is reduced to 50%, which – when including excise duties and VAT – comes down to reducing pump price by about 1/3 to ¼ from 2010 onward. A large effect can be noticed in 2010: lots of people buy a new car (sales go up 48% on average, big cars up to 60%), but annual mileage decreases significantly.
In later years, the situation stabilizes to what could already be seen in the runs discussed above: a shift from diesel cars to gasoline cars occurs, as gasoline cars typically spend more on fuel per vkm. The issue with small gasoline cars also losing market share in the CO_2 legislation runs is not present here, which proves this is due to the hefty increase in purchase price.

The effect of a decreasing fuel price on annual average mileage seems very moderate based on this run, so clearly, TREMOVE is on the lower end of the spectrum: total CO_2 emissions and fuel consumption go up by 2.2%, which results in an elasticity of -0.065 to -0.09.[127] It should be noted that TREMOVE 3.3's alternative scenario already contains a policy leading to a fleet average of 95g/km for new passenger cars by 2020, including the associated increase in purchase price. This implies that the importance of fuel consumption in the total user cost has decreased, while that of purchase cost has increased.

18.3.4 Conclusions from TREMOVE runs

Seven TREMOVE simulation runs have been investigated for the purpose of this study. Six of them deal with the exact same topic: an increase of purchase price in exchange for a decrease of the cost per km driven. The seventh run shows the effects of a fuel price decrease alone; with some caveats, this allows us to isolate the effect of a decrease in cost per km.

The main conclusion is that the rebound effect on CO_2 emissions is mainly the result of a change in vehicle purchase behaviour, rather than in driving behaviour. It appears that as cars become more expensive due to CO_2 regulation, overall car sales decrease and more of the desired improvement in fuel efficiency and CO_2 emissions is actually realized.
When more of the burden is carried by larger cars, a smaller part of the potential is achieved. This is due to the lower price sensitivity of luxury car buyers: they are willing to absorb the additional cost in order to keep the same level of comfort, performance and utility.

The most benefit in terms of CO_2 emissions can be reaped from small cars: they are the most efficient, and buyers are rather sensitive to cost increases. If they are to become more efficient, they

[127] Calculated as +2.2% / -25% or +2.2% / -33%.

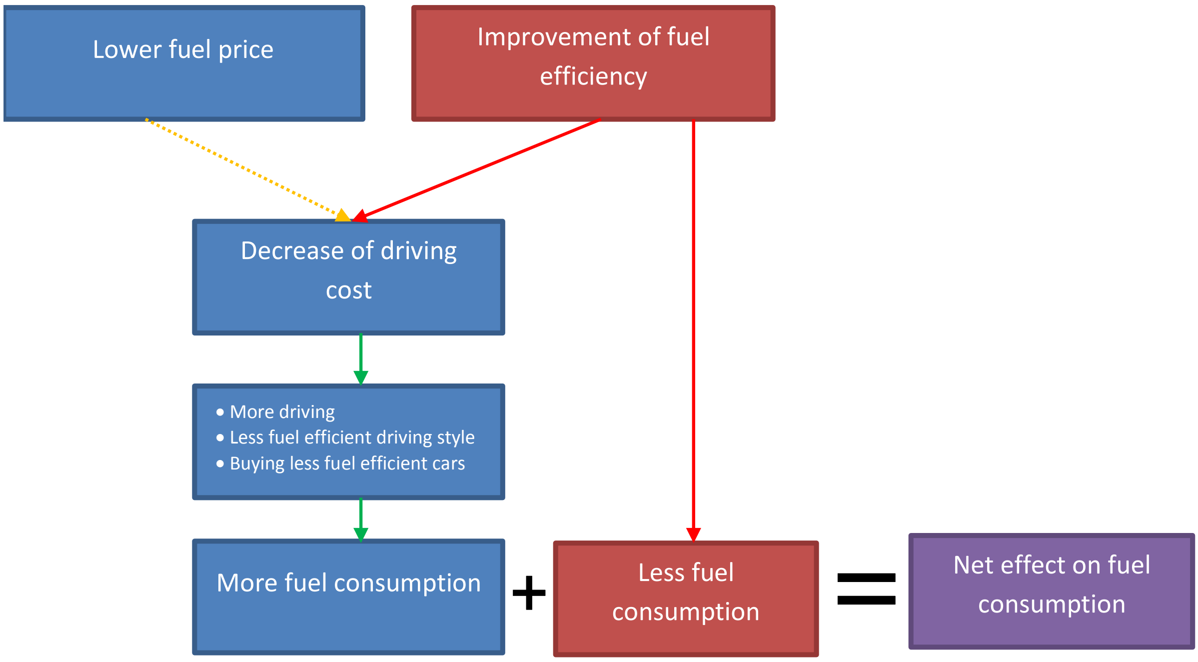
need to become much more expensive, and sales will drop. From the perspective of CO_2 emissions, this is the optimal situation. From an economic and social point of view, such an approach may raise questions.

To apply the results of these runs to the current situation, the place on the cost curve for each type of vehicle is essential to know. A higher cost for buyers that are most sensitive to price (i.e. buyers of smaller cars) implies lower sales of those cars, and a higher improvement in total CO_2 emissions.

Elasticity of driving behaviour (annual mileage per vehicle) in TREMOVE is on the lower end of the spectrum, but certainly not out of the expected range in the short term. If this would indeed be higher in the longer term, as literature suggests, the rebound effect would be more important, and a smaller share of the potential would be achieved.

18.3.5 Fit within elasticity approach

Available literature suggests that elasticities of fuel consumption with regard to fuel price are around -0.25 in the short run, and around -0.6 in the longer run. By definition of the concept of elasticity, this means that a fuel price decrease of 1% would cause fuel consumption (of the total fleet) to go up by 0.25% in the short run, and by 0.6% in the long run.
However, the present study does not consider fuel price changes, but changes in fuel efficiency. As literature does not provide evidence on the direct link between fuel efficiency and fuel consumption, a proxy needs to be found, and this can be done through the elasticity of fuel consumption with regard to fuel price. Broadly speaking, one could say there is equivalence between a change in fuel price and a change in fuel efficiency, as both generate a change in the cost of fuel per vehicle.km driven. However, while both change the cost, an efficiency improvement also has the effect of lowering physical fuel consumption, which needs to be accounted for in the calculation of the net result. The causal chain would be as follows:



The blue rectangles contain the argumentation which can be quantified from the literature above. The extra effect of a fuel efficiency improvement can also be quantified: it is equal to the target set forth by the EC, thus equal to the ratio of the new target and the starting value: (95 g/km) / (130 g/km) = 73%$\frac{95\mathrm{g/km}}{130\mathrm{g/km}} = 73\%$, or an improvement of 27%.

Now both effects have to be merged.

1. First of all, there is a cost change of 27% due to the improvement in fuel efficiency. The elasticity approach tells us this would lead to an increase of fuel consumption by 27%*|-0.25|=6.75% in the

short run, and 27%*|-0.6|= 16.2% in the long run. So, if the initial level of fuel consumption would be 100, the new levels (only accounting for the cost change) would be 106.75 and 116.2.
2. Second, the improvement of fuel efficiency has to be accounted for. Of all the fuel that would be consumed after a cost change, only 73% is actually consumed due to the efficiency improvement. The level of consumption would then be 73%*106.75 = 77.9 (ST) and 73%*116.2 = 84.8 (LT). As we started from an initial level of 100, these are the percentages of improvement that are realized.

A 27% improvement of fuel efficiency does not lead to a decrease of total fuel consumed of 27%, but only 22.1% (ST) and 15.2% (LT) due to the rebound effect of lower cost of fuel.

However, an improvement in fuel efficiency does not come for free. While the underlying assumption of the argumentation above only sees changes in fuel cost, the car itself also becomes more expensive as a result of the technology to improve fuel efficiency. The literature on the link between car price and car sales is largely insufficient for the analysis done in the present study, let alone on the link between car price and fuel consumption.

Therefore, we can build on TREMOVE. While the elasticities from literature are higher than the apparent TREMOVE elasticity, (as found in the analysis of the v3.3 sensitivity runs) they are certainly still within a reasonable range. TREMOVE is able to reflect the combined effects of a fuel efficiency improvement and a purchase price increase due to its nested structure, which accounts for all relevant cost changes.

The results from the TREMOVE modelling exercise indicate that as car manufacturers move up the cost curve to improve the fuel efficiency of the car, the fuel cost effect (more driving because of lower fuel expenditure) is gradually overtaken by the purchase cost effect (lower car sales due to purchase price increases).

This is because TREMOVE estimates that vehicle purchase behaviour would have a more important effect on CO_2 emission levels than driving behaviour. The two main changes in purchase behaviour are:

- Less cars are being sold due to the increasing importance of purchase price in TCO.
- For customers that do buy a car, it becomes less interesting to buy a small car or a diesel car, as the relative difference with larger/gasoline cars in terms of efficiency and price decreases.

TREMOVE projects that the first effect becomes more and more dominant as the target becomes more stringent, as price-sensitive small car buyers are being pushed out of the market.

Due to the model's structure (the purchase decision, modelled as a nested logit, has some rigidity built into it), the second effect is rather limited, and could be higher in reality in the longer run. This would lead to slightly higher average fuel consumption than TREMOVE projects.

Nonetheless, the indication that the allocation of reduction efforts affects the size of the rebound effect is a vital one. The fact that the model gives a greater decrease in sales of small cars than in big cars for the same relative price increase is indeed undeniable: these buyers are much more sensitive to price and their purchase decision depends more on TCO.

18.4 Application to current project

To apply the results of the runs to the current situation, an estimate is needed of the relative increases in cost and efficiency, ideally for each of the vehicle types. The required information, derived from chapter 10, is summarized in Table 133.

Table 133 Cost and CO_2 reduction effects of the policy under review (in comparison to 2015 target of 130g/km).

Fuel consumption	**2015**	**2020**
Diesel small	100%	70%
Diesel medium	100%	74%
Diesel large	100%	84%
Gasoline small	100%	75%
Gasoline medium	100%	76%
Gasoline large	100%	78%
Relative purchase price increase		
Diesel small	0%	18.3%
Diesel medium	0%	9.1%
Diesel large	0%	13.2%
Gasoline small	0%	13.2%
Gasoline medium	0%	8.5%
Gasoline large	0%	5.0%

The 100% slope ensures a hefty increase in purchase cost for all vehicles, but particularly, in relative terms, for smaller sizes. This will likely impact the size and composition of the fleet: as has become apparent from the TREMOVE runs done in the past, purchase price is of relatively higher importance for buyers of small vehicles, so their total sales and market share could drop significantly as a result of price increases of 18.8% and 24% (for diesel and gasoline, respectively).

Runs D22 and D23 have shown that the effect can be so large that the actual evolution of total emissions of new vehicles will drop more than would be expected based on an unchanged fleet (i.e. if the efficiency improvements would simply be applied to the fleet without the more stringent emissions limits). For example in D23, 0.7% extra emission savings were reached as a result of the combination of knock-on effects: with an unweighted average cost increase of 8.8%, the model projected a drop in emissions of 14.39%, whereas the target was only 1-120/140 or 14.29%; 14.39/14.29=1.007.

Given that the estimated cost increase is notably higher in this case (unweighted average of 11%), it seems reasonable to state that at least 1% to 2% of the efficiency improvement can be added to the regulation-imposed drop in emission levels. Thus, instead of a 1-95/130= 26.92% drop in the CO_2 emissions of the new fleet, a drop of 27.19% to 27.45% could be expected. Theoretically, this would be equivalent to fleet averages, ceteris paribus, of 94.32 to 94.65 g/km. Of course, given the projected evolution of the fleet towards a higher share of large vehicles (as part of the rebound effect), fleet averages would in fact be slightly higher than 95g/km, if no other action is taken.

The approach of this concluding section is based solely on the TREMOVE work. Ideally, we would have liked to make a comparison of both knock-on effects from literature and TREMOVE. For fuel prices, it was demonstrated that TREMOVE elasticity is on the lower end of the spectrum. While this literature on fuel price elasticities is relatively easy to come by and fairly straightforward, that is not the case for car purchase price. One of TREMOVE's main features is a detailed vehicle purchase decision tree that is calibrated on recent vehicle sales. While not perfect, it is the most suited tool for this part of the evaluation. Therefore, the results above represent the most complete indication of rebound effects available within the context of this study.

Further research work on this topic should focus on a more extensive search for available literature on car purchase price elasticities. Combined with a thorough analysis based on TREMOVE (the model mechanism as well as a number of dedicated runs) to dig deeper in the interaction between purchase cost and sales shares, this should allow for a detailed comparison of all effects in play, enabling a more reliable estimation of the net effect of knock-on consequences of CO_2 legislation on overall CO_2 emissions.

A Position of ‘strong weight reduction’ and ‘full hybridisation’ in the cost clouds

In this appendix, the position of CO_2 reduction packages including ‘strong weight reduction’ and/or ‘full hybridisation’ are shown. The packages including the CO_2 reduction options ‘strong weight reduction’ and ‘full hybridisation’, amongst other options, are depicted as purple and yellow markers respectively. Packages including ‘full hybridisation’ can also include ‘strong weight reduction’. The position of the cost curves in the figures results from the shape of the lower envelope of the cloud, including a safety margin. Therefore, the CO_2 reduction packages located on the cost curves do not necessarily represent the actual packages that would need to be applied to achieve a certain CO_2 reduction.

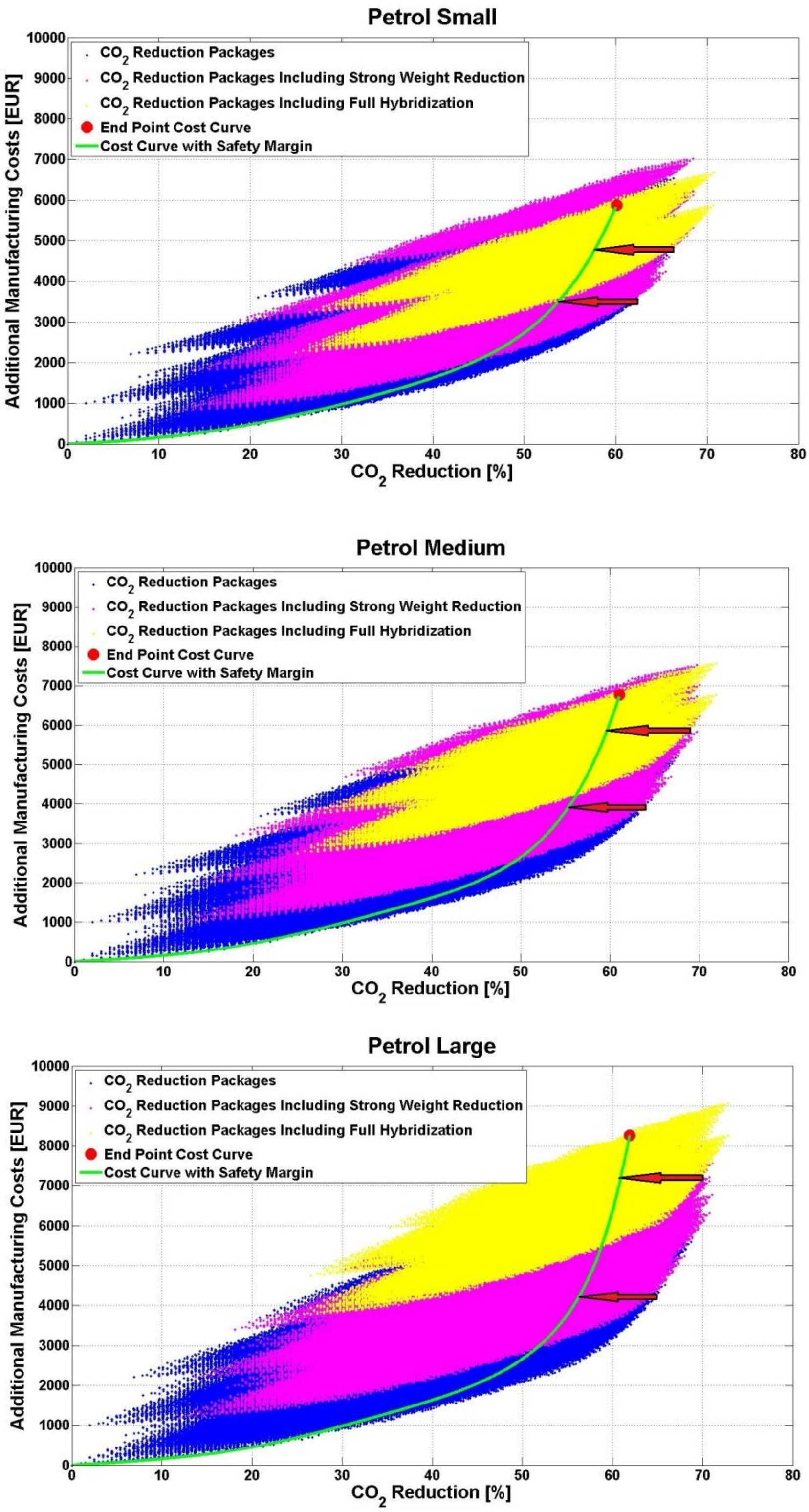


Figure 102 Cost curve for small-sized, medium-size and large-sized petrol cars (additional manufacturer costs as a function of relative reduction of Type Approval CO_2 emission). The red dot indicates the maximum reduction potential for the assessed measures at the lowest cost. The arrows indicate the position on the cost curve where the technologies full-hybridisation and/or strong weight reduction become part of the most cost-effective packages. The baseline CO_2 values are 148.7 g/km for small-sized, 188.6 g/km for medium-sized and 264.2 g/km for large-sized petrol cars.

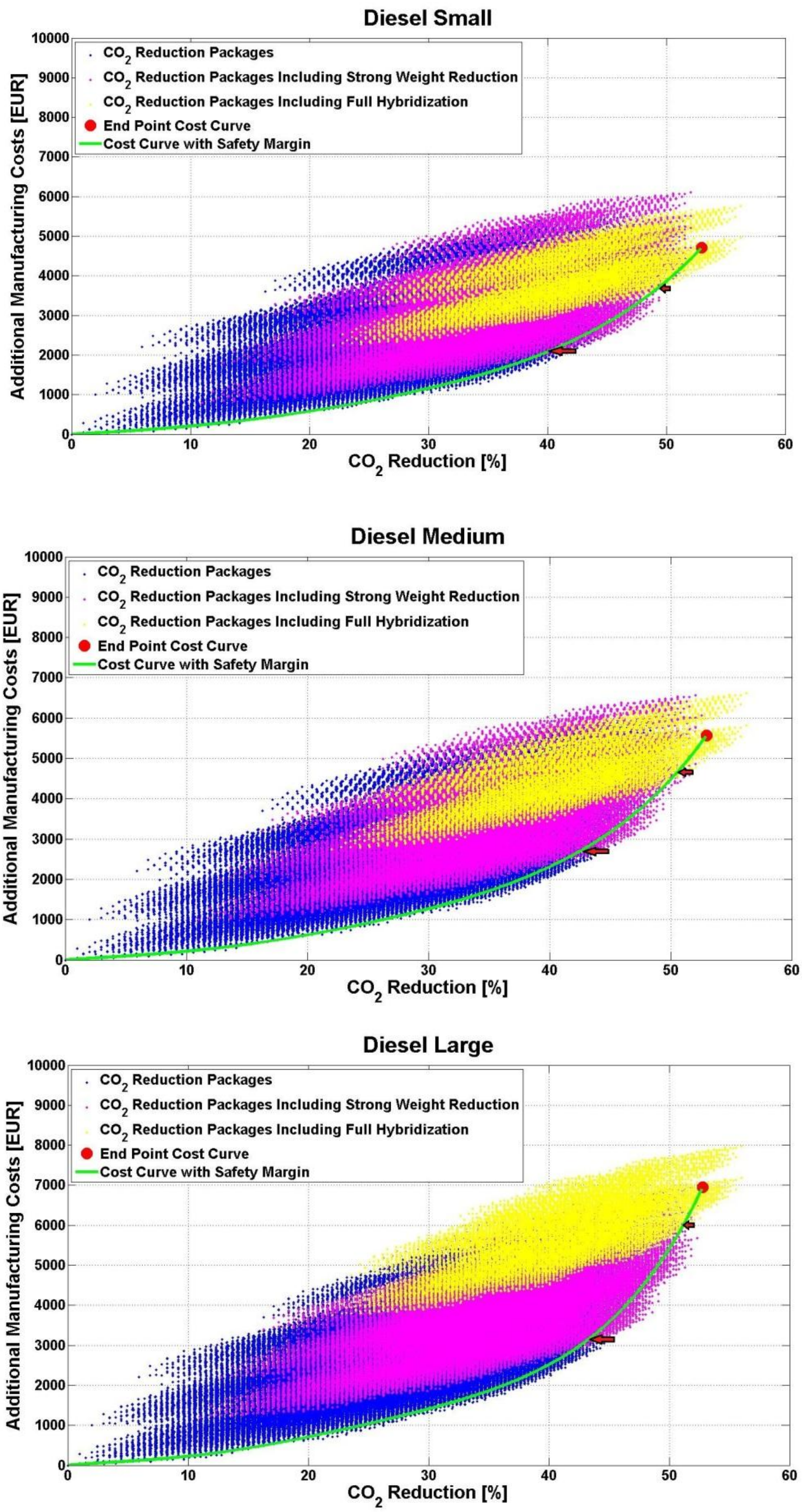


Figure 103 Cost curve for small-sized, medium-size and large-sized diesel cars (additional manufacturer costs as a function of relative reduction of Type Approval CO_2 emission). The red dot indicates the maximum reduction potential for the assessed measures at the lowest cost. The arrows indicate the position on the cost curve where the technologies full-hybridisation and/or strong weight reduction become part of the most cost-effective packages. The baseline CO_2 values are 122.87 g/km for small-sized, 157.0 g/km for medium-sized and 212.9 g/km for large-sized diesel cars.

B Cost curves with absolute CO_2 reduction values

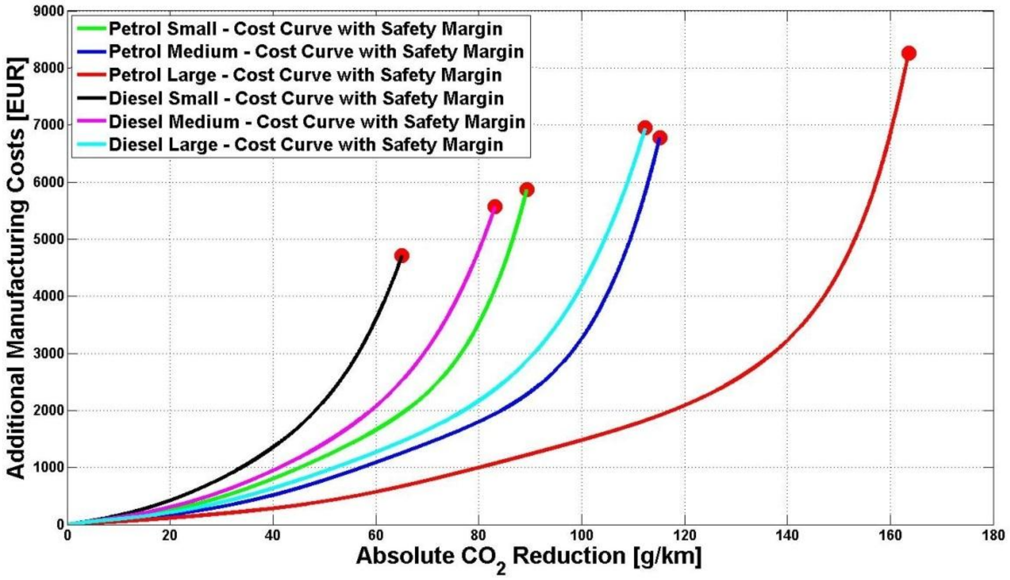


Figure 104 Cost curves for all segments (additional manufacturer costs as a function of absolute reduction in Type Approval CO_2 emission). The red dot indicates the maximum reduction potential for the assessed measures at the lowest costs for each cost curve.

C Alternative cost curves (scenario a) reflecting alternative accounting for progress observed in the 2002-2009 period

In the methodology for Service Request 1 cost curves are defined relative to 2002 baseline vehicles. To this end the cost assessment model used to estimate the costs for meeting the 2020 targets contains information per manufacturer on the sales, average mass and average CO_2 emissions of vehicle in all discerned 6 segments (small / medium / large vehicles on petrol and diesel) derived from a sales database for 2002. In addition the model contains the similar data for the year 2009 which is used as a description of the present situation. In the assessment model differences in the average CO_2 emissions per manufacturer per segment are assumed to be fully attributable to the effect of applying CO_2 reducing technologies from the cost curves and the CO_2 impact of changes in average vehicle mass per manufacturer per segment between 2002 and 2009.

Monitoring of new passenger car sales in the EU has shown that since 2002 CO_2 emissions have declined significantly without noticeable impacts on vehicle price. It is suggested that this development shows that a significant part of the observed reductions may have other origins than the application of technologies that are included in the cost curves that are and have been used for assessing the costs of meeting the targets.

In principle the observed reduction in the type approval CO_2 value of new vehicles between 2002 and 2010 may be considered to be a combination of the following possible contributions:

- Effects of application of identifiable technologies such as those included in the technology table underlying the cost curves developed in Chapter 2;
- CO_2 reduction due to small technical improvements that are not mentioned in technical specifications of vehicles and are not included in the cost curves developed in this project and in the 2006 TNO/IEEP/LAT study[128];
- Effects of optimising the powertrain calibration by improving trade-offs against other parameters;
- The possible utilization of flexibilities in the test procedure.

Identification of the size of all different possible contributions is at present not possible.

To obtain some indication of the possible gap between the CO_2 impact of the identifiable application of technologies from the cost curves and the total observed reductions a limited evaluation has been carried out of comparable vehicle model / variants in different segments in 2002 and 2010. The comparison includes two model variants for each vehicle size class (small / medium / large) for both gasoline and diesel for 2002 and 2010, taken from the list of top 5 vehicle models in the UK for each year.

For the petrol vehicles application of various CO_2 reducing technologies could be identified. For the diesel only start-stop was found to applied in one of the example vehicles, while for all 5 other vehicles the reduction in CO_2 emissions could not be contributed to any technology.

Taking account of available information for these vehicles on applied CO_2-reducing technologies and the reduction percentages assumed for these technologies in the technology table for the 2012-15 timeframe (see TNO/IEEP/LAT 2006 report) as well as the influence of differences in mass between the 2002 and 2010 vehicles[129], the comparison suggests that combined causes not related to the application of these technologies might represent a reduction potential $\delta_{2002\text{-}2010}$ of on average around:

- 11% for petrol vehicles, and
- 15% for diesel vehicles.

[128] Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars. Smokers R., et al., Contract nr. SI2.408212, Final Report, TNO Report, Oct 31, 2006.

[129] Using the formula: $\Delta CO_2/CO_2 = 0.65\ \Delta m/m$ derived in the 2006 TNO/IEEP/LAT study.

These values have been derived from the comparison as follows:

$$\delta_{2002-2010} = 1 - E_{2010} / (E_{2002} \times (1 + 0.65 \times (m_{2010} - m_{2002}) / m_{2002}) \times \prod_{i=1}^{n} (1 - \delta_i))$$

with E_{2002} and E_{2010} resp. m_{2002} and m_{2010} the CO_2 emission and mass of the vehicles in 2002 and 2010, and δ_i the reduction potentials of the identified headline technologies.

Table 134 Comparison of similar vehicle models on petrol in 2002 and 2010.

Petrol		Small		Medium		Large	
		B		C	D	E	H
2002	Manufacturer / Model	Ford Fiesta 1.3	Vauxhall Corsa 1.2	Ford Focus 1.8 16V	BMW 318i	Mercedes Benz E 240	Honda CR-V
	Engine	I4, IDI	I4, IDI	I4, IDI	I4, IDI, VVT+L	V6, IDI, VVT	I4, IDI, VVT+L
	Engine size (cc)	1297	1199	1796	1995	2597	1998
	Engine power (kW)	51	55	85	105	130	110
	Transmission Type	M5	M5	M5	M6	M6	M5
	CO_2 emissions - Combined (g/km)	147	146	181	180	257	216
	CO_2 emissions - corrected for 2002-10 mass change	141	157	190	183	262	226
	Vehicle Kerb Mass (kg)	1107	1010	1195	1395	1570	1468
	Headline technologies						
	VVT				x	x	x
	VVL				x		x
	Power/Weight ratio	21.71	18.36	14.06	13.29	12.08	13.35
2010	Manufacturer	Ford	Vauxhall	Ford	BMW	Mercedes Benz	Honda
	Model	Fiesta 1.25	Corsa 1.2	Focus 1.8 16V	318i	E 200 CGI BlueEfficiency	CR-V 2.0i-VTEC
	Engine	I4, IDI	I4, IDI, VVT	I4, IDI	I4, DI, VVT,	I4, DI, VVT, TC	I4, IDI, VVT+L
	Engine size (cc)	1242	1229	1798	1995	1796	1997
	Engine power (kW)	44	59	92	105	135	110
	Transmission Type	M5	M5	M5	M6	A6	M6
	CO_2 emissions - Combined (g/km)	127	139	167	146	175	192
	Vehicle Kerb Mass (kg)	1041	1130	1288	1435	1615	1569
	Headline technologies						
	VVT		x		x	x	x
	VVL				-		x
	Direct Injection				x	x	
	Medium downsizing					x	
	Start/Stop				x	x	
	Power/Weight ratio	23.66	19.15	14.00	13.67	11.96	14.26
	Δ	2%	1%	0%	0%	0%	1%
	reduction due to applied technologies relative to 2002	0%	3%	0%	10%	25%	0%
	estimate for 2010 value based on applied technologies (g/km)	141	153	190	165	197	226
	difference with realised 2010 value (g/km)	**14**	**14**	**23**	**19**	**22**	**34**
	relative additional reduction to bridge gap between realised and estimated 2010 value	**10%**	**9%**	**12%**	**12%**	**11%**	**15%**

Table 135 Comparison of similar vehicle models on diesel in 2002 and 2010.

Diesel		Small		Medium		Large	
		B		C	D	E	H
2002	Manufacturer	Peugeot	Ford	Ford	VW	Mercedes Benz	Land Rover
	Model	206 HDi éco 70	Fiesta 1.4 TDCi	Focus 1.8 TDCi	Passat 1.9 TDI	E 220 CDI	Freelander Td4
	Engine	I4, DI, VGT	I4, DI, VGT	DI, VGT	I4, DI, VGT	I4, DI, VGT	I4, DI, VGT
	Engine size (cc)	1398	1399	1753	1896	2148	1950
	Engine power (kW)	50	50	66	74	110	82
	Transmission Type	M5	M5	M5	M5	M6	M5
	CO_2 emissions - Combined (g/km)	116	114	143	151	174	205
	CO_2 emissions - corrected for 2002-10 mass change	134	114	142	160	183	210
	Vehicle Kerb Mass (kg)	1049	1145	1267	1381	1610	1645
	Headline technologies						
	VGT	x	x	x	x	x	x
	Power/Weight ratio	20.98	22.90	19.20	18.66	14.64	20.06
2010	Manufacturer	Peugeot	Ford	Ford	VW	Mercedes Benz	Land Rover
	Model	207 HDi FAP 90	Fiesta 1.4 TDCi	Focus 1.6 TDCi	Passat 2.0 TDI	E 220 CDI BlueEfficiency	Freelander 2.2 Td4_e
	Engine	I4, DI, VGT	I4, DI, VGT	I4, DI, VGT	I4, DI, VGT	I4, DI, VGT	I4, DI, VGT, Start/Stop
	Engine size (cc)	1560	1398	1560	1968	2143	2179
	Engine power (kW)	66	50	66	81	125	110
	Transmission Type	M5	M5	M5	M5	M6	M6
	CO_2 emissions - Combined (g/km)	120	110	115	143	139	158
	Vehicle Kerb Mass (kg)	1304	1141	1249	1510	1735	1710
	Headline technologies						
	VGT	x	x	x	x	x	x
	Start/stop						x
	Power/Weight ratio	19.76	22.82	18.92	18.64	13.88	15.55
	Δ	-1%	0%	0%	0%	-1%	-5%
	reduction due to applied technologies relative to 2002	0%	0%	0%	0%	0%	3%
	estimate for 2010 value based on applied technologies (g/km)	134	114	142	160	183	204
	difference with realised 2010 value (g/km)	**14**	**4**	**27**	**17**	**44**	**46**
	relative additional reduction to bridge gap between realised and estimated 2010 value	**11%**	**3%**	**19%**	**11%**	**24%**	**23%**

The reduction potentials used to estimate the possible contribution of identified headline technologies are derived from the 2006 TNO/IEEP/LAT study and are listed in the Table 136 below:

Table 136 Reduction potentials for different headline technologies applied to 2009 petrol and diesel vehicles.

Gasoline

	data from TNO/IEEP/LAT 2006 study used for assessing 2015 target			data from SR1 used in assessment for assessing 2020 target		
	pS	pM	pL	pS	pM	pL
Headline technologies						
VVT	3%	3%	3%	4%	4%	4%
VVL	7%	7%	7%	9%	9%	9%
Direct Injection	10%	10%	10%	9%	9%	10%
Medium downsizing	8.5%	10%	10%	7.0%	8%	9%
Start/Stop	7%	7%	7%	5%	5%	5%

Diesel

	data from TNO/IEEP/LAT 2006 study used for assessing 2015 target			data from SR1 used in assessment for assessing 2020 target		
	pS	pM	pL	pS	pM	pL
Headline technologies						
VGT	-	-	-	-	-	-
Start/stop	3%	3%	3%	4%	4%	4%

Using reduction potentials for 2020 (from this study) rather than the values for 2015 from the 2006 TNO/IEEP/LAT study does not significantly affect the estimates for the part of the observed reduction that may be related to other origins than the application of technologies that are included in the cost curves.

The values found from the above comparison for the possible size of reductions that may not be attributable to technologies included in the SR1 cost curves is actually of the same order or magnitude or in some cases even higher than the average reductions per segment observed between 2002 and 2009 (based on SR1 database) as depicted in Table 137.

Table 137 Comparison of average mass and CO_2 emissions of new vehicles sold in Europe in 2002 and 2009.

	Reference mass					
Segment	pS	pM	pL	dS	dM	dL
Average 2002	956	1286	1697	1046	1395	1815
Average 2009 - weighted by 2002 sales	1045	1358	1833	1149	1489	1888
Difference	9%	5%	7%	9%	6%	4%

	CO2					
Segment	pS	pM	pL	dS	dM	dL
Average 2002	149	189	264	123	157	213
Average 2009 - weighted by 2002 sales	135	170	253	118	149	200
Difference	-9.9%	-11.1%	-4.3%	-4.4%	-5.3%	-6.6%

	CO2					
Segment	pS	pM	pL	dS	dM	dL
Average 2002 corrected for 2002-09 mass increase*	**158**	**196**	**278**	**131**	**164**	**218**
Absolute difference 2002 corrected vs 2009	22	26	25	13	15	19
Relative difference 2002 corrected vs 2009	-14.2%	-13.1%	-8.8%	-9.9%	-9.0%	-8.5%

*) using the formula: $\Delta CO_2/CO_2 = 0.65\ \Delta m/m$

This has led to the decision to apply the following additional reductions for the scenario variant representing the assumption that a given share of the reductions achieved in the 2002-2009 period can not be attributed to application of technologies that are included in the technology tables underlying the cost curves:

- petrol: 10%
- diesel: 9%

It may be assumed that these reductions have not been entirely realized without additional costs. Therefore a small additional cost of around €30 has been assumed in factoring in the above additional reduction potential in the cost curves. The value has also been used as a tuning variable to make sure that not too much non-linearity is introduced into the costs curves around 9% to 10% reduction. The corrections for the 2002-2009 progress have been worked into adapted cost curves in the following manner:

- The basic cost curves are represented by $y = \Sigma a_i x^i$ with i = 1 to n
- Each point on this cost curve can be corrected to account for the additional reduction potential by writing:

  $$y' = y + C$$

  $$x' = 1 - (1 - x)(1 - d)$$

  with C the additional costs and d the relative reduction compared to the 2002 baseline vehicle that is attributed to other causes than application of technologies on the cost curve.

Resulting coefficients for the polynomial cost curves are presented in Table 138.

Table 138 Coefficients of alternative cost curves (scenario variant a) based on alternative accounting for the 2002-2009 progress.

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S				7.145E+05	-7.982E+05	2.473E+05	7.937E+03	-3.277E+03	3.572E+02	64.1%	5895
p,M				1.275E+06	-1.655E+06	7.128E+05	-9.992E+04	6.760E+03	1.358E+01	65.0%	6795
p,L	3.024E+07	-6.709E+07	6.163E+07	-3.015E+07	8.508E+06	-1.473E+06	1.890E+05	-1.212E+04	4.965E+02	65.7%	8290
d,S					2.220E+05	-2.074E+05	7.218E+04	-6.282E+02	5.147E+01	57.2%	4736
d,M					3.222E+05	-3.025E+05	1.034E+05	-3.434E+03	5.665E+01	57.2%	5596
d,L				5.741E+05	-1.245E+05	-2.848E+05	1.578E+05	-1.466E+04	6.230E+02	57.0%	6971

D Evaluation of US EPA data on costs and potentials for CO_2 reducing technologies in cars and assessment of its implications for Service Request #1

D.1 Introduction

Under Service Request #1 (SR1) on “Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars”, which is carried out by a consortium consisting of TNO, AEA, CE Delft, Ricardo, IHS, Ökopol and TML as part of the Framework Contract on Vehicle Emissions, an assessment is carried out of the costs for meeting the 95 g/km target set for passenger cars in 2020. This assessment is based on information on costs and potentials for CO_2 reducing technologies obtained from literature, in-house expertise and data submitted in response to a questionnaire sent out to (associations) of car manufacturers and component suppliers. Evaluation of this information and the subsequent construction of cost curves were carried out in the first half of 2010.

More recently various reports (see Literature section at the end of this Annex) have become available that describe the results of detailed studies carried out in support of the US legislation on light duty vehicle greenhouse gas emission standards, specifically for the 2017-2025 timeframe. This Annex reviews that information and assesses its possible implications for the assessment of the costs for meeting 95 g/km in Europe in 2020.

Work reported in this Annex comprised of the following steps:

- Evaluation of the reports of projects carried out in support of the US legislation;
- Development of methods to adapt costs curves obtained in the US EPA reports in such a way that they can be indicatively applied to the EU situation and compared to the cost curves from SR1;
    - This specifically focuses on a comparison of baseline vehicles and developing ways of translating results that are applicable to 2008 baseline vehicles in the US studies to values that are applicable to 2002 baseline vehicles as used in SR1. In addition also considerations on the different cycles used in the US and the EU are given.
- Based on the above two steps, an evaluation of the possible implications of the EPA data, to the extent that they are currently available, for the work carried out under SR1, specifically focusing on the question of whether these would justify significant adaptations of the cost curves used to evaluate the EU target for 2020;
- Development of proposals for dealing with implications of the above activities in the context of finalizing the report on SR1 and delivering results to the European Commission for use in its Impact Assessment.

With respect to the work presented in this Annex the following notes are relevant:

- Complete overviews of final data sets on costs and reduction potentials of technologies, as used for the US 2017-2025 legislation were not yet available at the time of this review. For the US study Ricardo US has performed vehicle simulations to assess overall reduction potentials of packages of different technical measures. FEV has carried out detailed cost breakdown analyses. Results from both studies, which would provide relevant information for the translation from US to EU situation, are not yet available.
- From EPA studies detailed information on costs and reduction potentials of technologies is only available for petrol cars.

D.2 Comparison of baseline vehicles for the US EPA studies and SR1

Similar to SR1 the studies carried out by EPA specify costs and reduction potentials for individual CO_2 reducing technologies as a starting point for the analysis of the costs of meeting specific reduction targets. For different vehicle classes costs and reduction potentials are specified relative to baseline vehicles. The baseline for the US studies is 2008, while the studies for the EU situation use 2002 as baseline year. The first issue to be addressed in the context of assessing the applicability of US data to the EU situation therefore is the comparison of baseline vehicles used in the EPA and the SR1 study. Main issues are:

- Consistency of segment definition between US EPA studies and 3 segments in model for EU
- Comparability of typical / baseline vehicles within corresponding segments
  - Vehicle mass
  - Engine and transmission technology status
  - Engine size and power in relation to vehicle mass (power-to-weight ratio)
  - Vehicle CO_2 emission
- Implications of possible differences for translation of reduction potential and cost estimates for different technologies to the EU situation.

For information on baseline definitions see [EPA-2010a], section B-1, and [EPA-2010c], page 3-61. The first report relates to the 2017-2025 period, the second to 2012-2016. Both studies appear to work with the same baseline. The [EPA 2010d] memo contains lists of packages of technologies, as well as their reductions and costs, applied to these baseline vehicles. Available documents do not contain full information on the baseline vehicles used for the EPA assessment. Especially information on vehicle mass and CO_2 emissions is missing.

The 2002 baseline vehicles as defined in [TNO-2006] and also used for SR1 are listed in the table below:

Table 139 2002 baseline vehicles as used in SR1 and [TNO 2006] (developed from Polk Marketing Systems data).

	Petrol Small	**Petrol Medium**	**Petrol Large**	**Diese Small**	**Diesel Medium**	**Diesel Large**	**Grand Total**
CO_2 (g/km)	148.7	188.6	264.2	122.8	157.0	212.9	166.6
Vehicle mass (kg)	956	1282	1698	1046	1396	1816	1246
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)	

The two vehicle categories from the EPA assessment that provide useful reference for the EU situation are:

- Sub-compact
  - Has a 1.5 L, 4 cylinder in line engine and a 4 speed automatic transmission
  - In the Ricardo simulations performed in support of the EPA studies the Toyota Yaris is used as example vehicle
    - Mass: 2625 lb (ETW) = 2375 lb (curb weight) = 1077 kg = 1177 kg (EU reference mass)
    - Baseline vehicle CO_2 emission for the US test cycle is 210 g/ mile, i.e. 132 g/km.
- Small car (compact car)

- Has a 2.4 L, 4 cylinder in line engine and a 4 speed automatic transmission
- In the Ricardo simulations the Toyota Camry is used as example vehicle
    - Mass: 3625 lb (ETW) = 3375 lb (curb weight) = 1530 kg = 1630 kg (EU reference mass)
    - Baseline vehicle CO_2 emission for the US test cycle is 261 g/mile, i.e. 163 g/km.

In the SR1 segment definition the Toyota Yaris is in the segment “small”. The engine capacity of the US model, however, is larger than what is typical for this segment in the EU situation. The US Yaris baseline (2008) is 19% heavier than the SR1 “small” baseline average and 8% lighter than the SR1 “medium” baseline average for 2002. Considering also engine size (Yaris: 1.5L, SR1 medium 2002: 1.7L), results from EPA on the Yaris could also be compared with the SR1 segment “medium”.

The Camry is categorized as “large” in the EU situation.

The 4 speed automatic gear box in the US baseline vehicles may be expected to result in some 10% higher fuel consumption than for equivalent vehicles with manual transmission in the EU.

According to the graph below, the ratio of engine power over displacement is rather similar for 2008 US cars and 2002 EU cars, with even somewhat higher average values for US cars. Based on engine state-of-the art the US 2008 reference vehicles may thus be considered equivalent to EU 2002 baseline vehicles.

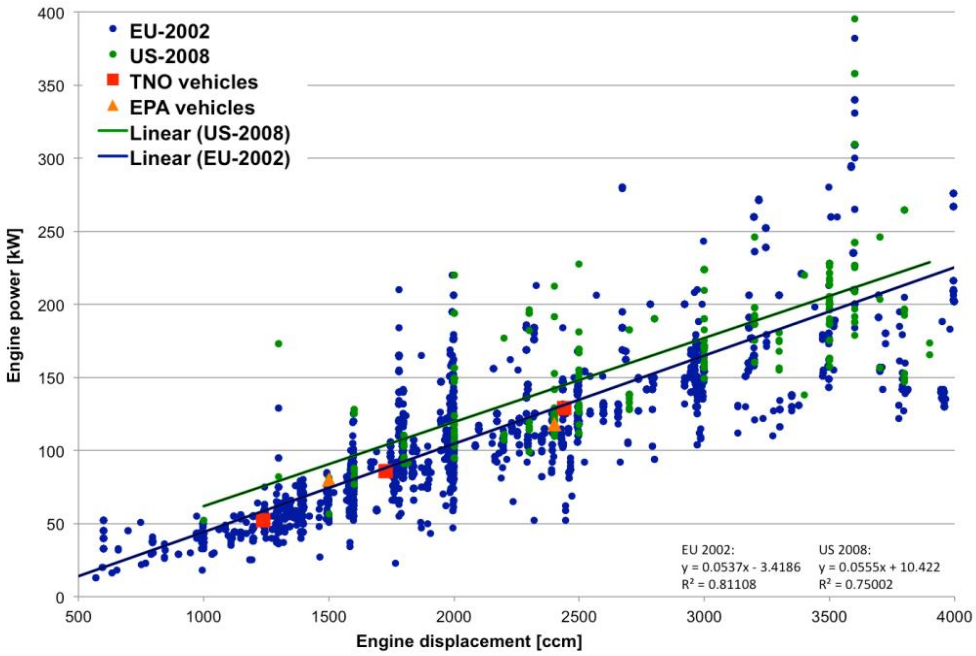


Figure 105 Comparison of engine displacement and engine power for EU 2002 vehicles and US 2008 vehicles.

All of the above seems to indicate that the comparability of baseline vehicles is reasonably good as far as state of engine technology, kW/L and kW/tonne are concerned, and can not explain the possible differences in reduction potentials and costs that may be found in comparing the US data with the data used for the EU in SR1. However:

- It is still unclear what is the impact of these 6 years of technological evolution on the basic engine technology, i.e. how much of the reduction potential of the different technological options could have been captured already in the case of the US 2008 baseline. A 2002 Ford Fiesta 1.25L (typical for the 2002 EU baseline for small vehicles) seems similar to a 2008 Yaris 1.5L on “paper specs” (16V, no turbo, no DI, no VVT) but it was considerably less fuel efficient.
- The remaining issue is the impact of the 4 speed automatic transmission in the baseline on the reduction potential of options. The fact that the 4sp AT leads to lower overall efficiency should not be expected to significantly affect the relative reduction potential of most measures. It does, however, affect the reduction potential of technical measures associated with the transmission.

- In the OMEGA Master set [EPA-2010d] the first reduction step is to replace the 4sp AT by a 6sp DCT (duel clutch transmission).
- Note: In US the 2012 Yaris with 1.5 L engine is available with 5sp MT and 4-speed Electronically Controlled AT with intelligence (ECT-i). Price difference is 725 - 800 US$. Mileage estimates are very close, though: (mpg city / highway / combined) 30/38/33 vs 30/35/32 for 5sp MT and 4sp AT.

D.3 EU and US test cycles

Another issue, to be taken into account is different test cycles in the US and the EU, and the extent to which relative reductions achieved on one would lead to similar reductions on the other.

- The NEDC consists of approx. 25% idling time, which is important when comparing the CO_2 benefits for the hybrid technologies. This is likely to affect the reduction potential of start-stop systems and of various levels of hybridization on the NEDC vs. the US test cycle.
- The US FTP cycle is significantly more aggressive than the NEDC. For vehicles with similar engine capacity this would e.g. significantly affect the potential of engine downsizing.
- Differences in cycle characteristics may also affect impacts of weight reduction and of measures aimed at reducing resistance factors.

In this context it should be noted that the theoretical different maximum benefits for hybrids and other advanced options for US vs. EU cycles depend on having a system that is optimised for the cycle. Detailed differences in hybrids specifications may affect the level of benefits achieved.

D.4 Evaluation of EPA data on costs and reduction potentials of CO_2 reducing technologies applicable to petrol vehicles

The main information sources for this evaluation have been:

- An overview of EPA data for 2012-2016 can be found in [EPA 2010b]
- The "Interim Joint Technical Assessment Report" [EPA-2010a] and the OMEGA Master-set of packages [EPA-2010d] are about the 2017-2025 timeframe.
  - The [EPA 2010a] report provides descriptions of technologies and cost numbers, but no clearly summarized information on reduction potentials.
  - The figures wrt total costs and reduction potentials of packages of options as listed in the OMEGA Master-set of packages [EPA-2010d] can be used to deduce costs and reduction potentials for individual options (by comparing packages that only differ one option). It should be noted that the reduction potentials listed already contain a correction for dis-synergies as calculated by the OMEGA model.

For translating US EPA data to the EU situation in principle two approaches can be followed:

1 A one-by-one comparison of the EPA data for individual technologies with the SR1 data set.

- Followed by inserting the alternative EPA-based data into the SR1 technology data set and calculating new cost curves using the SR1 approach.
- In doing so one needs to make sure that the figures for the options defined in the US data relative to a 2008 baseline can be applied to the EU situation relative to a 2002 baseline. If necessary corrections need to be applied.

2 Drawing cost curves on the basis of the information on packages available from the OMEGA Master-set of packages [EPA-2010d] and comparing these to the cost curves as derived in SR1.

The second method can be considered **top-down**, while the first is a **bottom-up** approach.

Approach 1: One-by-one comparison of the EPA data for individual technologies with the SR1 data set

a) Based on the OMEGA Master-set of packages [EPA-2010d]

A complete overview of the data for individual technologies underlying the assessment for the 2017-2025 was not yet available at the time of this evaluation. Results for packages of different options, however, are reported in [EPA-2010d] on the OMEGA Master-set of packages. By comparing packages that only differ by one option, the figures with respect to total costs and reduction potentials of packages of options as listed in [EPA-2010d] can be used to deduce costs and reduction potentials for individual options. This yields the following rough comparison:

Table 140 Comparison of data derived from [EPA-2010d] and data from SR1 for medium size petrol cars.

	EPA			SR1	
technology	**Δcosts 2020 [€]**	**ΔCO2 from 2008 base [%]**	**technology**	**Δcosts 2020 [€]**	**ΔCO2 from 2002 base [%]**
DCP	53	2.9	cam phasing	80	4
DVVL	90	3.0	variable valve actuation and lift	280	10
GDI + TDS on I3 with HEV	458	9.9	direct injection, stratified charge	500	9
I4 > I3 + GDI + TDS	353	11.7			
EGR on GDI + TDS	358	5.4	EGR	0	0
SS	227	2.1	start-stop	200	5
HEV (incl. downsizing)	1809	33.5	full hybrid	2750	25
3% weight reduction	5	1.95	mild weight reduction	160	2
0 > 10% weight reduction	23	6.7	medium weight reduction	400	6
0 > 15% weight reduction	67	10.1	strong weight reduction	1000	12
0 > 20% weight reduction	161	13.5			
0 > 25% weight reduction	309	16.8			
0 > 30% weight reduction	589	20.2			

Note: The figures for the 3% weight reduction can not be derived from the OMEGA Master set, as this option is always combined with DCT. The values indicated here have been assumed to be able to translate values for the step from 3% to x% weight reduction to the complete 0% to x% reduction.

The following observations can be made:

- In comparing reduction percentages it should be noted that the figures from [EPA-2010d] are corrected for dis-synergies[130], while the SR1 figures are not. For transfer of the EPA data into the SR1 methodology an increase in reduction potential would thus be justified for some (powertrain related) options.
- The DCT has not been included in the comparison as it interferes with the conversion of the US to the EU baseline.
- The most significant differences relate to the costs and reduction potential of full hybridization and of weight reduction.
- EGR is excluded as a separate technology in the EU data set but is considered a cost effective option on its own in the US EPA assessment.
- The level of disaggregation of technological options is less in the EPA approach than in the TNO approach used for the EU. In the EPA approach some options are already a package of measures.

The EGR technology for petrol cars as referenced in the EPA study is part of a technology package known as “EGR Boost” – this is one option to achieve strong downsizing. The EGR on its own is not the primary source of CO_2 benefit (instead it’s an enabler technology). In the cost and reduction data as listed in the technology tables of SR1 EGR is assumed to be included in downsizing and should **not** be added as a separate technology.

[130] Dis-synergies is a term used for the issue that different technologies may tackle the same energy loss factors (e.g. direct injection, down-sizing and hybridization which all either improve efficiency of part load operation or reduce the extent to which the engine is operated in part load), so that their reduction potentials can not be simply added when two or more of these technologies are combined into a package.

- As an individual technology the theoretical role of ("external") EGR in improving efficiency slightly by pumping loss reduction has been overtaken by other technologies (e.g. VVT) having more attractive cost trade-offs as well as other benefits, and is not expected to be seen in the market as a stand-alone CO_2 reduction technology. For this reason it was not included in the list of headline technologies for SR1. There is a role for EGR in future gasoline engines in combination with other technologies. However, the EGR system should be seen as an enabler rather than actually reducing CO_2 directly. Depending on the particular technical solution EGR can be one of the possible enablers for stratified charge DI (to help noxious emissions control) or strong downsizing (as part of the "EGR Boost" concept to achieve this – as detailed in EPA study).
- The costs for EGR in combination with these technologies are already implicitly considered in the figures used for SR1, as EGR is one of the options for the required enabling technologies. Differing detail technical solutions will vary slightly in their cost/benefit, but since the methodology used for SR1 does not allow specific technology combinations to be considered, these subtleties cannot be captured. So it must be seen that the technology characterisation is somewhat generic, but the cost/benefit estimates compiled are nonetheless generally valid.

EGR can be assumed to have been fitted to all EU diesel passenger cars since 2002 and including the baseline. Since it has been required to meet emissions legislation over the whole period, it can't really be treated as an "option" of any kind, and in any case it does not in itself directly reduce CO_2 emissions. It is therefore suggested that improvements are attributed to general progress over the period.

- The use of EGR is expected to continue for the foreseeable future. Tuning fuel consumption by optimising the trade-offs between air system losses, combustion efficiency and noxious emissions is an integral part of diesel engine development. Future engines are likely to make further progress in improving CO_2 emissions in this way, including by exploring new opportunities that result from changes in emissions control technology. Examples of this are NO_x aftertreatment (whether by means of LNT or SCR) and variations in EGR circuit architecture (such as "long route" EGR) that can be designed to give improved CO_2 emissions, at the expense of higher engine-out NO_x but whilst still meeting tailpipe emissions limits.
- In SR1 these technologies have not been categorised as CO_2-reduction devices, since they are required anyway to meet noxious emissions legislation. There are many ways in which these systems can be designed to reduce CO_2, but such approaches do not necessarily require specific "bolt-on" hardware and levels of CO_2 benefit are likely to be highly application-specific (outcome of trade-off between several design parameters). Thus no specific technologies, costs or benefit levels were included in the SR1 analysis.

The possible degree of downsizing, the enabling technology required and the potential benefits all depend strongly on the base engine technology. Direct US-EU comparisons (including those of hybridisation benefits) may not be valid.

b) Based on one-by-one transfer of data for individual technologies from different EPA studies

A one-by-one comparison of the EPA data for individual technologies with the SR1 numbers could in principle be carried out on the basis of information provided by the available EPA studies for the 2012-16 timeframe and the incomplete information available for the 2017-25 timeframe. From various reports it is clear that data for the 2012-16 timeframe have been adapted to derive estimates for 2017-25. A one-by-one transfer of data for the 2017-25 timeframe to the EU situation, however, is not possible as the complete set of final numbers for 2017-25 was not yet published at the time of this comparison. Instead a combination of available data for 2012-16 and for 2017-25 could be used. Data for 2012-16 could be translated to the 2017-25 timeframe by applying assumptions on cost reductions (learning effects) and technology improvements, but this would be rather speculative. In addition this analysis would need to be combined with expert judgment on aspects for which assumptions need to be made in order to allow translation of EPA data to the EU situation.

Based on discussions between TNO and Ricardo as well as internal discussions between Ricardo UK (involved in SR1) and Ricardo US (involved in simulation work for EPA) is was decided that on the basis of currently available data and within the scope, budget and timeframe of the SR1 project a direct technology-by-technology (or bottom-up) translation of EPA results to the EU situation can not be carried out in a reliable and meaningful way. This decision has been based on the following considerations:

- The budget of the US studies was around an order of magnitude higher than that of the EC work, so limitations in the scope and accuracy of the latter vs. the former are to be expected. EPA studies were supported by state-of-the-art powertrain simulations, carried out by Ricardo, and detailed technology cost breakdown analysis, carried out by FEV. Both studies are tailored to the US situation.
- Any comparison between the original EPA work and SR1 risks significant errors due to extensive and fundamental differences in baseline vehicles, test cycles, and details of headline technology specifications. A robust comparison is only possible on the basis of detailed consideration of the assumptions.
- It is highly recommended that any serious analysis of alignment between the studies is performed on the basis of EU-specific simulations of packages and technology cost breakdowns, similar to work done by Ricardo and FEV in support of the US EPA studies.

Approach 2: Cost curves based on the OMEGA Master-set

Although not graphically displayed the set of most cost-effective packages of options for increasing reduction levels, as given by the OMEGA Master set presented in [EPA-2010d], actually constitute cost curves. Through application of modifications to correct for the difference in baseline, these cost curves can be translated into indicative cost curves for the EU situation that can be compared to the cost curves constructed in SR1. The advantage of such a top-down approach is that all technology definitions and corresponding reduction percentages are combined in an internally consistent manner in the OMEGA model, which may not be the case in a one-to-one transfer of data for individual technologies to the SR1 methodology. The disadvantage is that data for individual technologies are not corrected to reflect differences e.g. related to the test cycle.

As an example the translation has been carried out for the vehicle category sub-compact. The baseline vehicle for that segment has a 1.5 L, 4 cylinder in line engine and a 4 speed automatic transmission. The packages and their reduction potentials and costs are as given in the table below.

Note that the OMEGA model takes dis-synergies into account when it calculates the total reduction potential of a package of technical options. Cost curves based on this dataset therefore do not and should not be corrected for a safety margin anymore (see SR1 methodology as explained in Chapter 2).

Table 141 Cost and reduction potentials of packages of measures from the OMEGA Master set [EPA-2010d] for sub-compact petrol cars.

Vehicle Class	Technology Package #	Mass Rdxn	Engine	Transmission	System Voltage	2020 Cost	2025 Cost	CO2 Rdxn from 2008 base
Subcompact	**100**	**0%**	**1.5L 4V DOHC I4**	**4sp AT**	**12V**			
Subcompact	101	3%	4V DOHC I4+ATT	6sp DCT-dry	12V	$181	$172	21.0%
Subcompact	102	3%	4V DOHC I4+ATT+DCP	6sp DCT-dry	12V	$251	$236	23.3%
Subcompact	103	3%	4V DOHC I4+ATT+DCP+DVVL	6sp DCT-dry	12V	$371	$344	25.6%
Subcompact	104	3%	4V DOHC I3+ATT+DCP+GDI+TDS	6sp DCT-dry	12V	$722	$662	32.3%
Subcompact	105	10%	4V DOHC I3+ATT+DCP+GDI+TDS	6sp DCT-dry	12V	$746	$683	35.6%
Subcompact	106	15%	4V DOHC I3+ATT+DCP+GDI+TDS	6sp DCT-dry	12V	$805	$737	37.9%
Subcompact	107	15%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS	6sp DCT-dry	12V	$925	$845	39.0%
Subcompact	108	15%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-dry	12V S-S	$1,227	$1,105	40.2%
Subcompact	109	15%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-dry	12V	$1,402	$1,237	42.2%
Subcompact	110	15%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-dry	12V S-S	$1,705	$1,497	43.5%
Subcompact	111	20%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-dry	12V S-S	$1,352	$1,218	42.5%
Subcompact	112	25%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-dry	12V S-S	$1,551	$1,397	44.7%
Subcompact	113	30%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS	6sp DCT-dry	12V S-S	$1,923	$1,734	46.9%
Subcompact	114	20%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-dry	12V	$1,527	$1,350	44.4%
Subcompact	115	25%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-dry	12V	$1,725	$1,529	46.6%
Subcompact	116	30%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR	6sp DCT-dry	12V	$2,098	$1,866	48.8%
Subcompact	117	20%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-dry	12V S-S	$1,829	$1,610	45.6%
Subcompact	118	25%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-dry	12V S-S	$2,028	$1,789	47.7%
Subcompact	119	30%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+SS+EGR	6sp DCT-dry	12V S-S	$2,401	$2,126	49.8%
Subcompact	120	15%	4V DOHC I3+ATT+DCP+DS+HEV	6sp DCT-dry	HEV	$2,663	$2,342	49.0%
Subcompact	121	20%	4V DOHC I3+ATT+DCP+DS+HEV	6sp DCT-dry	HEV	$2,770	$2,439	50.6%
Subcompact	122	25%	4V DOHC I3+ATT+DCP+DS+HEV	6sp DCT-dry	HEV	$2,969	$2,618	52.3%
Subcompact	123	30%	4V DOHC I3+ATT+DCP+DS+HEV	6sp DCT-dry	HEV	$3,341	$2,955	54.0%
Subcompact	124	15%	4V DOHC I3+ATT+DCP+DVVL+DS+HEV	6sp DCT-dry	HEV	$2,783	$2,451	50.0%
Subcompact	125	20%	4V DOHC I3+ATT+DCP+DVVL+DS+HEV	6sp DCT-dry	HEV	$2,890	$2,547	51.6%
Subcompact	126	25%	4V DOHC I3+ATT+DCP+DVVL+DS+HEV	6sp DCT-dry	HEV	$3,089	$2,727	53.2%
Subcompact	127	30%	4V DOHC I3+ATT+DCP+DVVL+DS+HEV	6sp DCT-dry	HEV	$3,461	$3,064	54.9%
Subcompact	128	15%	4V DOHC I3+ATT+DCP+GDI+TDS+HEV	6sp DCT-dry	HEV	$3,274	$2,895	54.0%
Subcompact	129	20%	4V DOHC I3+ATT+DCP+GDI+TDS+HEV	6sp DCT-dry	HEV	$3,381	$2,991	55.5%
Subcompact	130	25%	4V DOHC I3+ATT+DCP+GDI+TDS+HEV	6sp DCT-dry	HEV	$3,580	$3,171	57.0%
Subcompact	131	30%	4V DOHC I3+ATT+DCP+GDI+TDS+HEV	6sp DCT-dry	HEV	$3,953	$3,508	58.5%
Subcompact	132	15%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-dry	HEV	$3,872	$3,395	56.7%
Subcompact	133	20%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-dry	HEV	$3,979	$3,492	58.1%
Subcompact	134	25%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-dry	HEV	$4,177	$3,671	59.5%
Subcompact	135	30%	4V DOHC I3+ATT+DCP+DVVL+GDI+TDS+EGR+HEV	6sp DCT-dry	HEV	$4,550	$4,008	61.0%

For comparison with the data used for assessing the costs for meeting the EU target of 95 g/km in 2020 it is decided that the EPA data for 2020 are the most appropriate. The EPA data for 2025 contain fairly significant cost reductions for technologies that in the EU situation for 2020 are not expected to be used on a large scale to meet the target.

For translating costs values in US$ need to be converted to values in €, for which an exchange rate of 0.75 has been used.

Understanding the composition of step 1 in the OMEGA Master set

A striking issue in the above table is the 21% reduction that is attributed to package 101 in which a 3% weight reduction is applied (yielding some 2% reduction in CO_2 emissions) in combination with a package of “anytime technologies” (ATT) and in which the 4sp AT is replaced by a 6sp DCT. On what is included in the ATT the following is information is available:

- According to [EPA-2010a] “Our “anytime technologies” (ATT) […] consist of low friction lubes, engine friction reduction, aggressive shift logic (automatic transmission only), early torque converter lock-up (automatic transmission only), and low rolling resistance tires.”
- Direct information obtained from EPA, however, has confirmed that some anytime technologies are not mentioned in this definition but were included in the ATT-technology packages. These are: a) improved aerodynamics, b) improved accessories, c) electric power steering.

The tables below analyse whether the above is consistent with the available data on the overall reduction potential and costs of the ATT package and of the package 101. Data on individual anytime technologies are not yet available from the reports covering the 2017-25 period and thus were derived from reports covering the 2012-2016 timeframe.

Table 142 Bottom-up estimate of the total cost and reduction potentials of a package of anytime technologies for sub-compact petrol cars.

Anytime technologies	EPA 2012-16	
	[%]	[US$]
low friction lubes	0.5	3
engine friction reduction	1-3	50
aggressive shift logic (automatic transmission only)	1-2	28
early torque converter lock-up (automatic transmission only)	0.5	25
low rolling resistance tires	1-2	6
aero 1+2	*4*	*168*
power steering	*1.5*	*94*
efficient accessories	*1-2*	*76*
combination	**10.1-14.5**	**450**

The upper table constructs a bottom-up estimates the combined reduction potential and costs of a package containing all mentioned ATT options. The table below follows a top-down approach by deriving estimates for the reduction potential and costs for the combined ATT options by decomposing the total reduction potential and costs of package 101 into known contributions from weight reduction and application of a 6sp DCT and remaining reduction potential and costs which are to be attributed to ATT. This can be done with the following formula:

$$\delta_{ATT} = 1 - (1 - \delta_{package\ 101}) / ((1 - \delta_{4sp\ AT > 6sp\ DCT}) \times (1 - \delta_{3\%\ weight\ red.}))$$

Table 143 Top down estimate for the reduction potential and costs for the combined ATT options by decomposing the total reduction potential and costs of package 101 into known contributions from weight reduction and application of a 6sp DCT.

1st package of OMEGA Master set	EPA 2017-25	
	[%]	[US$]
package 101: 3% weight red. + ATT + 4sp AT > 6sp DCT	21	181
3% weight reduction	2	5
4sp AT > 6sp DCT	8-13	-170
ATT - low eff. improvement of DCT (8%)	12.4	346
ATT - high eff. improvement of DCT(13%)	7.3	346

The match between the two tables is not exact but sufficiently good to conclude that most or all of the technologies in the upper table may be assumed to be included in the ATT that are part of package 101.

Baseline conversion

In order to be able to compare the US cost curves to the ones derived in SR1 for the European situation at least a conversion is needed to translate the US baseline to the EU baseline. This comprises two steps:

- Transmissions: A first step relates to the applied transmission type and is a conversion of the US baseline with the 4sp AT to the EU baseline situation in which small and medium sized vehicles are characterised by a 5sp MT. For this translation two different options could be considered depending on assumptions with respect to the role of the DCT in the cost curve:

    a. In this approach the 4sp AT is thought to be replaced by a 5sp MT before application of the US cost curve. This step involves a cost reduction as well as an efficiency improvement. In this approach it is assumed that the DCT may still offer a benefit relative to the 5sp MT on the US cycle.

  - The reduction potential of the first step in the OMEGA Master set is corrected for the efficiency improvement of the 4sp AT > 5sp MT conversion so that the contribution of the DCT to this first step is reduced to its reduction potential relative to a 5sp MT rather than a 4sp AT.
  - The cost of the first package are corrected by adding the cost reduction achieved by replacing the 4sp AT by a 5sp MT to the total costs of the package;

b. An alternative approach is that one assumes that by application of the 6sp DCT the efficiency of the US baseline is brought to the level of the EU baseline with the 5sp MT. The DCT is assumed not to offer a benefit relative to the 5sp MT.
  - The reduction potential of the first step of the OMEGA Master set should then be corrected by excluding the reduction potential claimed in the EPA literature for replacing a 4sp AT by a 6sp DCT;
  - The costs of the first package are corrected by subtracting the cost differential associated with replacing a 4sp AT by a 6sp DCT.

Method b is considered the correct approach. The mechanical efficiency of the DCT is largely comparable to that of a manual transmission. The potential that is attributed to DCT compared to 5sp MT in SR1 is then solely related to the fact that the DCT allows the use of optimal shifting points on the NEDC rather than the prescribed ones for manual transmissions. This advantage will **not** have been included in the EPA estimate.
  - In fact, when looking at it in this way the DCT potential wrt shifting points could even be added to the EPA cost curve for the baseline translation.
  - At the same time is should be noted that the above is a 1st order approximation. Depending on the type of DCT employed (wet/dry clutch, actuation type), it is not generally valid to state that DCT and MT have similar mechanical efficiency (especially taking into account energy requirements for shifting). Even the best DCT efficiency tends to be slightly worse than that of a manual transmission.

- <u>Improvements in baseline vehicles between 2002 and 2008:</u> For both above methods another issue in the translation of baselines is the difference in CO_2 emissions of the 2008 US baseline and the 2002 EU baseline. The Yaris with 1.5L engine and 4sp AT used as example for US sub-compact baseline vehicles has a CO_2 emission of 132 g/km. This is significantly less than equivalent vehicles would have emitted in 2002. The difference needs to be attributed to improvements that are not part of the EPA cost curve. Due to the equivalence in considered technologies, such reductions are also not part of the EU cost curves.
  - The EU 2002 average small petrol vehicle has a CO_2 emission of 149 g/km. According to the 2010 database used in SR1 this has reduced to 135 g/km in 2010.

Table 144 Development of emissions from petrol cars between 2002 and 2008/9.

	US Yaris	S,p	M,p	L,p	EU avg petrol	EU avg all fuels
2002 Monitoring Mechanism					173.5	167.2
2002 database for [TNO 2006]		148.6	188.8	263.9		
2008 US baseline	132					
2008 Monitoring Mechanism					156.6	153.5
2009 database for SR1*		135.3	170.0	253.0		
Relative reduction 2002-08/9		9.0%	10.0%	4.1%	9.7%	8.2%

*) Sales-weighted per segment using 2002 sales data per manufacturer to exclude impact of shifts inside segment or between manufacturers on avg. CO2

  - A difference of around 9% seems justified to further correct 2008 US baseline vehicles to 2002. Both in the EU and the US this reduction may be largely attributable to combinations of small technical improvements. The costs of these improvements will not be zero, but will also not be significant. In the calculations below a value of €100 is assumed.

- For the EU there are concerns that after 2008 a significant part of the observed reductions may be attributable to utilization of flexibilities in the test procedure rather than actual application of technical improvements.
- Here it should be mentioned that this issue, i.e. which part of the observed reductions over the 2002-2009 period are to be attributed to application of technologies that are included in the cost curves, should be dealt with also in the absence of EPA data and the question of how to translate these to the EU situation. This subject is discussed in Annex C.

Baseline conversion using method b: US vehicle with 6sp DCT considered equivalent to EU vehicle with 5sp MT

Table 145 Translation of cost curves based on [EPA-2010d] for sub-compact petrol cars to the EU 2002 baseline by accounting for differences related to the baseline vehicles.

	EPA OMEGA 2020 data corrected for baseline difference		EPA OMEGA - 2020 data relative to US 2008 baseline			EPA OMEGA 2020 data corrected for baseline difference		EPA OMEGA - 2020 data relative to US 2008 baseline		
	red.' [%]	**cost ' [€]**	red. [%]	cost [€]	cost [USD]	**red.' [%]**	**cost ' [€]**	red. [%]	cost [€]	cost [USD]
US baseline 4AT	0.0	0	0	0	0	0	0	0.0	0	0
4 AT > 6 DCT	0.0	0	10	-128	-170	0	0	10.0	-128	-170
EU baseline 5 MT	0.0	0				0.0	0			
2002-2008 progress	0.0	0				9.0	100			
6 DCT +ATT + 3% weight red	**12.2**	**263**	21.0	136	181	**20.1**	**363**	21.0	136	181
	14.8	**316**	23.3	188	251	**22.4**	**416**	23.3	188	251
	17.3	**406**	25.6	278	371	**24.8**	**506**	25.6	278	371
	24.8	**669**	32.3	542	722	**31.5**	**769**	32.3	542	722
	28.4	**687**	35.6	560	746	**34.9**	**787**	35.6	560	746
	31.0	**731**	37.9	604	805	**37.2**	**831**	37.9	604	805
	32.2	**821**	39.0	694	925	**38.3**	**921**	39.0	694	925
	33.6	**1048**	40.2	920	1227	**39.5**	**1148**	40.2	920	1227
	35.8	**1179**	42.2	1052	1402	**41.6**	**1279**	42.2	1052	1402
	37.2	**1406**	43.5	1279	1705	**42.9**	**1506**	43.5	1279	1705
	36.1	**1142**	42.5	1014	1352	**41.9**	**1242**	42.5	1014	1352
	38.6	**1291**	44.7	1163	1551	**44.1**	**1391**	44.7	1163	1551
	41.0	**1570**	46.9	1442	1923	**46.3**	**1670**	46.9	1442	1923
	38.2	**1273**	44.4	1145	1527	**43.8**	**1373**	44.4	1145	1527
	40.7	**1421**	46.6	1294	1725	**46.0**	**1521**	46.6	1294	1725
	43.1	**1701**	48.8	1574	2098	**48.2**	**1801**	48.8	1574	2098
	39.6	**1499**	45.6	1372	1829	**45.0**	**1599**	45.6	1372	1829
	41.9	**1649**	47.7	1521	2028	**47.1**	**1749**	47.7	1521	2028
	44.2	**1928**	49.8	1801	2401	**49.2**	**2028**	49.8	1801	2401
	43.3	**2125**	49.0	1997	2663	**48.4**	**2225**	49.0	1997	2663
	45.1	**2205**	50.6	2078	2770	**50.1**	**2305**	50.6	2078	2770
	47.0	**2354**	52.3	2227	2969	**51.8**	**2454**	52.3	2227	2969
	48.9	**2633**	54.0	2506	3341	**53.5**	**2733**	54.0	2506	3341
	44.4	**2215**	50.0	2087	2783	**49.4**	**2315**	50.0	2087	2783
	46.2	**2295**	51.6	2168	2890	**51.1**	**2395**	51.6	2168	2890
	48.0	**2444**	53.2	2317	3089	**52.7**	**2544**	53.2	2317	3089
	49.9	**2723**	54.9	2596	3461	**54.4**	**2823**	54.9	2596	3461
	48.9	**2583**	54.0	2456	3274	**53.5**	**2683**	54.0	2456	3274
	50.6	**2663**	55.5	2536	3381	**55.0**	**2763**	55.5	2536	3381
	52.2	**2813**	57.0	2685	3580	**56.5**	**2913**	57.0	2685	3580
	53.9	**3092**	58.5	2965	3953	**58.0**	**3192**	58.5	2965	3953
	51.9	**3032**	56.7	2904	3872	**56.2**	**3132**	56.7	2904	3872
	53.4	**3112**	58.1	2984	3979	**57.6**	**3212**	58.1	2984	3979
	55.0	**3260**	59.5	3133	4177	**59.1**	**3360**	59.5	3133	4177
	56.7	**3540**	61.0	3413	4550	**60.6**	**3640**	61.0	3413	4550

For the table above, which translates the OMEGA Master set for sub-compact class vehicles to a curve that can be indicatively compared to the EU costs curve, the following assumptions have been made:

- A 6sp DCT is €101 ($170) cheaper than a 4sp AT (based on [EPA-2010a]);
- The 6sp DCT is assumed 10% more efficient than 4sp AT (median of 8 – 13% range indicated in [EPA-2010a]. If we assume that the DCT brings the US baseline at the efficiency

level of the EU vehicle with 5sp MT, the reduction potential of the step from 4sp AT to 6sp DCT should be equal to the difference between 4sp AT and 5sp MT;
- The right hand side of the table presents results in which also a correction is applied for the 9% reduction that is assumed to have occurred between 2002 and 2008 and that should not be attributed to technologies included in the cost curve.

If the step accounting for progress in the 2002-08 period is excluded, one finds that the translated EPA curves more or less coincide with the cost curves for small and medium size petrol cars based on the SR1 assessment in the region of the cost reductions needed by different manufacturers to reach their specific 2020 targets (50 – 55% relative to 2002, see Annex I).

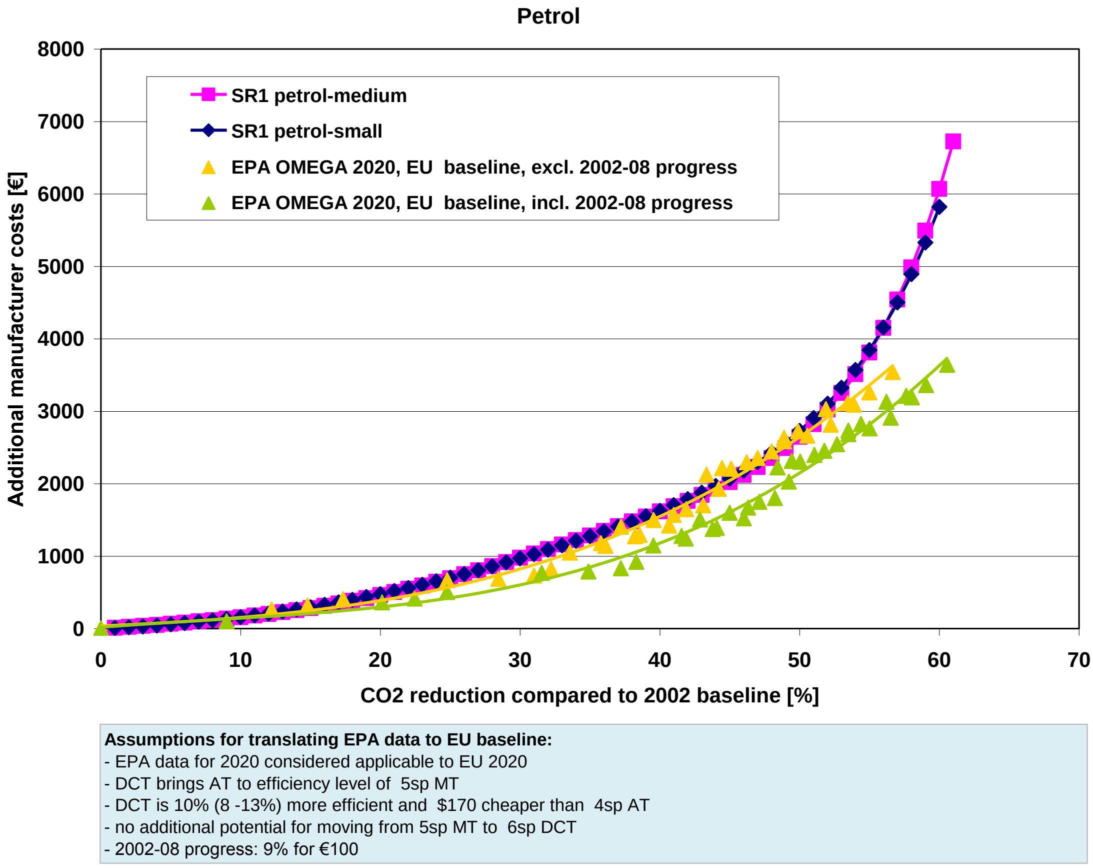


Figure 106 Comparison of cost curves from SR1 with indicative cost curves derived [EPA-2010d] for sub-compact petrol cars by accounting for differences related to the baseline vehicles

Including an 8% reduction at a cost of €100 for the progress in the 2002-08 period shifts the cost curve to a level that is significantly below the SR1 cost curves for the EU situation.

D.5 Considerations on possible further adjustments to make the EPA data and cost curves applicable to the EU situation

In the above graph the cost curve from the OMEGA Master set is translated to the EU situation by correcting for difference in the baseline. In first order this correction affects only the first package in the OMEGA Master set. Overall reduction percentages of other packages relative to the first package are assumed to remain unchanged.

However, as also noted for the bottom-up approach the effectiveness of various technologies may be different on the NEDC and the US test cycles. If the reduction potential for some options (e.g. start-stop and hybrid) would be higher on the NEDC than on the combined US cycle, a translation of US data to the EU situation would be equivalent to stretching the cost curve based on the OMEGA Master-set somewhat further horizontally. The same could be true for the additional potential offered by DCTs in the EU situation due to fact that it allows the use of optimal shifting points rather than the prescribed ones.

However, based on the same motivation that was given in relation to the bottom-up translation of figures for individual technologies from the US to the EU situation, it is at present not considered appropriate to apply further adjustments related to differences in effectiveness on different cycles. The currently available reports provide insufficient information on the reasonings that underly the potential estimates for individual technologies as well as package as option to allow a meaningful evaluation of such differences.

D.6 Conclusions

- The EC and EPA studies have performed complex analyses using different methodologies, for different test cycles and vehicle baselines, and using sets of future technologies that differ in detail in their assumptions and specifications. The budget of the US studies was around an order of magnitude higher than that of the EC work, so limitations in the scope and accuracy of the latter vs. the former are to be expected.
- Any comparison between the original EPA (US cycle) work and SR1 risks significant errors due to extensive and fundamental differences in baseline vehicles, test cycles, and details of headline technology specifications. A robust comparison is only possible on the basis of detailed consideration of the assumptions. It is highly recommended that any serious analysis of alignment between the studies is performed on the basis of EU-specific simulations of packages and technology cost breakdowns, similar to work done by Ricardo and FEV in support of the US EPA studies.
- For many technological options US-EPA data do seem to indicate significantly lower costs and higher reduction potentials than the figures used in SR1.
- The level of disaggregation of technologies in the EPA approach seems to be less than in the SR1 approach. Certain small innovations seem to be implicitly assumed as being applied in combination with more major innovations. Definitions of options in the US approach may therefore not be consistent with the definitions used in the EU approach. In translating results from EPA to the SR1 methodology in a **bottom-up approach**, i.e. technology by technology, this may lead to some level of double counting. Furthermore this bottom-up approach requires assumptions in translating data on individual options which are difficult to substantiate but do give room to some level of overestimation of e.g. cost reductions.
- Based on currently available information it is difficult to judge to what extent reduction potentials of technologies are different for the US test cycles and the NEDC. At this stage a straightforward use of EPA reduction potentials in a bottom-up calculation for the EU situation is considered not appropriate. Although in the end a bottom-up translation of information from the US to the EU case would be preferable, especially also in the light of assessing post 2020 targets, it is at this point in time not possible. The amount of assumptions needed to make the translation would make the exercise too arbitrary and would undermine the credibility of the result. As soon as more evidence becomes available from the EPA the bottom-up approach could be pursued further.
- A **top-down approach**, using resulting data on costs and reduction potentials of packages of measures as reported in the OMEGA Master-set [EPA-2010d] seems to provide a more credible approach for direct comparison, as in the OMEGA model the combined potentials are based on mutually consistent definitions. Also the OMEGA model takes account of possible dis-synergies in a fairly sophisticated way. In order to be able to apply cost curves derived from the OMEGA model to the EU situation minimally a translation of baselines is necessary which involves a correction for different transmission types and possibly a shift associated with reductions achieved in the 2002-2008 period through small technological improvements not included in the cost curves.

- When only corrected for the difference in transmissions used in the US and EU baseline vehicles (4sp AT > 5sp MT), the cost curves that result from [EPA-2010d] appear to be close to the SR1 cost curves. When also corrected for assumed reductions achieved in the 2002-2008 period, the cost curves derived from [EPA-2010d] predict lower costs for the same reduction than the SR1 cost curves.
- EPA data are available both for 2020 and 2025. The main difference between the two is the amount of cost reduction assumed for more advanced reduction options such as hybrid powertrains, where there widespread application is only expected to happen after 2020. As widespread application of hybrids is also not necessary to meet the EU target for 2020 (see e.g. graph in Annex I), the EPA 2020 data are considered most appropriate for translation to the EU situation.
- Specifically in the area around 50-552% reduction, which is the level of reduction in CO_2 emissions of petrol, required for manufacturers to meet the European 95 g/km target for 2020, the cost curves based on the OMEGA model appear to be very close to the cost curves from SR1. Using the EPA-based cost curves for the cost assessment for the EU target of 95 g/km is expected to result in costs that are at maximum €500 lower than the estimates based on the cost curves from SR1.
- For higher reduction levels a strong deviation can be observed between the TNO and EPA-based cost curves, with the EPA-based curves showing similar overall reduction potential but at significantly lower costs. The latter can be attributed by the strongly differing cost estimates for full hybrid powertrains and strong weight reduction in the US and EU assessment. Especially for assessment of post-2020 targets, therefore an in-depth assessment of the EPA results and application of these to the bottom-up approach as used in the SR1 assessment would be justified. For this more information on the final EPA results is necessary than is currently available.
- There may be reasons to assume that the reduction potential for some options (e.g. start-stop and hybrid) is higher on the NEDC than on the combined US cycle. In the translation of EPA cost curves to the EU situation this would shift the EPA-based cost curves further to the right leading to even lower costs for meeting the 2020 target. However, a closer look at the technologies involved and how they perform on the US and EU cycles is necessary to decide whether such further correction would be justified.
- Concluding, the evaluation of available results from the EPA studies in support of the US CO_2 target for passenger cars does provide strong indications that the costs for meeting the European 95 g/km target for 2020 could be lower than the estimates based on data collected in the European study (SR1).
- For the moment it is proposed to deal with this issue in SR1 by means of a scenario variant for the cost assessment. This variant should be based on a modified technology table, using data on cost and reduction potential from the EPA studies specifically for full hybrids and the various levels of weight reduction.

The latter is further worked out in Annex E.

D.7 References

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[EPA-2010a] US Environmental Protection Agency, National Highway Traffic Safety Administration, California Air Resources Board “Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025”, Interim Joint Technical Assessment Report, Washington DC, September 2010

[EPA-2010b] US Environmental Protection Agency, National Highway Traffic Safety Administration, “Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards –

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E Alternative cost curves (scenarios b and c) based on alternative technology data for the purpose of an indicative assessment of possible implications of EPA data for the EU situation

E.1 Introduction

The evaluation of available results from the EPA studies in support of the US CO_2 target for the 2017-2025 period for passenger cars, as presented in Annex D, provides indications that the costs for meeting the European 95 g/km target for 2020 could be lower than the estimates based on data collected in SR1. The most striking differences are found for the costs of full hybridization and for various levels of weight reduction.

At this point in time inclusion of the EPA data into the European assessment is not possible due to lack of background information. Any comparison between the original EPA (US cycle) work and SR1 risks significant errors due to extensive and fundamental differences in baseline vehicles, test cycles, and details of headline technology specifications. A robust comparison is only possible on the basis of more detailed consideration of the assumptions. It is highly recommended that a serious analysis of alignment between the studies is performed before data from EPA are taken on board in the assessment for the European targets.

E.2 Scenario definition

Scenario b) Alternative cost curves based on alternative technology data for the indicative assessment of possible implications of EPA-data for the cost for meeting 95 g/km in Europe

To get an indication of the possible implications of EPA data for the European situation, alternative cost curves have been constructed on the basis of a technology table in which the figures for full hybridization and various levels of weight reduction have been adapted to match information on costs and potentials as available from EPA studies.

The resulting technology tables are presented in Table 146 and Table 147 on the next page.

Resulting cost curves are presented in Figure 107 and Figure 108. Tables of coefficients are presented in Table 148 and Table 149 at the end of this Annex.

Scenario c) Alternative cost curves based on alternative technology data including alternative accounting for progress observed in the 2002-2009 period

The question of whether all of the reduction observed in the 2002-2009 period can be attributed to technologies included in the tables underlying the cost curves is relevant also for the application of these alternative cost curves. This issue was discussed in Annex C and also to some extent in the comparison of EPA and EU data in Annex D.

In order to deal with both issues a scenario can be constructed which uses cost curves which are based on the alternative technology table discussed above and which are also adapted to include alternative accounting for progress observed in the 2002-2009 period. By applying the operation described in Annex C for the development of cost curves for scenario a) on the alternative cost curves from scenario b) it is possible to create a scenario c) that combines both assumptions.

Resulting coefficients are presented in Table 148 and Table 149 at the end of this Annex.

Table 146	Alternative technology tables for petrol vehicles incorporating figures based on EPA studies.

Technology options for petrol cars		Small		Medium		Large	
Description		Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]
Engine options	Gas-wall heat transfer reduction	3	50	3	50	3	50
	Direct injection, homogeneous	4.5	180	5	180	5.5	180
	Direct injection, stratified charge	8.5	400	9	500	9.5	600
	Thermodynamic cycle imporvements e.g. split cycle, PCCI/HCCI, CAI	13	475	14	475	15	500
	Scale down architecture, 4-->3 cylinder	0	0	0	0	0	0
	Mild downsizing (15% cylinder content reduction)	4	200	5	250	6	300
	Medium downsizing (30% cylinder content reduction)	7	400	8	436	9	509
	Strong downsizing (>=45% cylinder content reduction)	16	550	17	600	18	700
	Cam-phasing	4	80	4	80	4	80
	Variable valve actuation and lift	9	280	10	280	11	280
	EGR	0	0	0	0	0	0
	Low friction design and materials	2	35	2	35	2	35
Transmission options	Optimising gearbox ratios / downspeeding	4	60	4	60	4	60
	Automated manual transmission	5	300	5	300	5	300
	Dual clutch transmission	6	650	6	700	6	750
	Continuously variable transmission	5	1200	5	1200	5	1200
Hybridisation	Start-stop hybridisation	5	175	5	200	5	225
	Micro hybrid - regenerative breaking	7	325	7	375	7	425
	Mild hybrid - torque boost for downsizing	15	1400	15	1500	15	1500
	Full hybrid - electric drive	28	1800	28	2200	28	3000
Driving resistance reduct	Mild weight reduction (~10% reduction of total weight)	6.7	25	6.7	31	6.7	38
	Medium weight reduction (~20% reduction of total weight)	13.5	160	13.5	200	13.5	240
	Strong weight reduction (~30% reduction of total weight)	20.2	590	20.2	738	20.2	885
	Lightweight components other than BIW	0	0	0	0	0	0
	Aerodynamics improvement	2	50	2	50	1.5	60
	Tyres: low rolling resistance	3	30	3	35	3	40
	Reduced driveline friction	1	50	1	50	1	50
Other	Thermo-electric waste heat recovery	2	1000	2	1000	2	1000
	Secondary heat recovery cycle	2	200	2	200	2	200
	Auxiliary systems efficiency improvement	8	420	8	440	8	460
	Thermal management	2.5	150	2.5	150	2.5	150

Table 147	Alternative technology tables for diesel vehicles incorporating figures based on EPA studies.

Technology options for diesel cars		Small		Medium		Large	
Description		Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]
Engine options	Combustion improvements	2	50	2	50	2	50
	Mild downsizing (15% cylinder content reduction)	4	50	4	50	4	50
	Medium downsizing (30% cylinder content reduction)	7	400	7	450	7	500
	Strong downsizing (>=45% cylinder content reduction)	15	500	15	600	15	700
	Variable valve actuation and lift	1	280	1	280	1	280
Transmission options	Optimising gearbox ratios / downspeeding	3	60	3	60	3	60
	Automated manual transmission	4	300	4	300	4	300
	Dual clutch transmission	5	650	5	700	5	750
	Continuously variable transmission	4	1200	4	1200	4	1200
Hybridisation	Start-stop	4	175	4	200	4	225
	Micro hybrid - regenerative breaking	6	375	6	375	6	375
	Mild hybrid - torque boost for downsizing	11	1400	11	1500	11	1500
	full hybrid - electric drive	25	1800	25	2200	25	3000
Driving resistance reducti	Mild weight reduction (~10% reduction of total weight)	6.7	25	6.7	31	6.7	38
	Medium weight reduction (~20% reduction of total weight)	13.5	160	13.5	200	13.5	240
	Strong weight reduction (~30% reduction of total weight)	20.2	590	20.2	738	20.2	885
	Lightweight components other than BIW	0	0	0	0	0	0
	Aerodynamics improvement	2	50	2	50	1.5	60
	Tyres: low rolling resistance	3	30	3	35	3	40
	Reduced driveline friction	1	50	1	50	1	50
Other	Thermo-electric conversion	2	1000	2	1000	2	1000
	Secondary heat recovery cycle	2	200	2	200	2	200
	Auxiliary systems improvement	7	420	7	440	7	460
	Thermal management	2.5	150	2.5	150	2.5	150

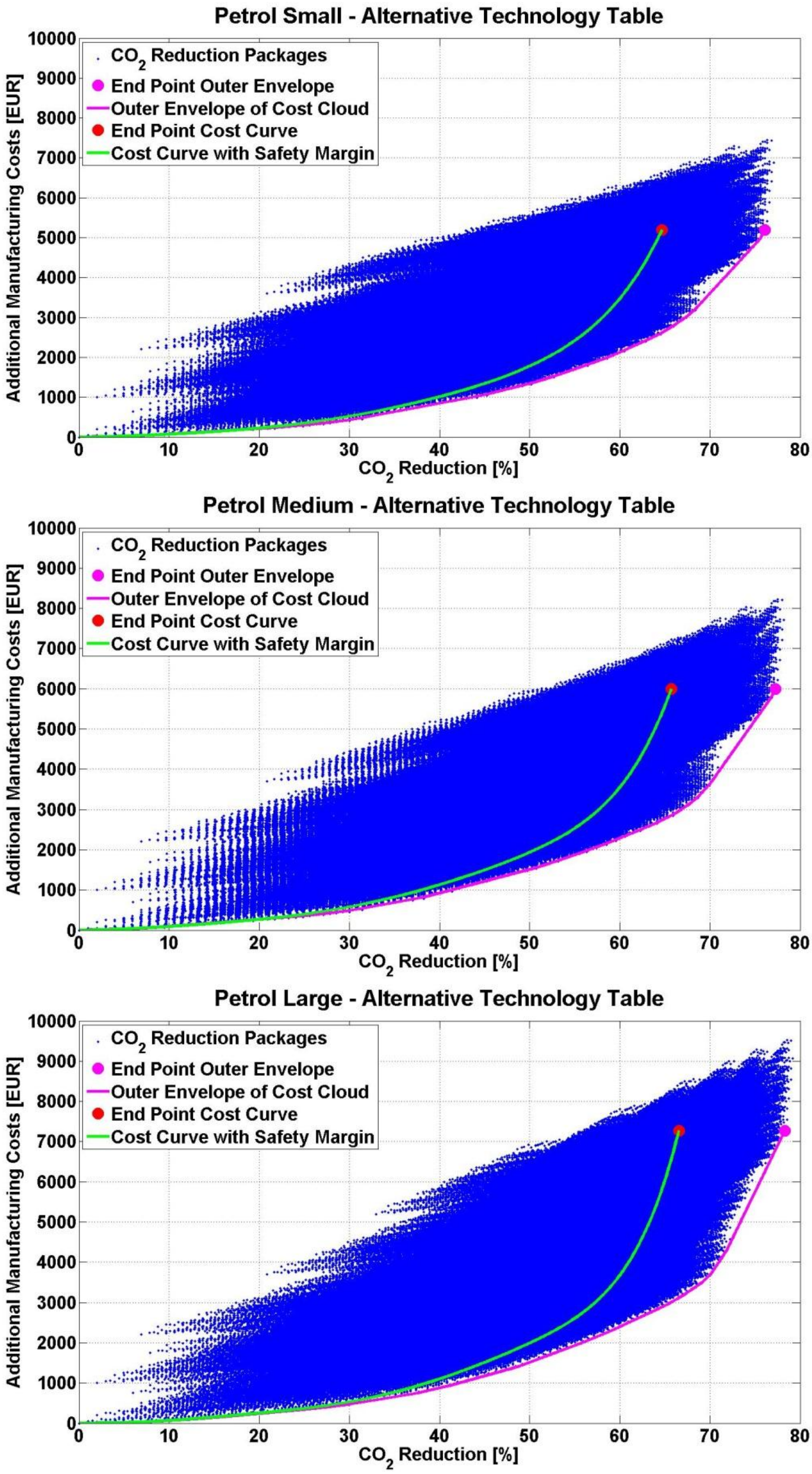
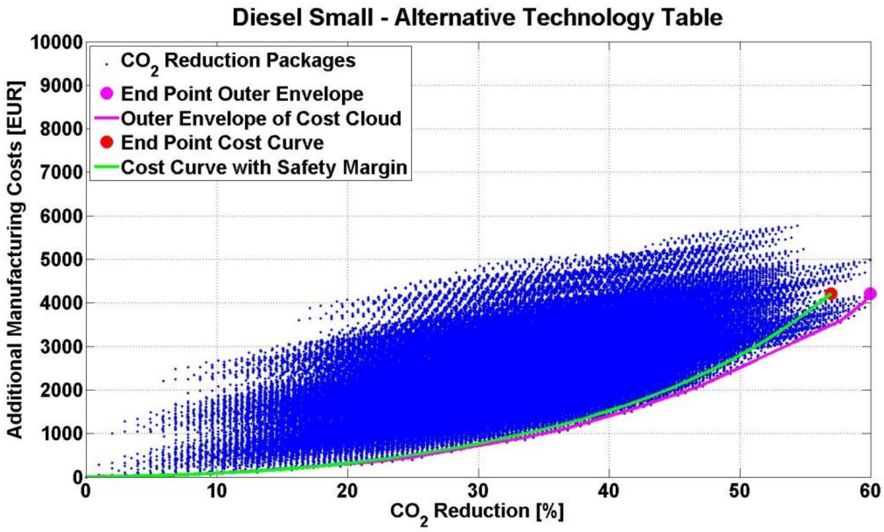
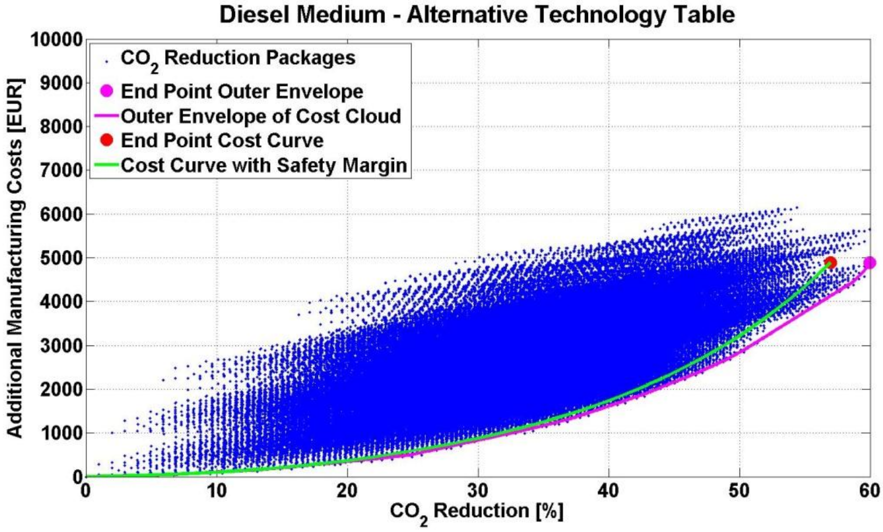


Figure 107 Alternative cost curves (Scenario b) based on alternative technology data for the indicative assessment of possible implications of EPA-data for the cost for meeting 95 g/km in Europe.





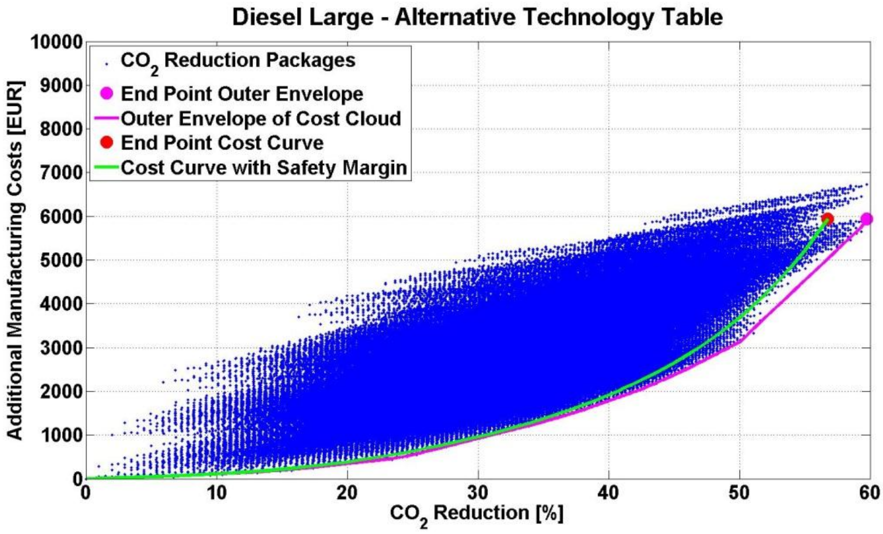


Figure 108 Alternative cost curves (Scenario b) based on alternative technology data for the indicative assessment of possible implications of EPA-data for the cost for meeting 95 g/km in Europe.

E.3 Coefficients for the alternative cost curve sets for scenarios a), b) and c)

Coefficients are presented in two ways:

1. With x defined as fraction in $y = \Sigma\, a_i\, x^i$ reduction = 50% => x = 0.5
2. With x expressed in percent points in $y = \Sigma\, a_i\, x^i$ reduction = 50% => x = 50

In these polynomials x is the reduction in CO_2 emission relative to the baseline vehicle for the segment and y are the additional manufacturer costs associated with that reduction.

Table 148 Coefficient values and end points for polynomial cost curves for petrol and diesel vehicles in 2020, relative to 2002 baseline vehicles, representing three scenario variants (with x defined as fraction).

With x defined as fraction

Original cost curves

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S				8.134E+05	-9.302E+05	3.859E+05	-6.922E+04	1.319E+04	6.453E+02	60.1%	5870
p,M				1.207E+06	-1.386E+06	5.381E+05	-7.426E+04	9.017E+03	9.985E+02	61.1%	6775
p,L	9.431E+07	-2.233E+08	2.180E+08	-1.121E+08	3.226E+07	-5.187E+06	4.602E+05	-1.672E+04	1.574E+03	61.9%	8265
d,S					2.193E+05	-1.757E+05	5.709E+04	9.584E+01	1.657E+03	53.0%	4711
d,M					4.147E+05	-3.757E+05	1.308E+05	-9.708E+03	2.151E+03	53.0%	5571
d,L				-1.549E+05	1.069E+06	-8.804E+05	2.701E+05	-2.236E+04	2.585E+03	52.8%	6946

Scenario a) Cost curves incl. alternative accounting for 2002-2009 progress

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S				7.145E+05	-7.982E+05	2.473E+05	7.937E+03	-3.277E+03	3.572E+02	64.1%	5895
p,M				1.275E+06	-1.655E+06	7.128E+05	-9.992E+04	6.760E+03	1.358E+01	65.0%	6795
p,L	3.024E+07	-6.709E+07	6.163E+07	-3.015E+07	8.508E+06	-1.473E+06	1.890E+05	-1.212E+04	4.965E+02	65.7%	8290
d,S					2.220E+05	-2.074E+05	7.218E+04	-6.282E+02	5.147E+01	57.2%	4736
d,M					3.222E+05	-3.025E+05	1.034E+05	-3.434E+03	5.665E+01	57.2%	5596
d,L				5.741E+05	-1.245E+05	-2.848E+05	1.578E+05	-1.466E+04	6.230E+02	57.0%	6971

Scenario b) Alternative cost curves based on modified technology table

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S			5.855E+05	-5.331E+05	1.006E+04	1.291E+05	-3.967E+04	8.037E+03	2.035E+02	64.7%	5187
p,M			2.308E+06	-3.708E+06	2.188E+06	-5.568E+05	5.835E+04	3.051E+03	3.949E+02	65.7%	5994
p,L			5.101E+06	-9.258E+06	6.405E+06	-2.076E+06	3.196E+05	-1.524E+04	5.278E+02	66.6%	7274
d,S					7.662E+04	-6.523E+04	3.117E+04	1.411E+03	4.571E+02	57.0%	4208
d,M					1.002E+05	-8.587E+04	3.924E+04	9.685E+02	6.101E+02	57.0%	4885
d,L				4.163E+05	-3.599E+05	8.095E+04	2.506E+04	-9.009E+02	9.073E+02	56.8%	5936

Scenario c) Alternative cost curves based on modified technology table + alternative accounting for 2002-2009 progress

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S			5.799E+05	-7.326E+05	3.134E+05	-5.815E+04	1.959E+04	-1.996E+03	2.510E+02	68.2%	5207
p,M			1.698E+06	-2.940E+06	1.954E+06	-6.307E+05	1.153E+05	-8.461E+03	3.863E+02	69.1%	6014
p,L			3.899E+06	-7.469E+06	5.485E+06	-1.917E+06	3.332E+05	-2.379E+04	7.817E+02	69.9%	7299
d,S					2.549E+04	-1.126E+04	1.569E+04	-1.059E+00	1.945E+02	60.8%	4233
d,M					6.072E+04	-4.470E+04	2.611E+04	1.162E+02	8.462E+01	60.8%	4910
d,L				8.894E+04	9.269E+03	-4.707E+04	3.236E+04	-2.666E+02	2.599E+01	60.7%	5961

Table 149 Coefficient values and end points for polynomial cost curves for petrol and diesel vehicles in 2020, relative to 2002 baseline vehicles, representing three scenario variants (with x defined in percent points).

With x defined in percent-points

Original cost curves

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End EUR
p,S				8.134E-07	-9.302E-05	3.859E-03	-6.922E-02	1.319E+00	6.453E+00	60.09	5870
p,M				1.207E-06	-1.386E-04	5.381E-03	-7.426E-02	9.017E-01	9.985E+00	61.07	6775
p,L	9.431E-11	-2.233E-08	2.180E-06	-1.121E-04	3.226E-03	-5.187E-02	4.602E-01	-1.672E+00	1.574E+01	61.91	8265
d,S					2.193E-05	-1.757E-03	5.709E-02	9.584E-03	1.657E+01	52.99	4711
d,M					4.147E-05	-3.757E-03	1.308E-01	-9.708E-01	2.151E+01	52.98	5571
d,L				-1.549E-07	1.069E-04	-8.804E-03	2.701E-01	-2.236E+00	2.585E+01	52.78	6946

Scenario a) Cost curves incl. alternative accounting for 2002-2009 progress

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End EUR
p,S				7.145E-07	-7.982E-05	2.473E-03	7.937E-03	-3.277E-01	3.572E+00	64.09	5895
p,M				1.275E-06	-1.655E-04	7.128E-03	-9.992E-02	6.760E-01	1.358E-01	64.97	6795
p,L	3.024E-11	-6.709E-09	6.163E-07	-3.015E-05	8.508E-04	-1.473E-02	1.890E-01	-1.212E+00	4.965E+00	65.71	8290
d,S					2.220E-05	-2.074E-03	7.218E-02	-6.282E-02	5.147E-01	57.22	4736
d,M					3.222E-05	-3.025E-03	1.034E-01	-3.434E-01	5.665E-01	57.21	5596
d,L				5.741E-07	-1.245E-05	-2.848E-03	1.578E-01	-1.466E+00	6.230E+00	57.03	6971

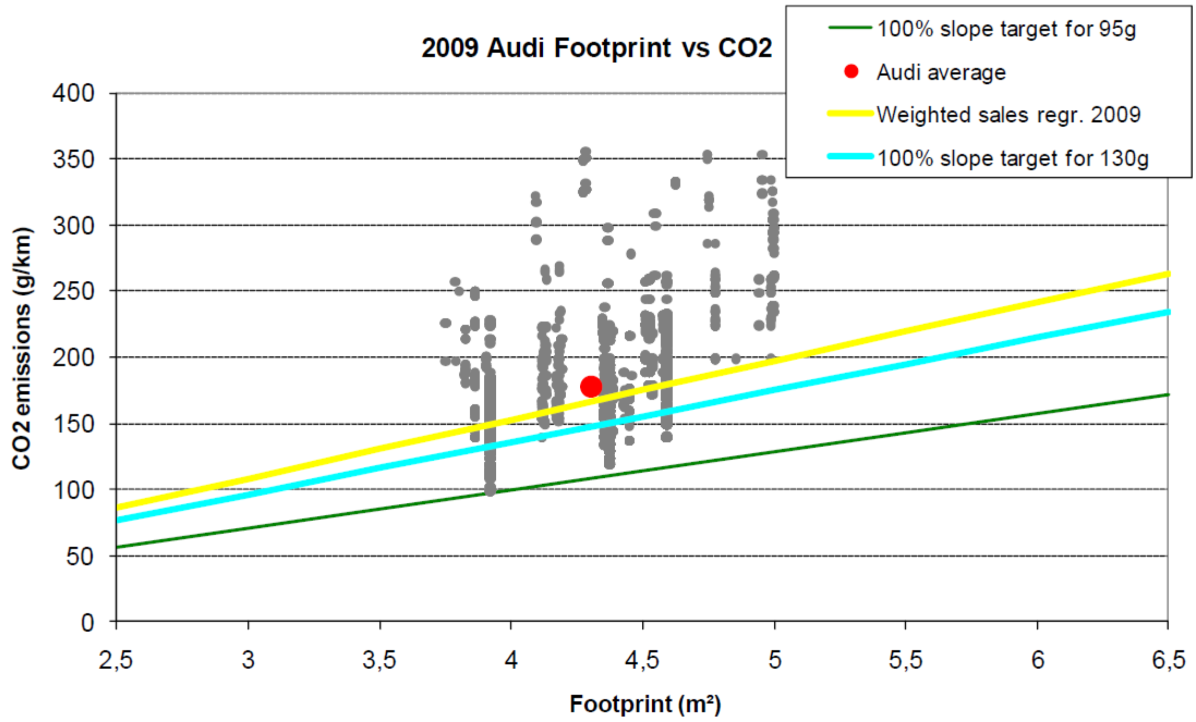
Scenario b) Alternative cost curves based on modified technology table

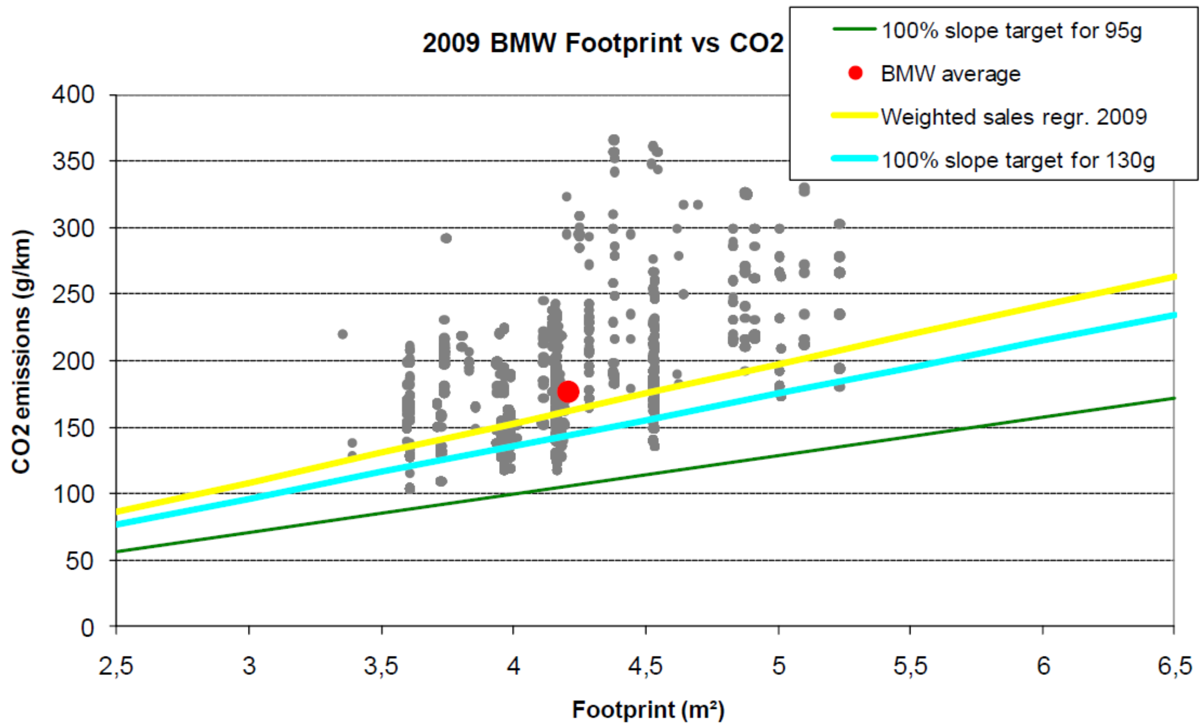
	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End EUR
p,S			5.855E-09	-5.331E-07	1.006E-06	1.291E-03	-3.967E-02	8.037E-01	2.035E+00	64.69	5187
p,M			2.308E-08	-3.708E-06	2.188E-04	-5.568E-03	5.835E-02	3.051E-01	3.949E+00	65.70	5994
p,L			5.101E-08	-9.258E-06	6.405E-04	-2.076E-02	3.196E-01	-1.524E+00	5.278E+00	66.57	7274
d,S					7.662E-06	-6.523E-04	3.117E-02	1.411E-01	4.571E+00	56.96	4208
d,M					1.002E-05	-8.587E-04	3.924E-02	9.685E-02	6.101E+00	56.96	4885
d,L				4.163E-07	-3.599E-05	8.095E-04	2.506E-02	-9.009E-02	9.073E+00	56.77	5936

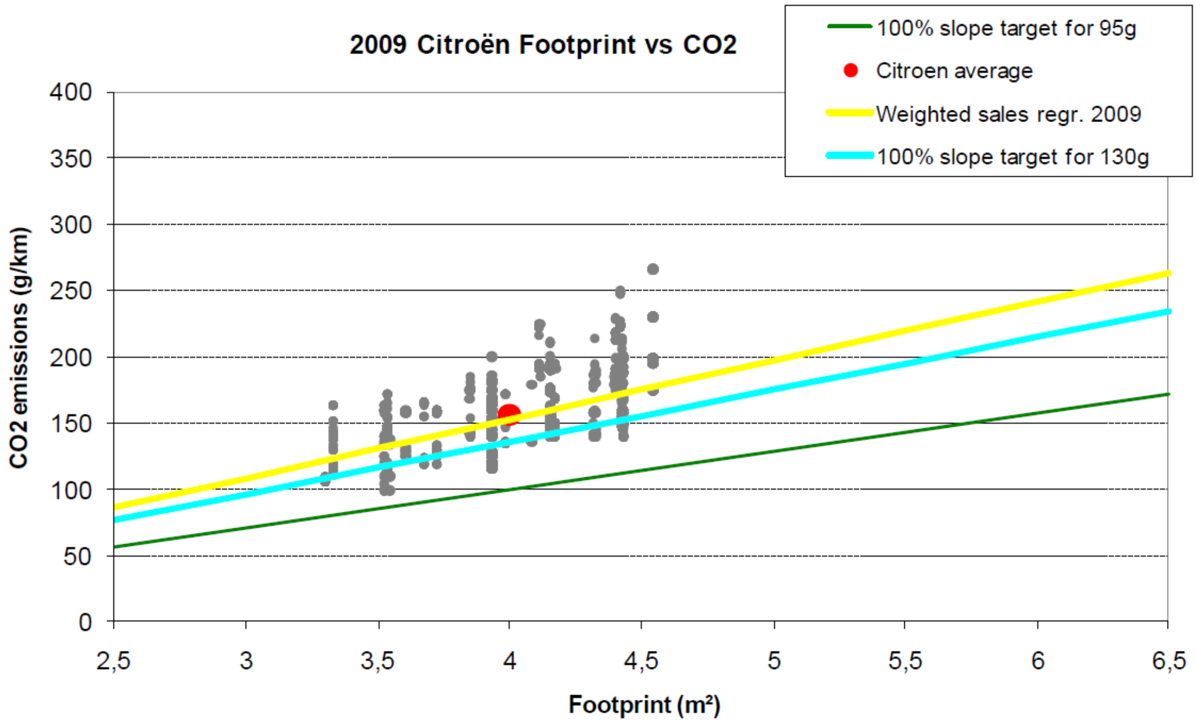
Scenario c) Alternative cost curves based on modified technology table + alternative accounting for 2002-2009 progress

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End EUR
p,S			5.799E-09	-7.326E-07	3.134E-05	-5.815E-04	1.959E-02	-1.996E-01	2.510E+00	68.22	5207
p,M			1.698E-08	-2.940E-06	1.954E-04	-6.307E-03	1.153E-01	-8.461E-01	3.863E+00	69.13	6014
p,L			3.899E-08	-7.469E-06	5.485E-04	-1.917E-02	3.332E-01	-2.379E+00	7.817E+00	69.91	7299
d,S					2.549E-06	-1.126E-04	1.569E-02	-1.059E-04	1.945E+00	60.84	4233
d,M					6.072E-06	-4.470E-04	2.611E-02	1.162E-02	8.462E-01	60.84	4910
d,L				8.894E-08	9.269E-07	-4.707E-04	3.236E-02	-2.666E-02	2.599E-01	60.66	5961

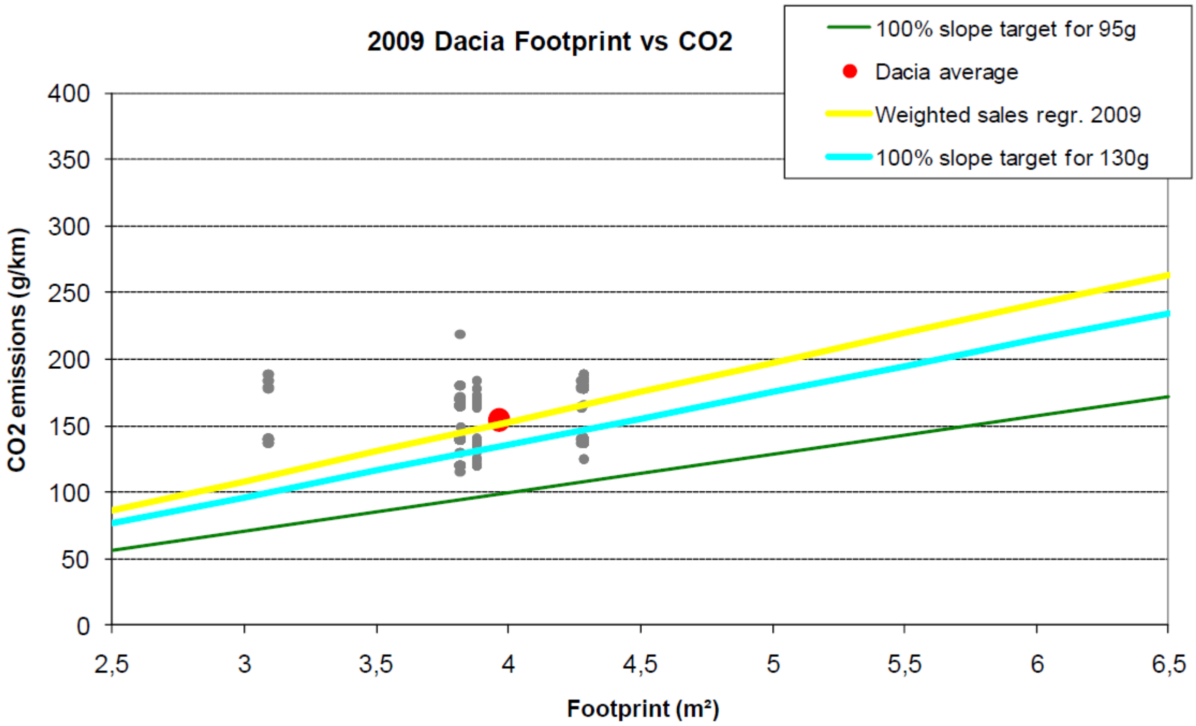
F Manufacturer Group Detailed Analysis



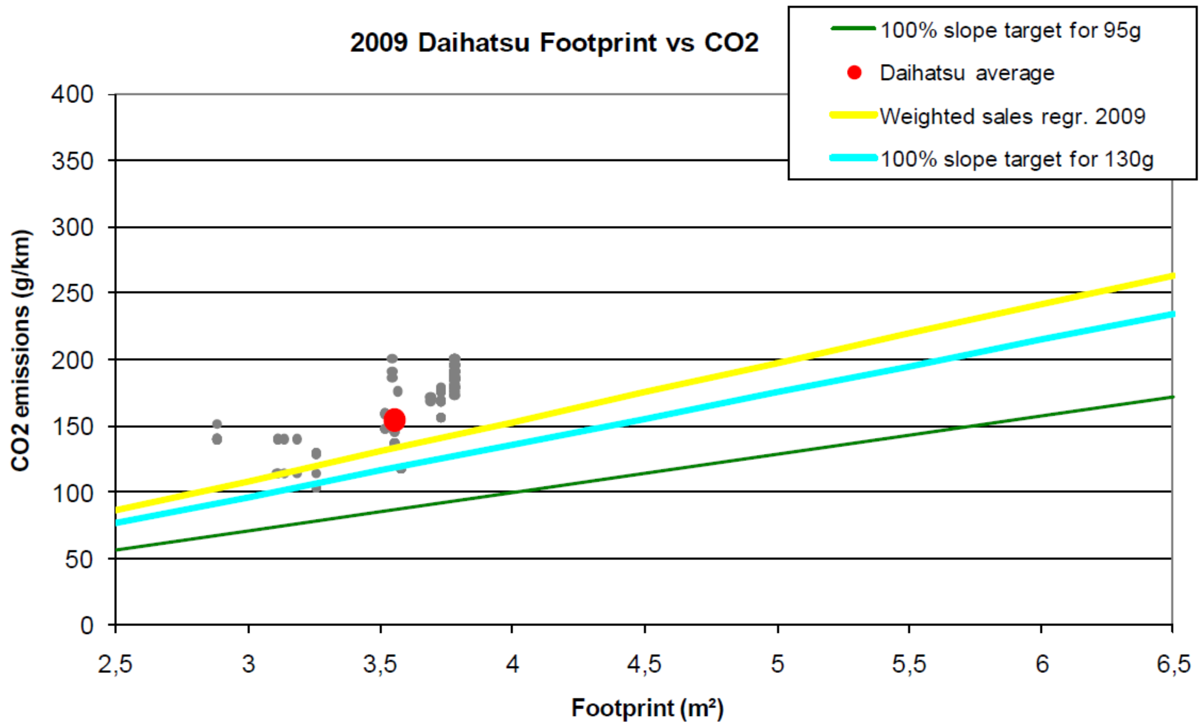


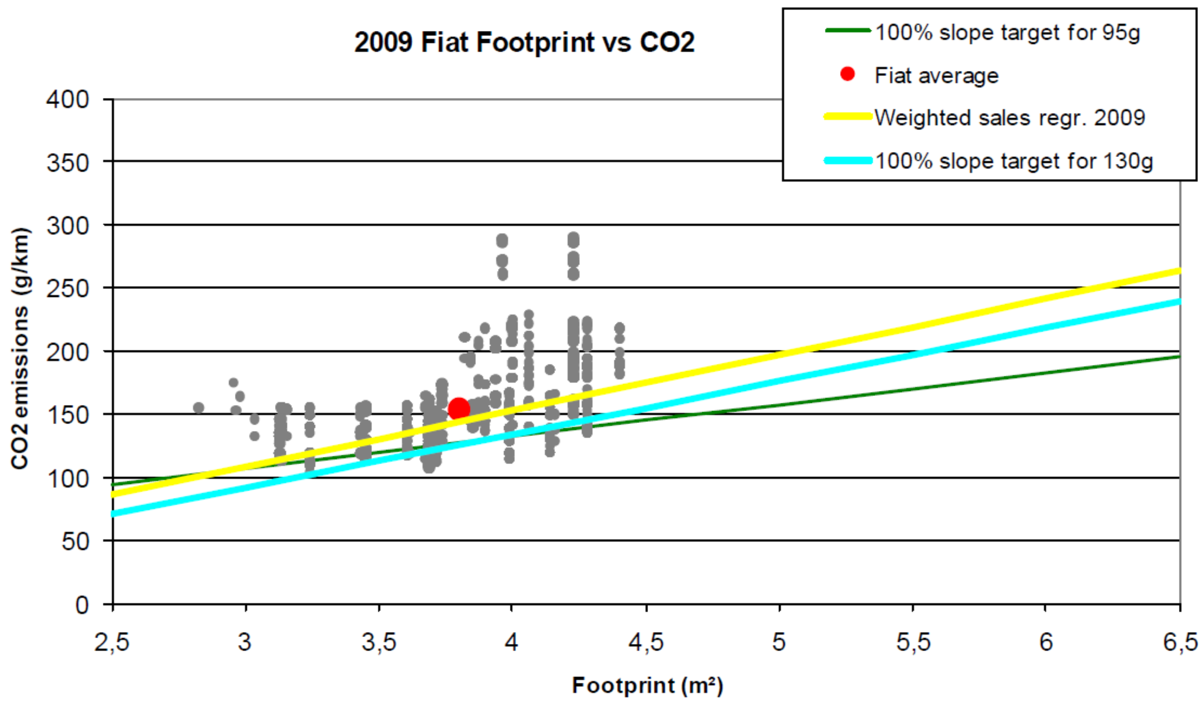


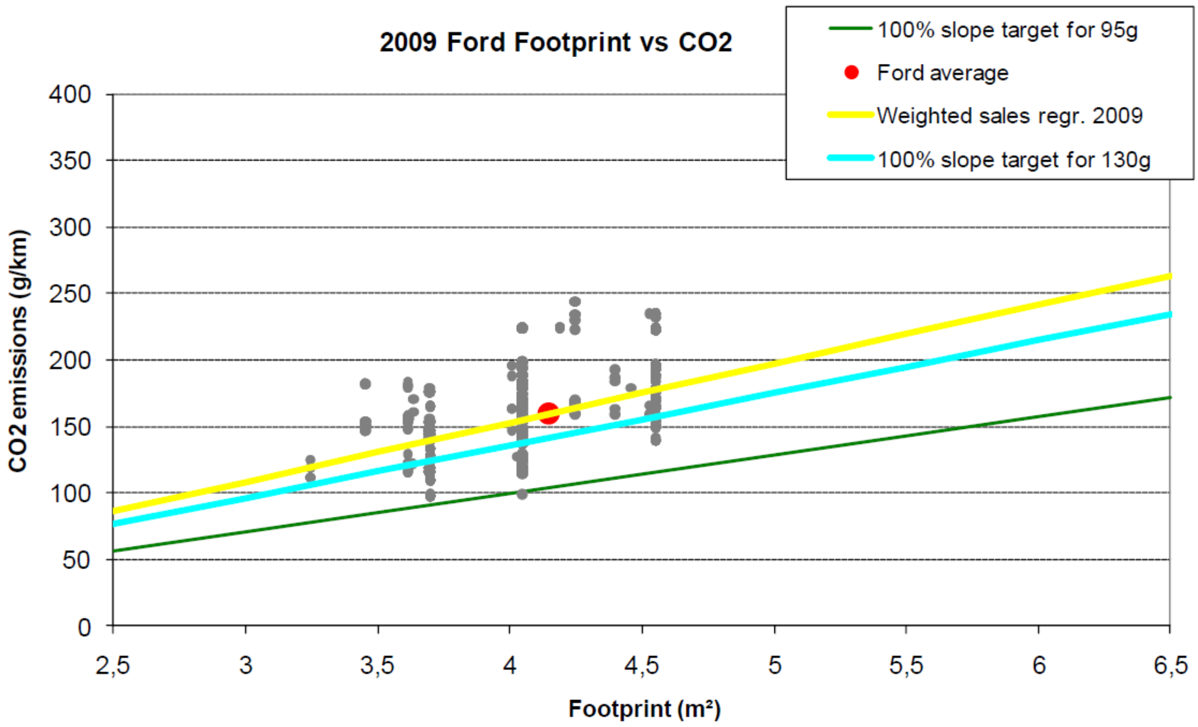
2009 Citroën Footprint vs CO2
100% slope target for 95g
Citroen average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)

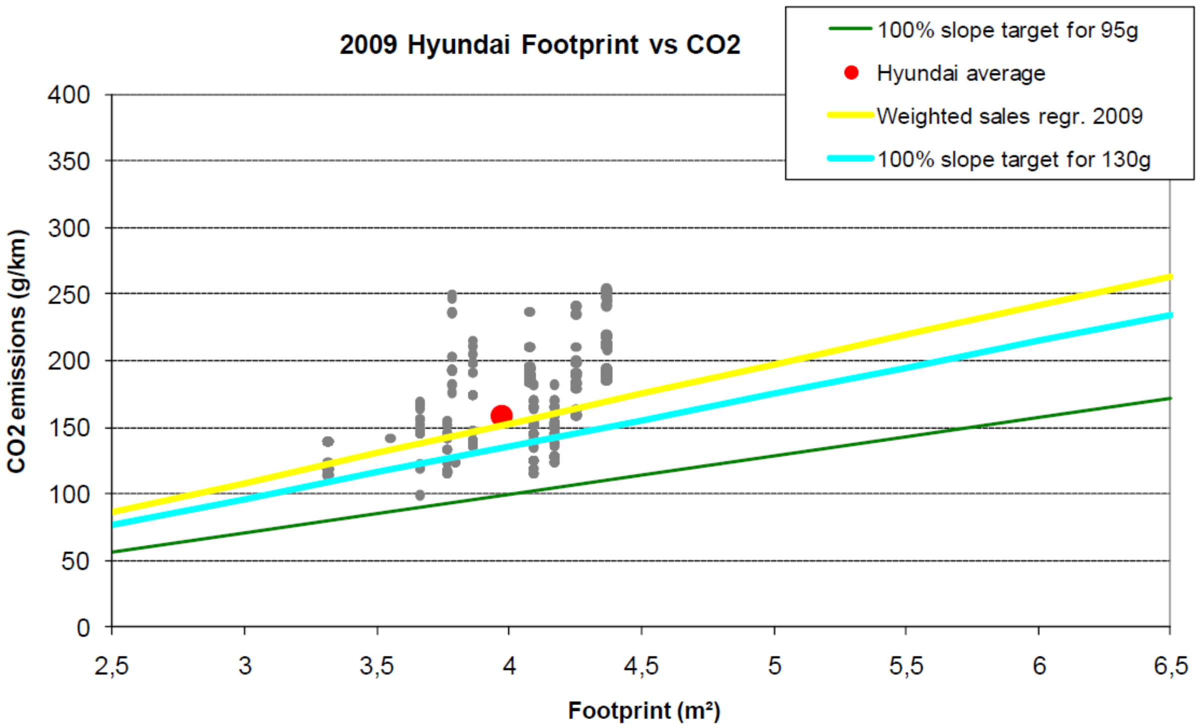


2009 Dacia Footprint vs CO2
100% slope target for 95g
Dacia average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)


2009 Daihatsu Footprint vs CO2
100% slope target for 95g
Daihatsu average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)


2009 Fiat Footprint vs CO2
100% slope target for 95g
Fiat average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)


2009 Ford Footprint vs CO2
100% slope target for 95g
Ford average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)


2009 Hyundai Footprint vs CO2
100% slope target for 95g
Hyundai average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
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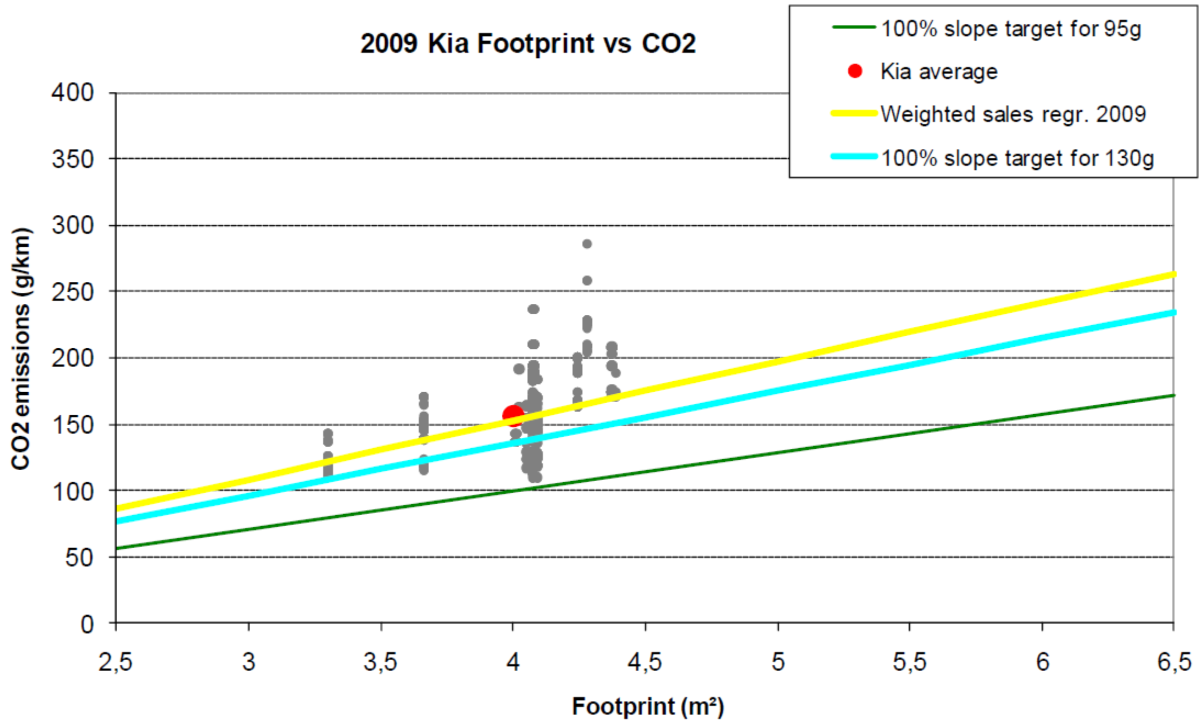
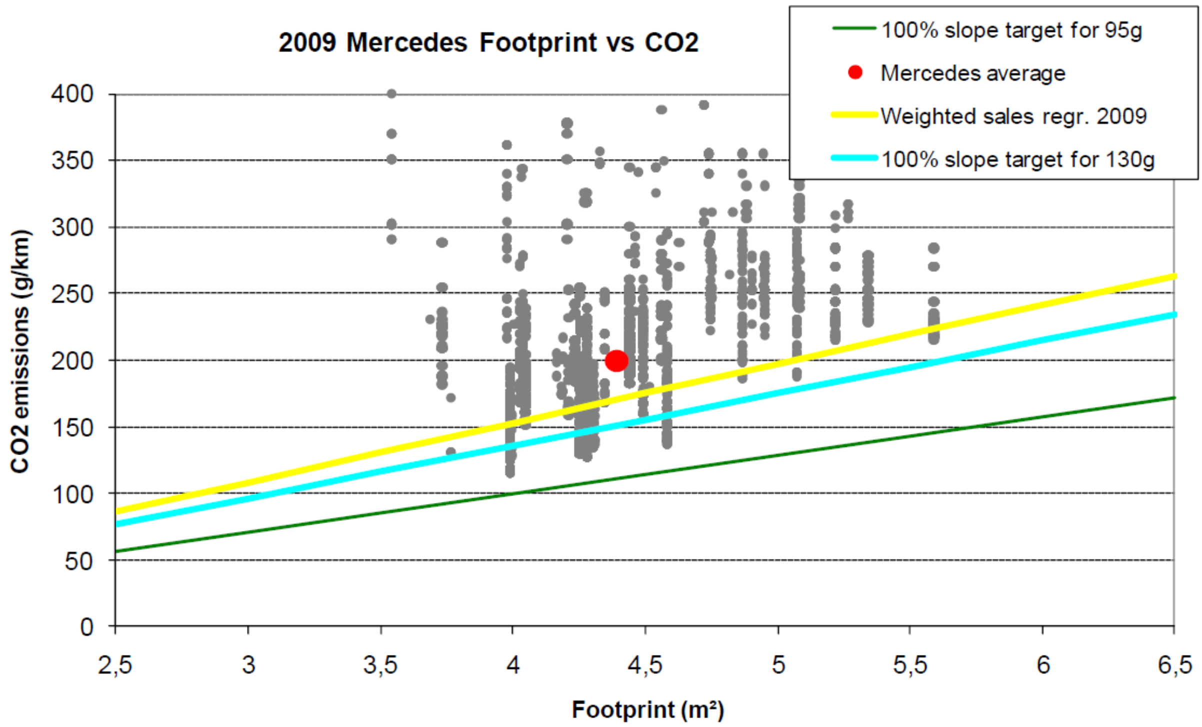
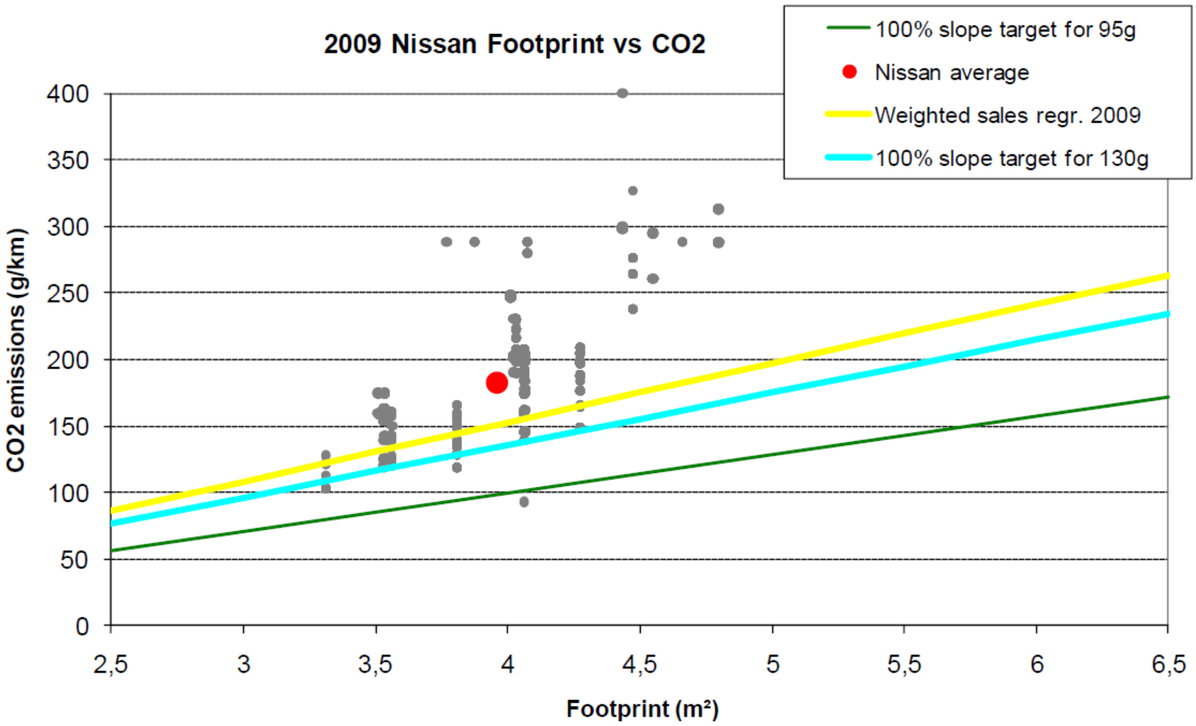
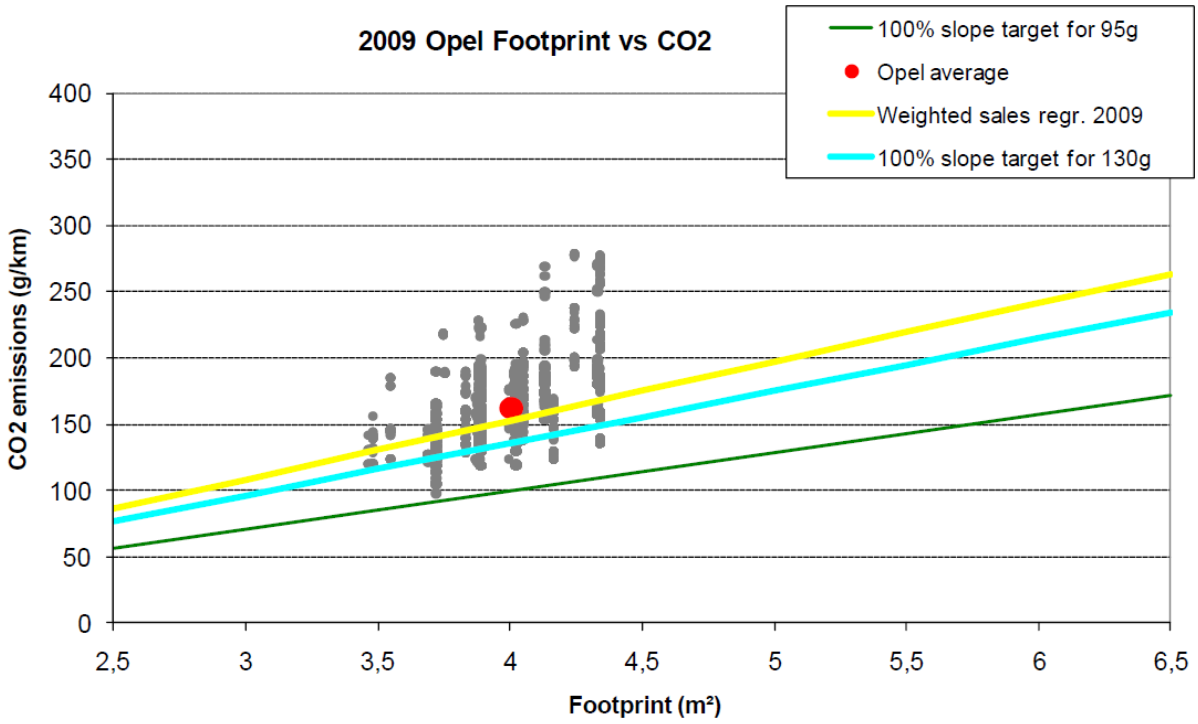
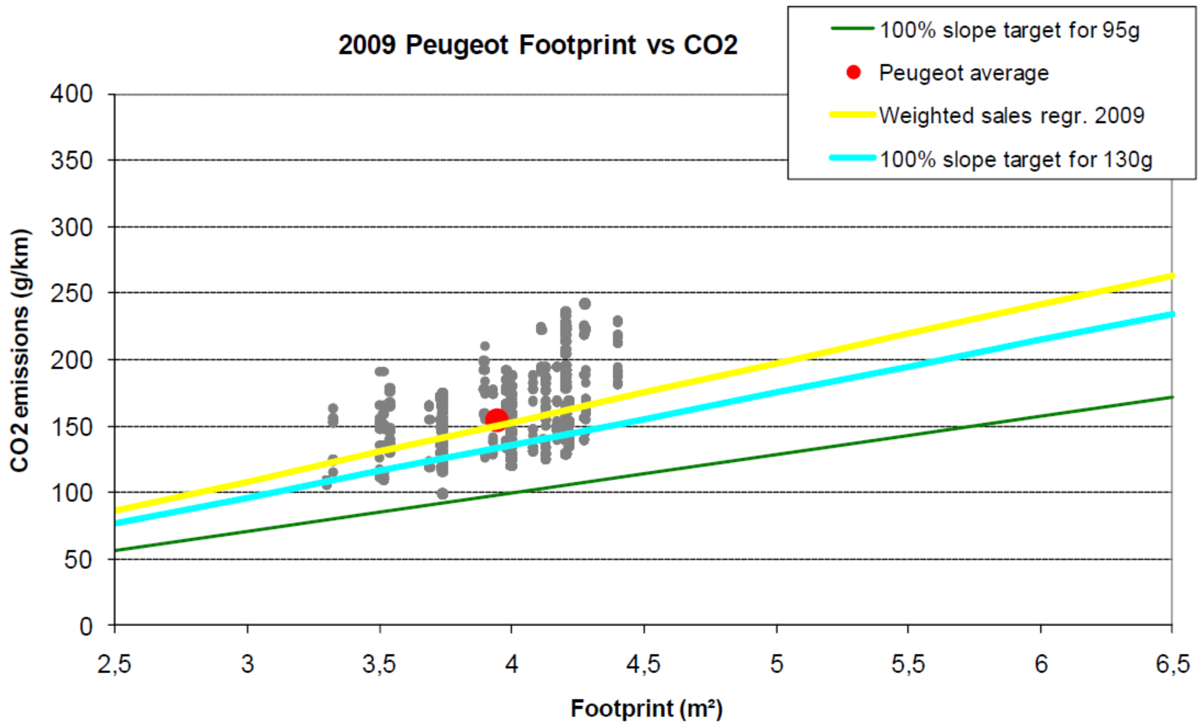
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)

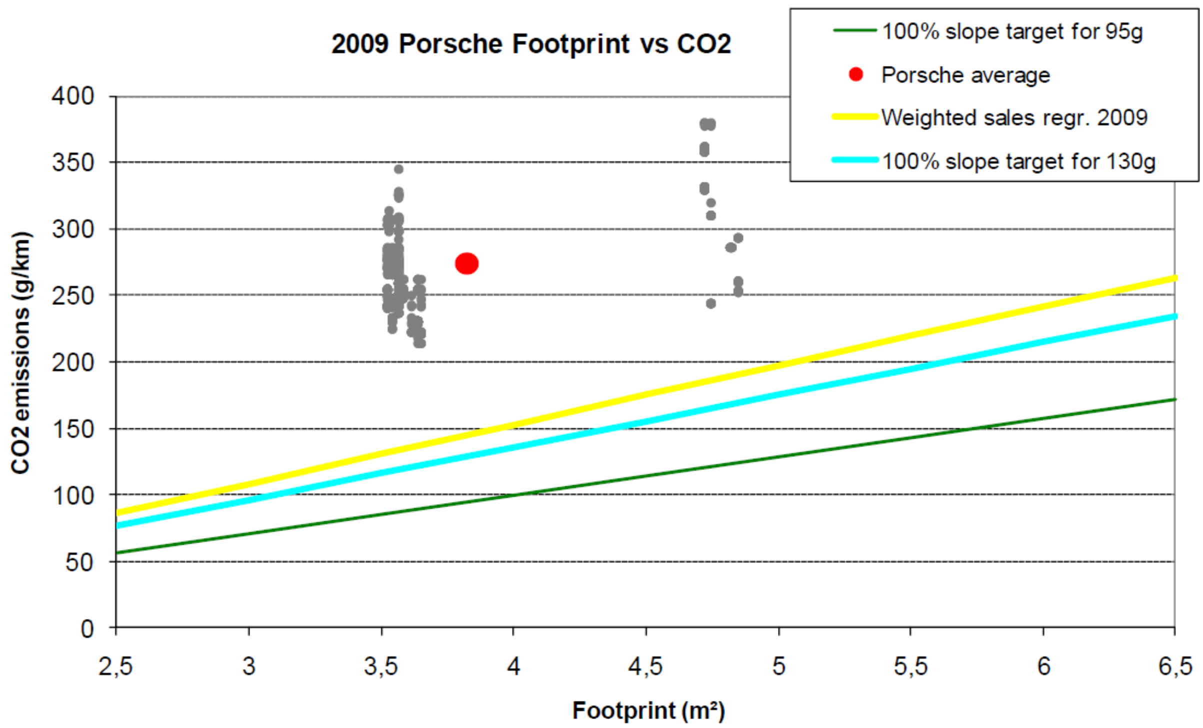

2009 Kia Footprint vs CO2
100% slope target for 95g
Kia average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
Footprint (m²)
0
50
100
150
200
250
300
350
400
2,5
3
3,5
4
4,5
5
5,5
6
6,5

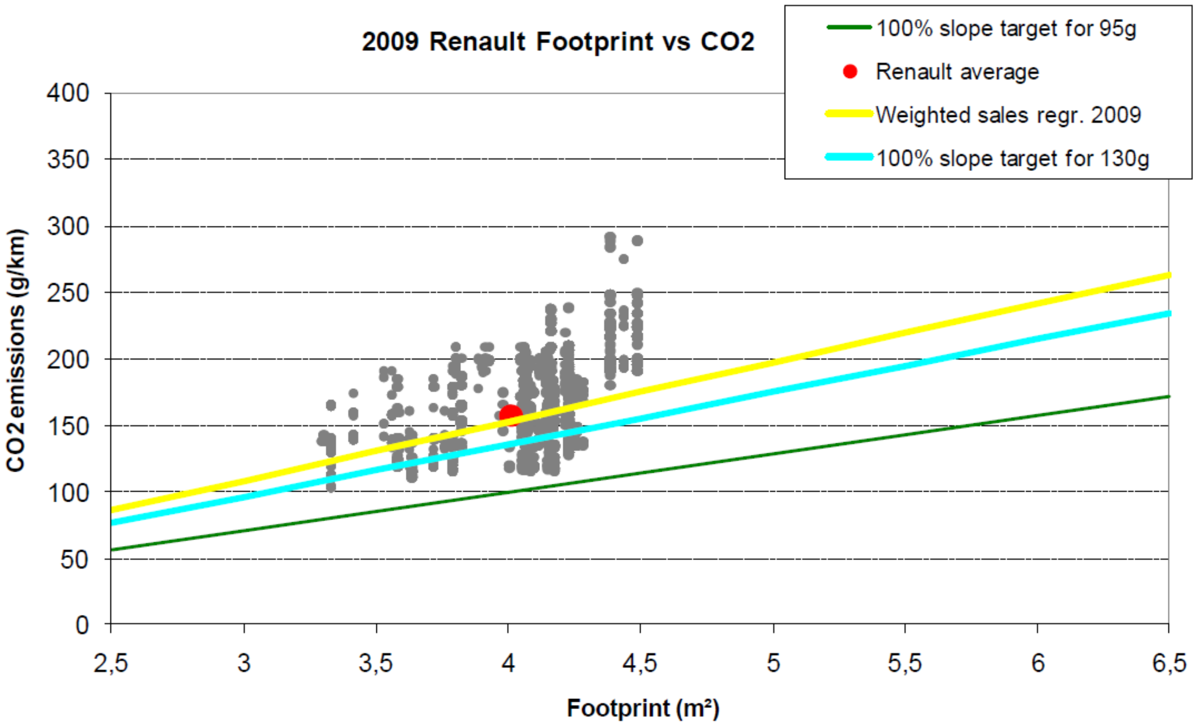

2009 Mercedes Footprint vs CO2
100% slope target for 95g
Mercedes average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
Footprint (m²)
0
50
100
150
200
250
300
350
400
2,5
3
3,5
4
4,5
5
5,5
6
6,5


2009 Nissan Footprint vs CO2
100% slope target for 95g
Nissan average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
Footprint (m²)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5


2009 Opel Footprint vs CO2
100% slope target for 95g
Opel average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
Footprint (m²)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5


2009 Peugeot Footprint vs CO2
100% slope target for 95g
Peugeot average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)


2009 Porsche Footprint vs CO2
100% slope target for 95g
Porsche average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)



2009 Renault Footprint vs CO2
100% slope target for 95g
Renault average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
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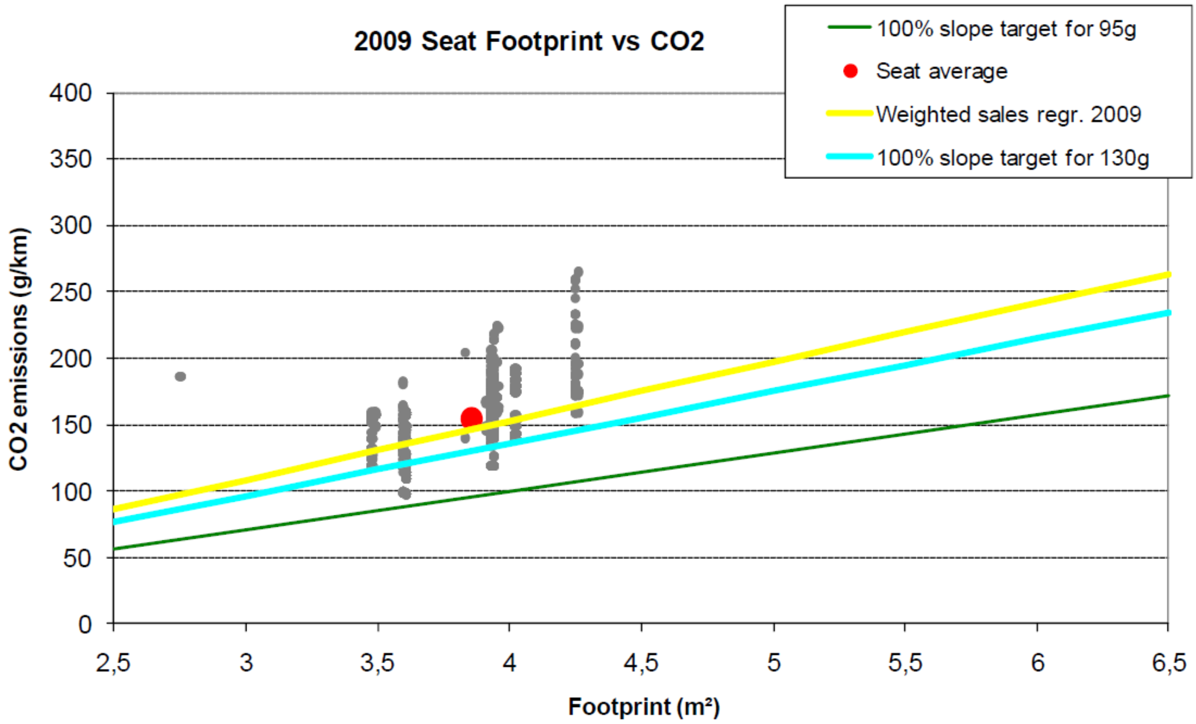
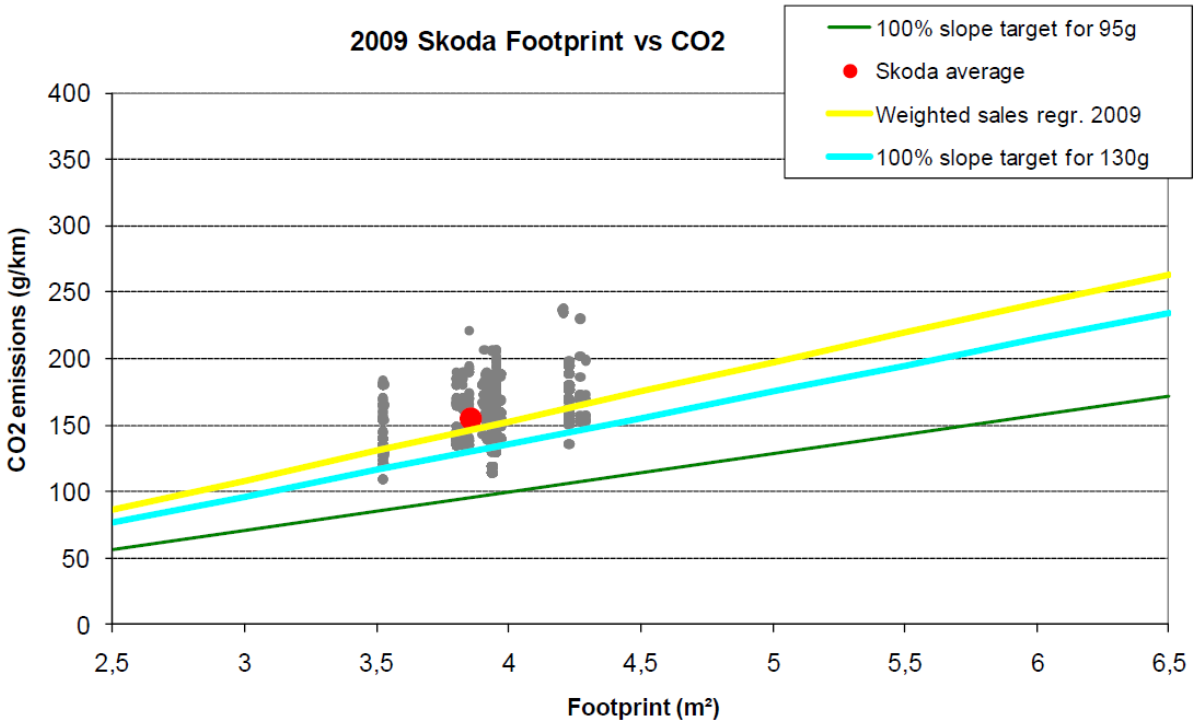
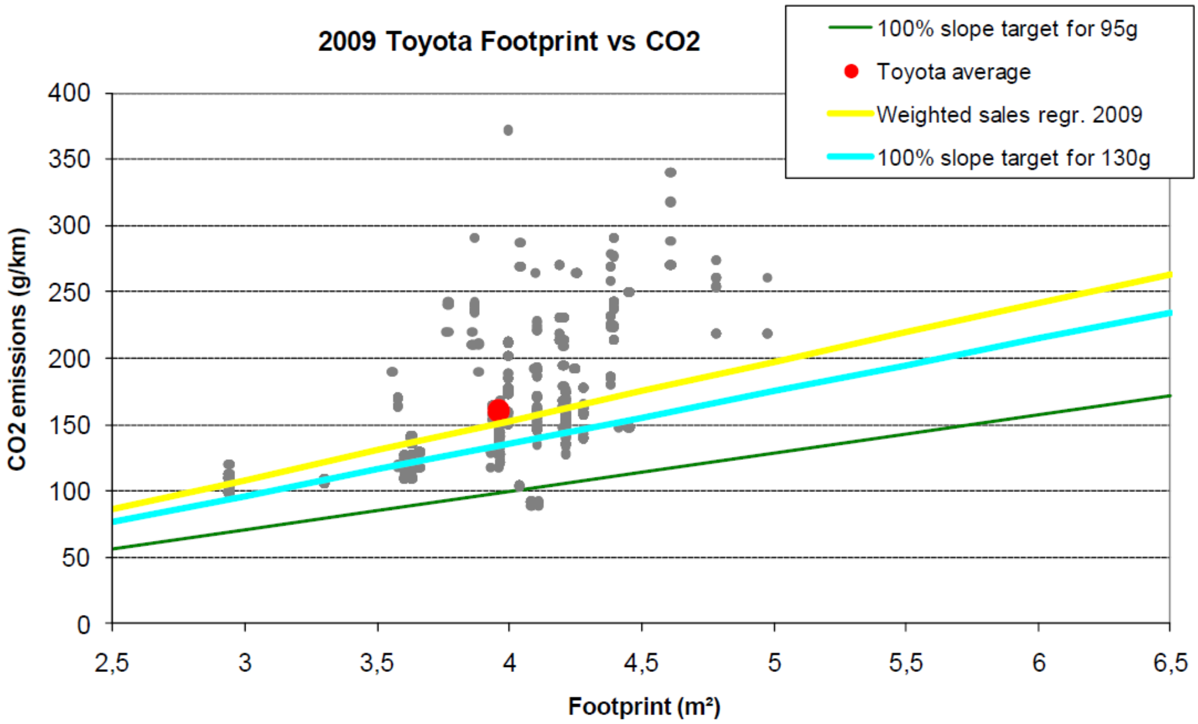
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)



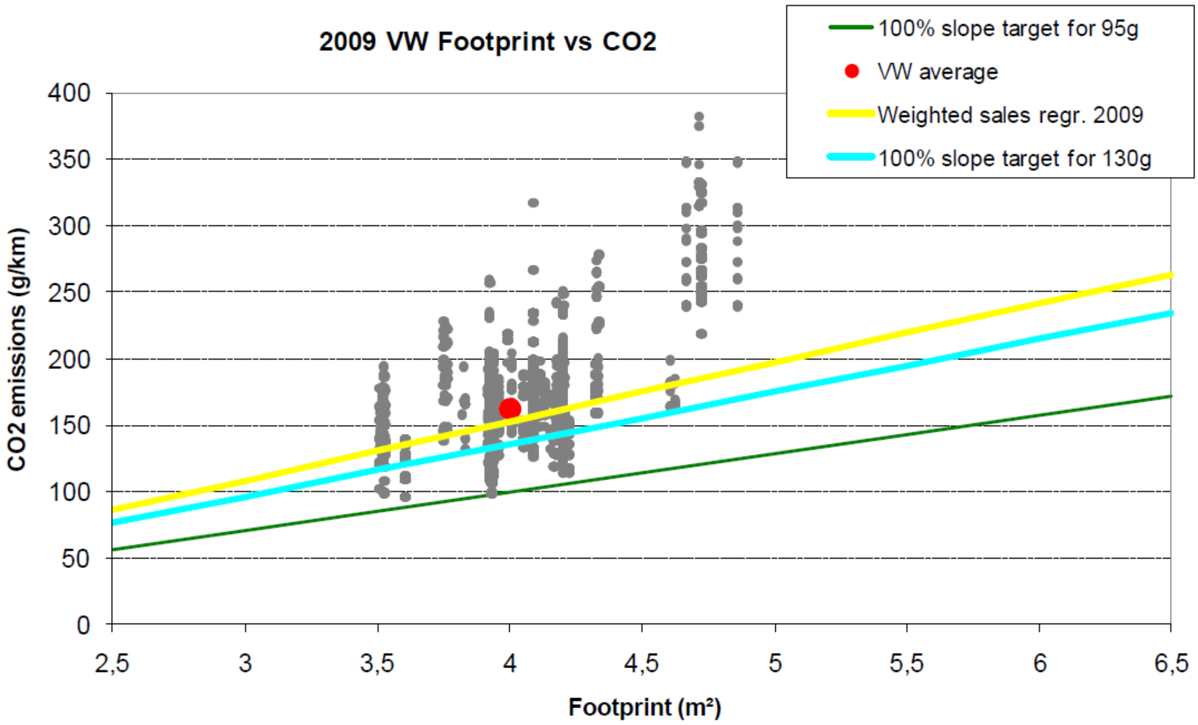
2009 Seat Footprint vs CO2
100% slope target for 95g
Seat average
Weighted sales regr. 2009
100% slope target for 130g
CO2 emissions (g/km)
400
350
300
250
200
150
100
50
0
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)



2009 Skoda Footprint vs CO2
100% slope target for 95g
Skoda average
Weighted sales regr. 2009
100% slope target for 130g
400
350
300
250
200
150
100
50
0
CO2 emissions (g/km)
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)



2009 Toyota Footprint vs CO2
100% slope target for 95g
Toyota average
Weighted sales regr. 2009
100% slope target for 130g
400
350
300
250
200
150
100
50
0
CO2 emissions (g/km)
2,5
3
3,5
4
4,5
5
5,5
6
6,5
Footprint (m²)



Source: IHS Global Insight.

G Average CO_2 emissions per manufacturer as function of various utility parameters

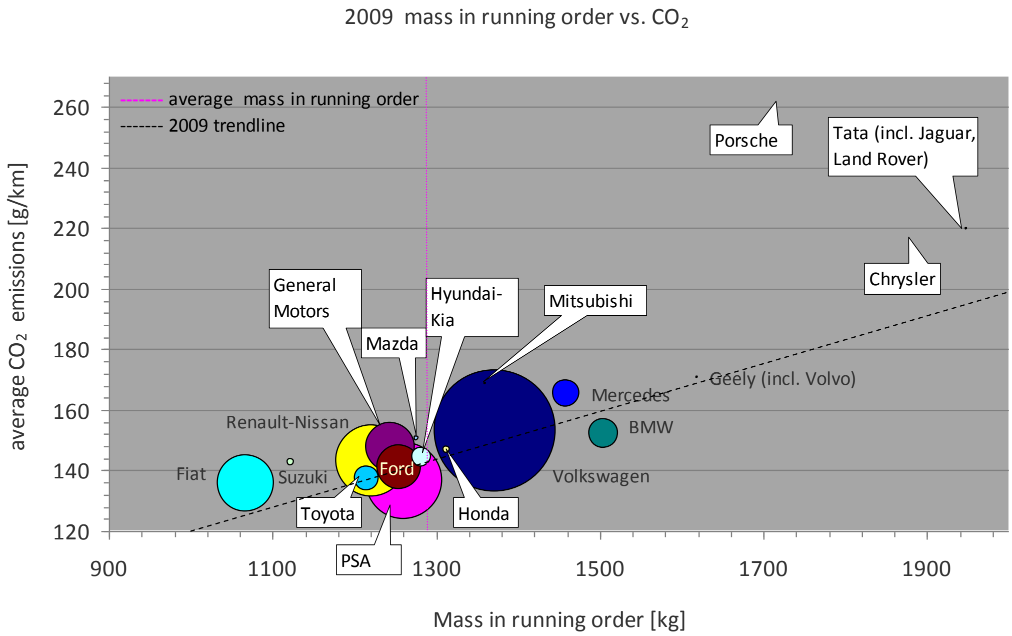


Figure 109 Average CO_2 emissions per manufacturer as function of mass; bubbles size indicates 2009 total sales (Source [TNO 2011]).

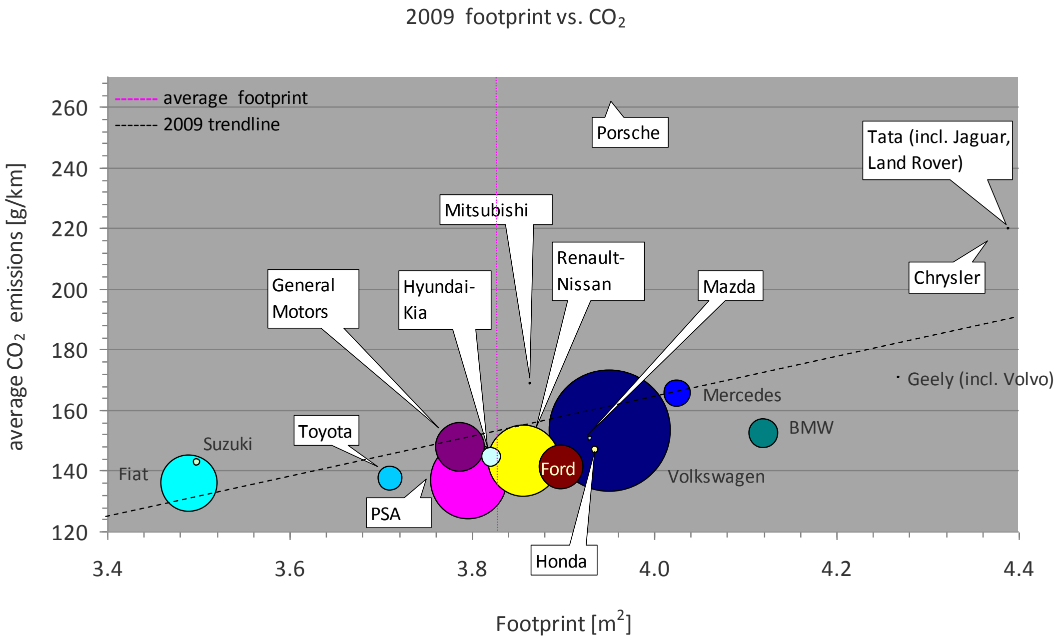


Figure 110 Average CO_2 emissions per manufacturer as function of footprint; bubbles size indicates 2009 total sales (Source [TNO 2011]).

H Summarised methodology description for generating CO_2 limit curves for the passenger vehicle fleet in 2020.

H.1 Introduction

On the basis of the 2010 passenger car sales database a first exercise has been carried out to develop utility-based limit functions for four different utility parameters, i.e.:

- mass
- footprint
- footprint*height, and
- normalised seat & trunk volume.

In the sections below, the methodology for generating utility based limit functions is explained shortly, thereafter the first examples of linear and truncated limit functions and their implications will be discussed per utility parameter.

Non-linear (i.e. curved) limit functions with floors and ceilings have not been included in this memo yet. A methodology for defining such limit functions has been defined, but for the purpose of the issues analysed here their implications are large the same as for the linear truncated limit functions.

H.2 Methodology

For every of the four utility parameters a linear limit function is generated by

- Firstly applying a sales weighted least squares fit method, to generate a linear correlation line through the set of CO_2 emission values for sold vehicles. This way, best sold vehicles appear rather closely around the curve, since the sales where taken into account.
- Subsequently a linear limit function is defined by drawing a line through the point defined by (<U>, 95), with <U> the sales weighted average utility value, in such a way that the relative reduction in CO_2 value compared to the 2010 sales weighted fit is identical for all utility values. This line is what is called the 100% slope limit function, in accordance with the methodology also used to define the limit functions for the assessment made in support of the legislation for the 130 g/km target for 2015.

For two utility parameters (i.e. mass and footprint), also different options of truncated limit functions have been generated by adding a floor and ceiling to the linear limit function. The methodology for defining a truncated linear limit function that assures that the 95 g/km is met is as follows:

- First a floor and ceiling are defined by means of their CO_2 value.
- In between the floor and ceiling, a linear limit line with 100% slope is generated based on the same principle as for the 100% slope linear limit function; the relative reduction (in comparison to the 2010 least squares fit) is equal for every utility value and is tuned to a level at which the sales weighted average of the target values for all newly sold vehicles equals 95 g/km.

For the purpose of this exercise two variants have been worked out:

- option 1: a floor of 70 g/km and a ceiling set at 190 g/km, i.e. twice the overall target value of 95 g/km;
- option 2: a floor of 70 g/km and a ceiling defined in such a way that the intersection between the sloped section and the ceiling is located at a utility value that is in between those of typical upper medium vehicles (e.g. BMW 5 series) and typical large vehicles (e.g. BMW 7 series).

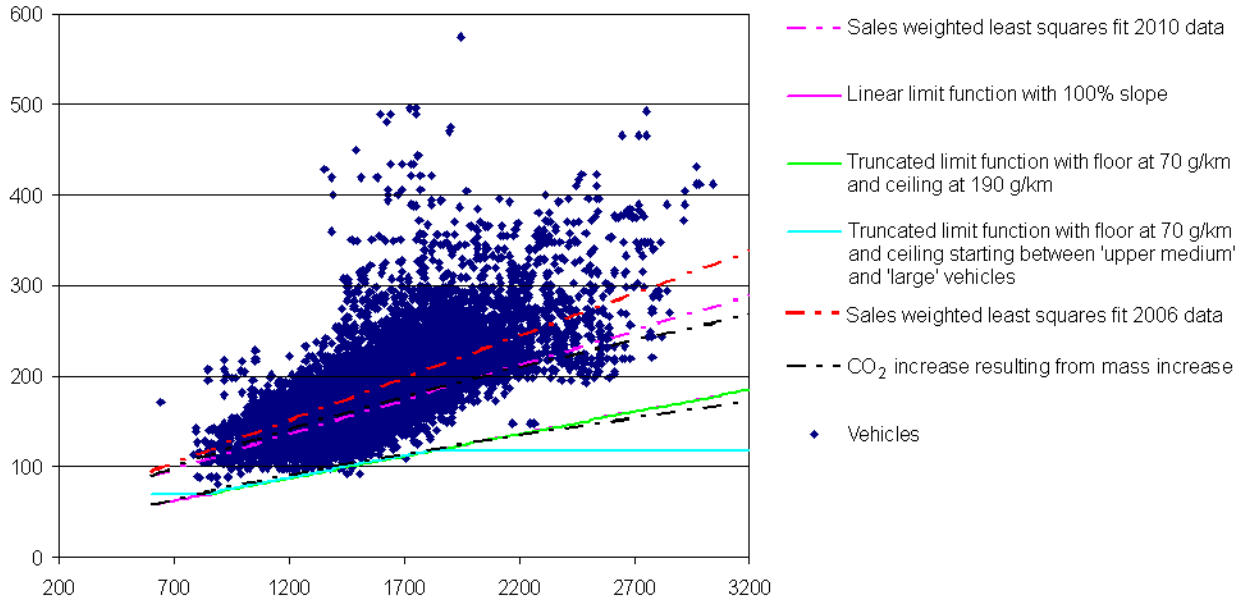
Considerations:

- Starting point of the method for defining these truncated linear limit functions is the 100% slope linear limit function. Truncated limit functions can also be defined based on limit functions with different slopes (e.g. 80%);
- When a ceiling is introduced to a linear limit function the larger vehicles get a tighter target. In order to still meet 95 g/km exactly the targets for smaller vehicles can thus be increased. This is

done by moving the sloped part of the limit function upwards while keeping the ratio to the 2010 sales weighted fit constant (= rotation around the point where the 2010 fit and the 100% limit function intercept the x-axis);
- When a floor is introduced to a linear limit function the smallest vehicles get a less tight target. In order to still meet 95 g/km exactly the targets for larger vehicles thus have to be lowered. This is done by moving the sloped part of the limit function downwards, again while keeping the ratio to the 2010 sales weighted fit constant.

H.3 Limit functions for different utility parameters

Mass



Notes: "2006" is the sales weighted least squares fit through the 2006 database which was used as a basis for defining the limit function for the 130 g/km target in 2015.

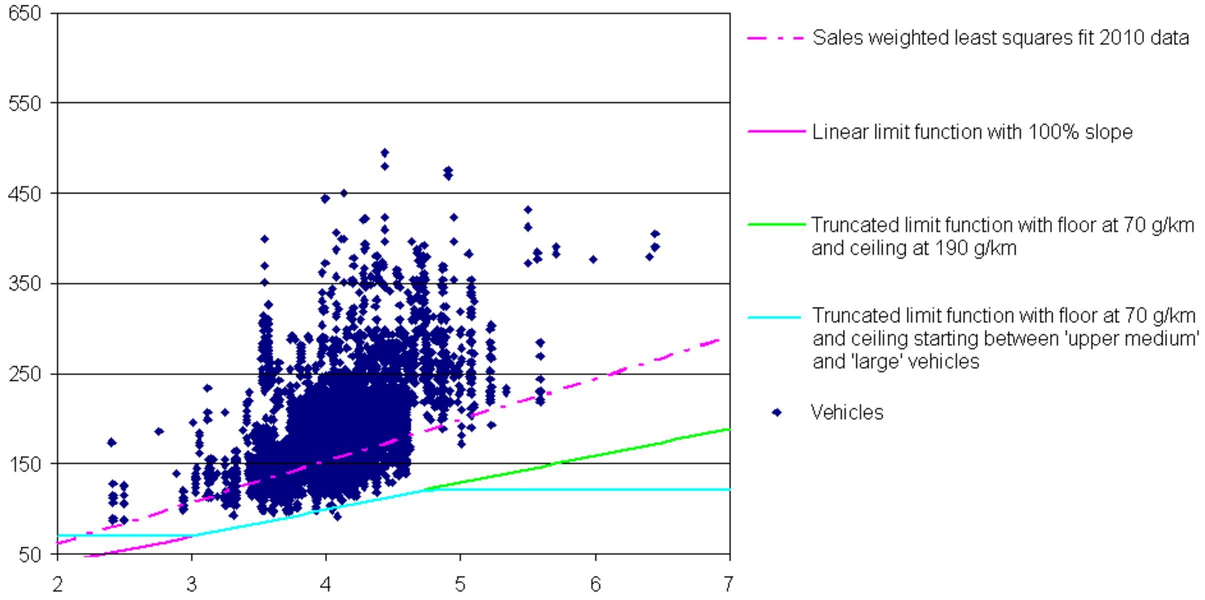
For mass as a utility parameter, several conclusions can be drawn from the limit curves plotted in the above graph:
- The CO_2 emission correlates relatively well to the vehicle mass. In fact, it shows the best correlation of the four utility parameters assessed.
- The slope of the least squares fit through the 2010 data is lower than the slope of the fit through the 2006 data generated for determining the 2015 target (2006 study). This means that the type approval CO_2 value of larger vehicles has decreased more (relatively and absolutely) than that of smaller cars. Furthermore the plotted vehicle data show an extended flat lower envelope for small cars. This "floor" is not an indication of a different physical relation between CO_2 and mass for small vehicles, but rather a result of the fact that national taxation systems do not reward manufacturers for marketing vehicles that emit less than 90 to 100 g/km.
- The two black dashed lines indicate slope along which the CO_2 emissions of vehicles of given mass and CO_2 emission increase as a result of mass increase, using the formula

$$\Delta CO_2 = 0.65 * \frac{\Delta m \cdot CO_2}{m}$$

This formula is valid for mass increase accompanied by an increase in engine power to keep vehicle performance constant. As can be seen the slope of the 100% linear limit function is lower than that of the line representing CO_2 increase as a function of mass increase for current vehicles (dashed line through the cloud). This means that a limit function with 100% slope for the 95 g/km target already discourages gaming with mass. When vehicles come closer to the limit function mass increase may help a little to get the closer to the line for large vehicles only.

- A ceiling for the truncated limit function set at two times the target value of 95 g/km (=190 g/km) only intercepts with the sloped part of the limit function beyond the heaviest registered cars and therefore has no effect.
- A floor value set at 70 g/km applies to only a very limited number of cars and therefore has almost no effect on the target for larger vehicles.
- For a limit function with a ceiling at 190 g/km and a floor at 70 g/km to meet the 95 g/km target the sloped part in between the floor and ceiling almost coincides with the non-truncated 100% slope linear limit function.
- For the purpose of assessing the effect of a ceiling between ‘upper medium’ and ‘large’ vehicles, another truncated limit function was designed in such a way that the ceiling would affect vehicles with mass above approximately 1800 kg (typical threshold derived from a review of typical vehicles of class ‘upper medium’ and ‘large’). This results in a ceiling of about 120 g/km. However, since only 5.8% of all sold vehicles is heavier than 1800 kg, the slope and positioning of the part in between the floor and ceiling is still affected only very minimally.
- A ceiling in a limit function is a political signal indicating that beyond a certain utility value and CO_2 threshold a further increase in utility is no longer rewarded by a higher target. The stricter target for large vehicles can be used to reduce the required reduction for smaller vehicles. Given the sales distribution of vehicles in Europe, however, the CO_2 threshold needs to be fairly low in order to have a noticeable impact on the targets set for manufacturers selling on average smaller cars.
- The only way to make a ceiling of 190 g/km affect targets for large existing vehicles is to combine it with a sloped part with a very high slope. This, however, can not be done without the following undesired consequences:
  - significantly more lenient targets than defined by the non-truncated 100% slope limit function for medium size vehicles with utility value just below the intercept of sloped part and ceiling;
  - possibly stricter targets for smaller vehicles (depending on the level of the floor in the limit function);
  - a slope for the middle part that is higher than the effect of mass increase on CO_2 so that gaming with mass would be strongly promoted.

Footprint



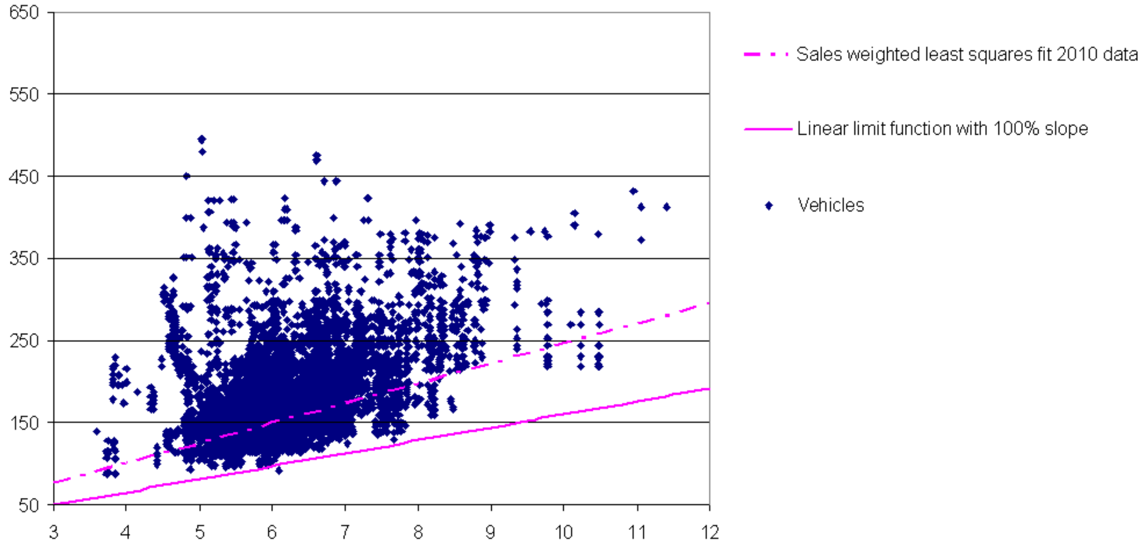
For footprint as a utility parameter, several conclusions can be drawn from the limit curve plot.

- Similar as for mass as a utility parameter, for the truncated limit curve, the ceiling of 190 g/km intercepts the sloped section at a utility value that is higher than that of any of the vehicles in the database, and therefore has no effect. Again also the effect of a floor at 70 g/km on the sloped part (in between the floor and the ceiling) is very minimal.

- Therefore also for footprint another truncated limit function was made to assess the effect of a ceiling that affects vehicles above the 'upper medium' segment. The ceiling and sloped part of the limit function are defined such that the ceiling applies to vehicles with a footprint larger than 4.75 m^2 (based on review of typical vehicles of class 'upper medium' and 'large'). Again, this results in a ceiling of about 120 g/km. Since in this case only 0.9% of all sold vehicles have a footprint of more than 4.75 m^2, the slope of the part of the limit function in between the floor and ceiling is affected even less than was the case for mass.

Footprint*Height

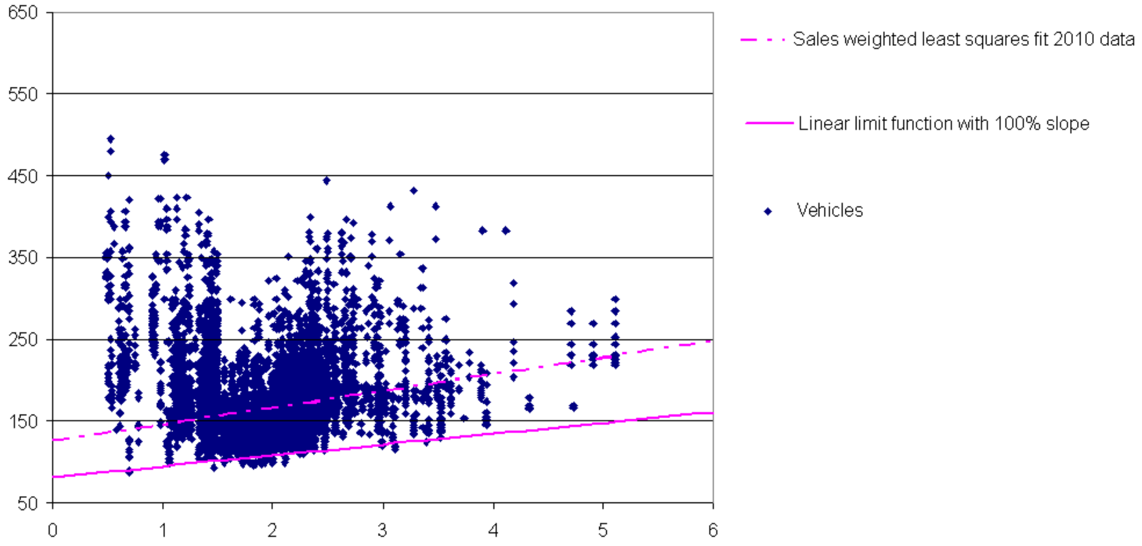
For the utility parameter 'footprint*height' for the moment only a linear limit curve was constructed from the least squares fit. Although no truncated limit curve was made, it can be seen that a floor and ceiling at respectively 70 g/km and 190 g/km will have very little impact.



Normalised seat & trunk volume

For the utility parameter 'normalised seat & trunk volume' only a linear limit curve was constructed from the least squares fit. It can be seen that CO_2 emissions correlate least well to this utility parameter.

Although no truncated limit curve was made, it can be seen that also here a floor and ceiling at respectively 70 g/km and 190 g/km will have very little impact. For a floor that would affect a significant number of existing vehicles the impacts are somewhat controversial. Vehicles with low 'normalised seat & trunk volume' are mostly sports cars with high CO_2 emissions. With the positively sloped linear limit function these vehicles get targets that are lower than those for all other cars and which they will certainly not be able to meet. Setting a floor here could then be defended as means to on the one hand reduce the required for small vehicles (e.g. Smart) and on the other hand make life somewhat easier for manufacturers of sports cars. But it is debatable whether this is desired in the context of a limit function based on a parameter that is strictly correlating with functional utility.



H.4 Conclusions

- The heavy concentration of sales around medium sized vehicles in the EU makes that floors and ceilings have to be set at very high (floors) respectively very low (ceilings) levels in order to affect the targets of a significant number of vehicles. If the purpose of the floors and ceilings is more than just giving a political signal, but also to effectively alleviate the reduction targets for medium sized cars, then they have to be set at even more extreme values.
- The above analysis shows that floors and ceilings are an interesting theoretical concept but that intuitively reasonable levels for these floors and ceilings do not have significant impacts. Setting floors above 70 g/km and ceilings of 150 g/km or less requires careful political consideration.
- The limit function for the 130 g/km target for 2015 is set at a 60% slope compared to the limit function that constitutes constant relative reduction compared to the sales weighted fit through the CO_2 emissions of existing vehicles (2006 database). The 2010 database reveals a significantly lower slope for the sales weighted fit through the CO_2 emissions of existing vehicles. It therefore seems defendable not to flatten the slope of the limit function for the 95 g/km targets very much compared to the 100% slope limit line defined on the basis the 2010 database. A 100% or 80% slope may already be a sufficient disincentive for gaming. This, however, requires further analysis.

I Overview of positions on the cost curve for each manufacturer group

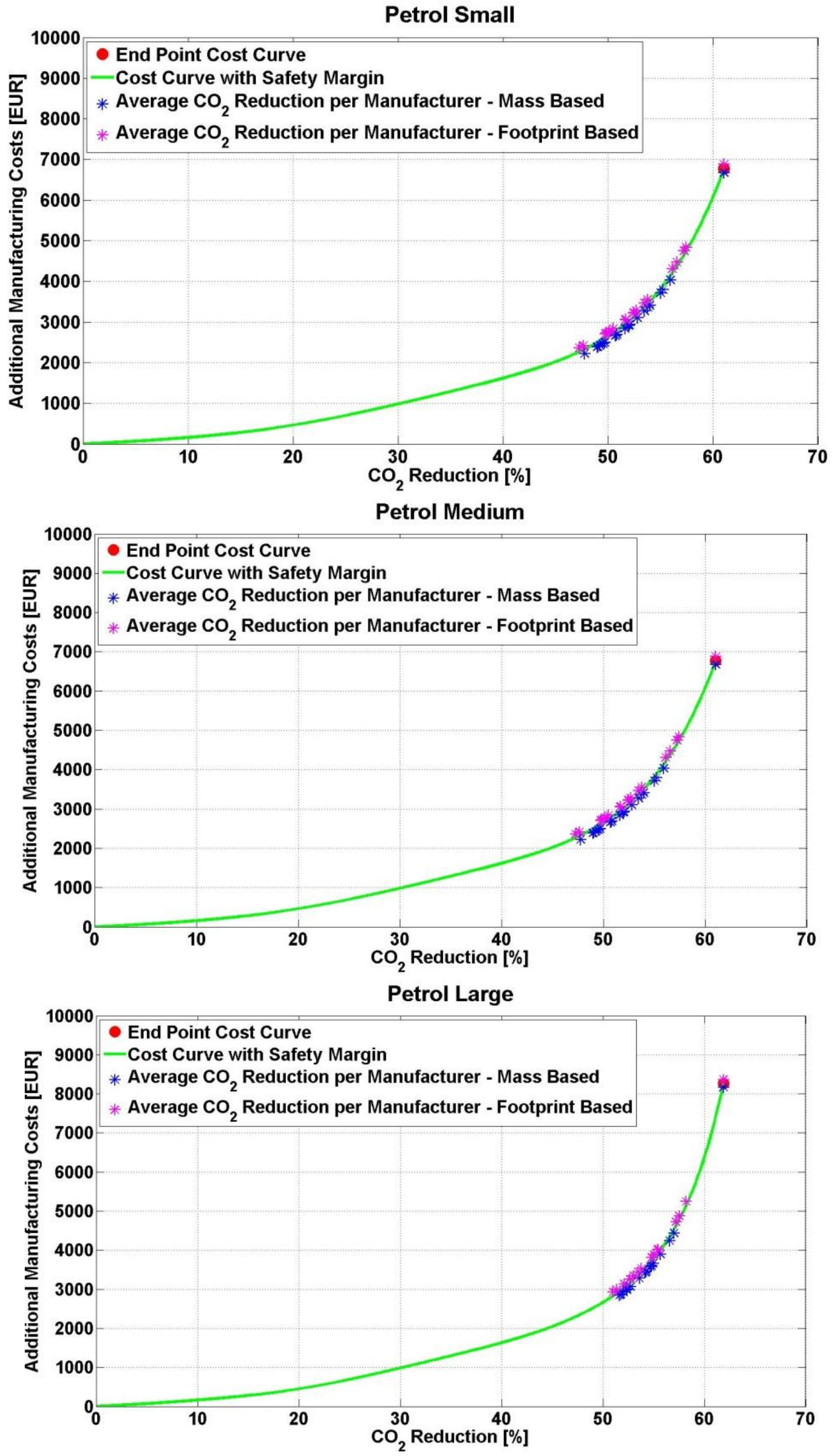


Figure 111 Position on the cost curve for each manufacturer group for small-sized, medium-sized and large-sized petrol cars. The blue asterisks represent the positions of each manufacturer group using a mass-based utility parameter. The magenta asterisks represent the positions of each manufacturer group using a footprint-based utility parameter.

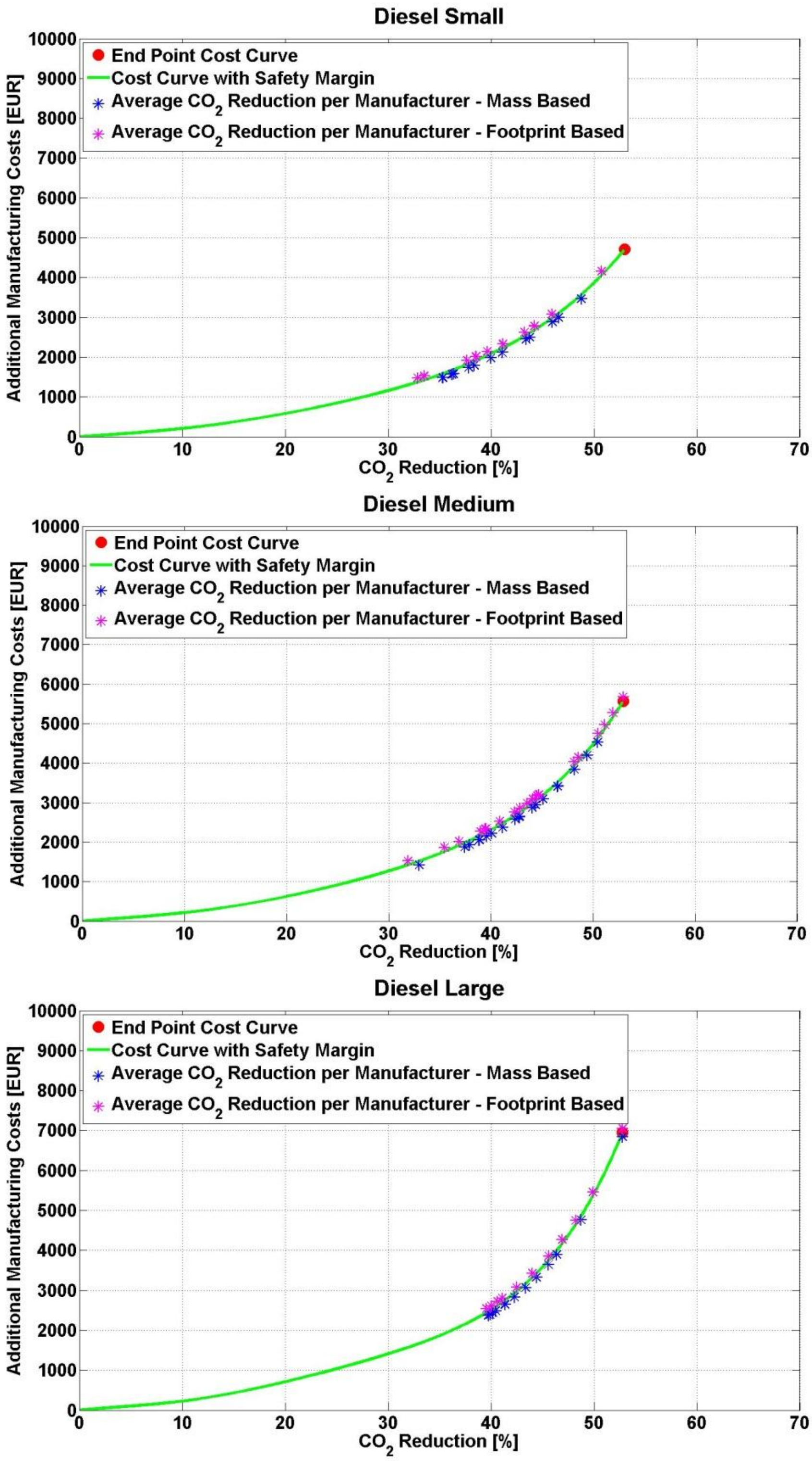


Figure 112 Position on the cost curve for each manufacturer group for small-sized, medium-sized and large-sized diesel cars. The blue asterisks represent the positions of each manufacturer group using a mass-based utility parameter. The magenta asterisks represent the positions of each manufacturer group using a footprint-based utility parameter.

J Detailed overview of assumed market shares and additional manufacturer costs of different types of electric vehicles

Table 150 Distribution of EV types within the four scenarios assessed within task 3. The averages are used in the calculations explained in the main task of section 10.4.

Electric vehicle type	Segment	Fuel type	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
			CO_2 emissions [g/km]	Sales share	Costs [€]	CO_2 emissions [g/km]	Sales share	Costs [€]	CO_2 emissions [g/km]	Sales share	Costs [€]	CO_2 emissions [g/km]	Sales share	Costs [€]
PHEV	Small	Petrol	53	10%	5172	49	10%	5172	53	11%	5172	-	0%	5172
PHEV	Medium	Petrol	64	22%	5700	58	24%	5700	64	21%	5700	-	0%	5700
PHEV	Large	Petrol	82	5%	5786	71	6%	5786	82	5%	5786	-	0%	5786
PHEV	Small	Diesel	41	1%	5703	36	1%	5703	41	1%	5703	-	0%	5703
PHEV	Medium	Diesel	52	19%	6192	46	21%	6192	52	18%	6192	-	0%	6192
PHEV	Large	Diesel	72	6%	6286	65	6%	6286	72	5%	6286	-	0%	6286
EREV	Small	Petrol	40	4%	5980	36	4%	5980	40	5%	5980	-	0%	5980
EREV	Medium	Petrol	49	7%	6513	42	6%	6513	49	7%	6513	-	0%	6513
EREV	Large	Petrol	62	2%	6555	53	2%	6555	62	2%	6555	-	0%	6555
EREV	Small	Diesel	31	1%	6426	26	0%	6426	31	1%	6426	-	0%	6426
EREV	Medium	Diesel	39	6%	7061	36	6%	7061	39	6%	7061	-	0%	7061
EREV	Large	Diesel	54	2%	7105	49	2%	7105	54	2%	7105	-	0%	7105
FEV	Small	-	0	6%	7957	0	5%	7957	0	7%	7957	0	40%	7957
FEV	Medium	-	0	8%	10193	0	6%	10193	0	8%	10193	0	50%	10193
FEV	Large	-	0	2%	11326	0	1%	11326	0	2%	11326	0	10%	11326
Average			**48**	**5%**	**6551**	**45**	**3%**	**6449**	**47**	**10%**	**6449**	**0**	**10%**	**9412**

K Detailed outputs from the assessment of impacts of an additional vehicle-based CO_2 limit

The tables and charts which follow in this Annex show a range of results for different limits selected in this study for analysis.

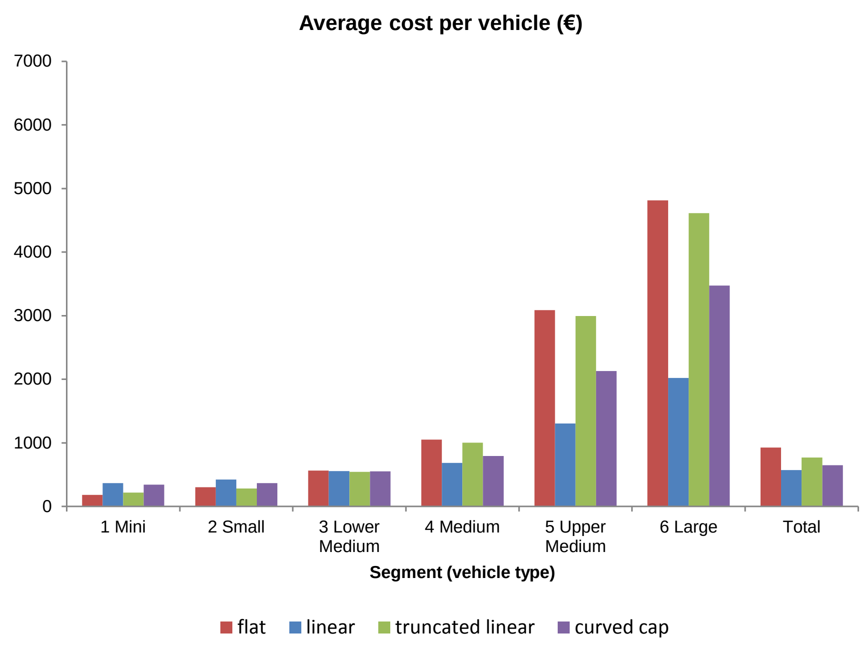
For each limit curve (flat, linear, truncated linear and curved), parameters have been chosen which achieve fleet average emissions of 120gCO_2/km, 115gCO_2/km and 110gCO_2/km. The first group of results show the impact of limits based on reference mass (estimated by taking kerb weight plus 60kg) and the second set of results show the impact of limits based on vehicle footprint.

The tables illustrate what proportion of the fleet is affected, an estimate of the costs associated with achieving the limit and the total buy-out premium which could be expected after reductions have been applied. The charts show the cost per vehicle for each market segment.

Aim of 120gCO_2/km fleet average emissions, Utility parameter – Reference Mass

Utility: mass Fleet average cap: 120 g/km	Flat cap For all M: EL = E1	Linear cap For all M: EL = E1 + a(M - M0)	Truncated linear cap For M ≥ M1: EL = E2 For M < M1: EL = E2 + b(M - M0)	Curved cap For all M: EL = E1 + (E2 - E1) x TANH(M/C)
E1	130	124	47	40
E2	-	-	132	160
M0	-	1346	1346	-
C	-	-	-	1500
a	-	0.0494	0.0494	-

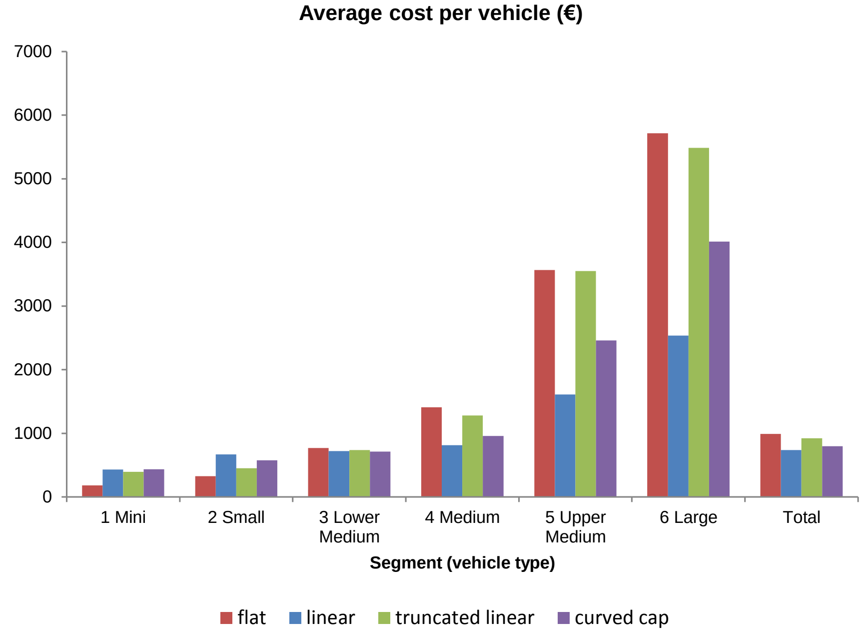
Utility: mass **Fleet average cap: 120 g/km**	Flat cap	Linear cap	Truncated linear cap	Curved cap
Total sales under cap [-]	5,903,167	4,309,217	5,076,152	4,509,906
% market share under cap	59%	43%	50%	45%
Total sales over cap [-]	4,152,392	5,746,342	4,979,407	5,545,653
% market share over cap	41%	57%	50%	55%
Total cost of reducing CO_2 emissions [€]	3,845,687,025	3,275,010,629	3,837,067,075	3,581,887,886
Average cost of reducing CO_2 emissions [€]	926	570	771	646
Average CO_2 emissions of market after reduction [g/km]	120	120	120	120
Number of vehicles exceeding cap after maximum reduction [-]	105,177	15,785	86,289	39,610
Average exceedance of cap [g/km]	18	16	19	14
Total buyout cost [€]	184,165,123	26,013,282	161,647,790	56,711,828
Average buyout cost per vehicle [€]	1,751	1,648	1,873	1,432



Aim of 115gCO_2/km fleet average emissions, Utility parameter – Reference Mass

Utility: mass Fleet average cap: 115 g/km	Flat cap For all M: EL = E1	Linear cap For all M: EL = E1 + a(M - M0)	Truncated linear cap For M ≥ M1: EL = E2 For M < M1: EL = E2 + b(M - M0)	Curved cap For all M: EL = E1 + (E2 - E1) x TANH(M/C)
E1	120	116	47	40
E2	-	-	123	160
M0	-	1346	1346	-
C	-	-	-	0
a	-	0.0494	0.0494	-

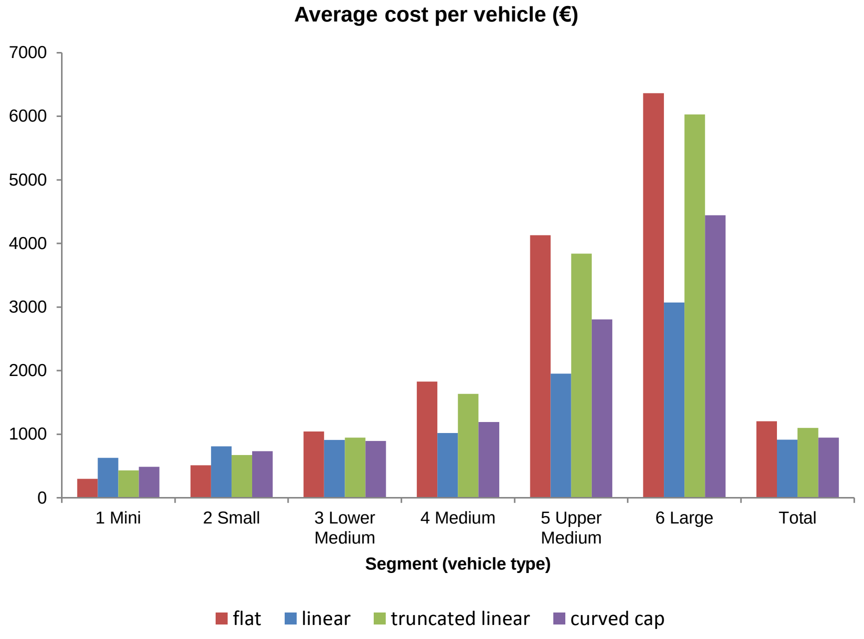
Utility: mass **Fleet average cap: 115 g/km**	Flat cap	Linear cap	Truncated linear cap	Curved cap
Total sales under cap [-]	3,792,910	2,586,747	3,332,271	2,847,439
% market share under cap	38%	26%	33%	28%
Total sales over cap [-]	6,262,649	7,468,812	6,723,288	7,208,120
% market share over cap	62%	74%	67%	72%
Total cost of reducing CO_2 emissions [€]	6,202,988,943	5,490,268,755	6,191,045,444	5,736,993,514
Average cost of reducing CO_2 emissions [€]	990	735	921	796
Average CO_2 emissions of market after reduction [g/km]	115	115	115	115
Number of vehicles exceeding cap after maximum reduction [-]	221,969	24,848	178,718	57,619
Average exceedance of cap [g/km]	16	18	16	15
Total buyout cost [€]	353,250,510	44,136,516	288,322,364	89,270,944
Average buyout cost per vehicle [€]	1,591	1,776	1,613	1,549



Aim of 110gCO_2/km fleet average emissions, Utility parameter – Reference Mass

Utility: mass Fleet average cap: 110 g/km	Flat cap For all M: EL = E1	Linear cap For all M: EL = E1 + a(M - M0)	Truncated linear cap For M ≥ M1: EL = E2 For M < M1: EL = E2 + b(M - M0)	Curved cap For all M: EL = E1 + (E2 - E1) x TANH(M/C)
E1	112	110	47	40
E2	-	-	116	160
M0	-	1346	1346	-
C	-	-	-	0
a	-	0.0494	0.0494	-

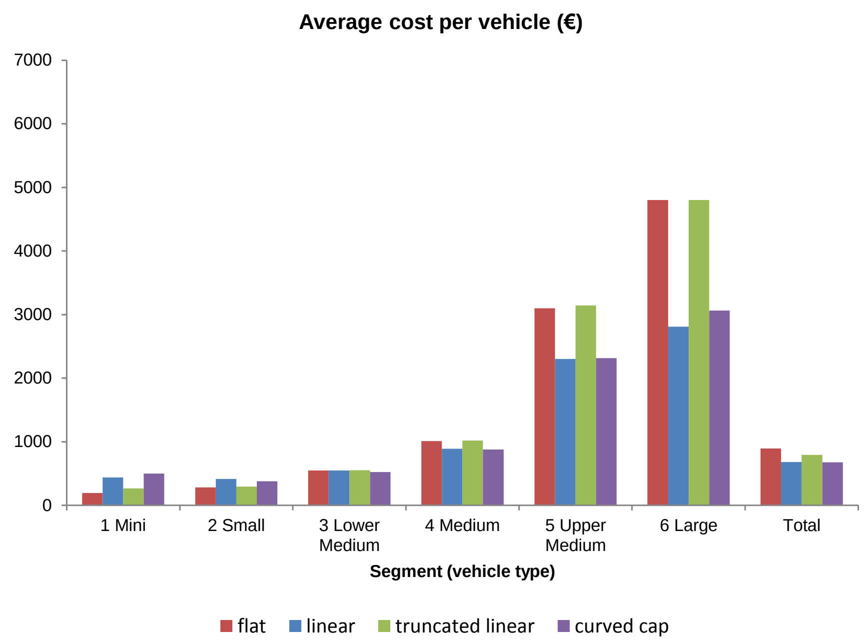
Utility: mass **Fleet average cap: 110 g/km**	Flat cap	Linear cap	Truncated linear cap	Curved cap
Total sales under cap [-]	2,572,937	1,458,225	2,126,505	1,798,902
% market share under cap	26%	15%	21%	18%
Total sales over cap [-]	7,482,622	8,597,334	7,929,054	8,256,657
% market share over cap	74%	85%	79%	82%
Total cost of reducing CO_2 emissions [€]	8,989,396,142	7,838,254,505	8,705,281,295	7,818,586,427
Average cost of reducing CO_2 emissions [€]	1,201	912	1,098	947
Average CO_2 emissions of market after reduction [g/km]	110	110	110	110
Number of vehicles exceeding cap after maximum reduction [-]	316,266	35,612	264,325	85,305
Average exceedance of cap [g/km]	18	18	17	15
Total buyout cost [€]	580,858,462	64,149,832	455,116,498	128,729,649
Average buyout cost per vehicle [€]	1,837	1,801	1,722	1,509



Aim of 120gCO_2/km fleet average emissions, Utility parameter – Footprint

Utility: footprint Fleet average cap: 120 g/km	Flat cap For all M: EL = E1	Linear cap For all M: EL = E1 + a(M - M0)	Truncated linear cap For M ≥ M1: EL = E2 For M < M1: EL = E2 + b(M - M0)	Curved cap For all M: EL = E1 + (E2 - E1) x TANH(M/C)
E1	130	124	47	-70
E2	-	-	130	193
M0	-	3.85	3.85	-
C	-	-	-	0
a	-	29.7	29.7	-

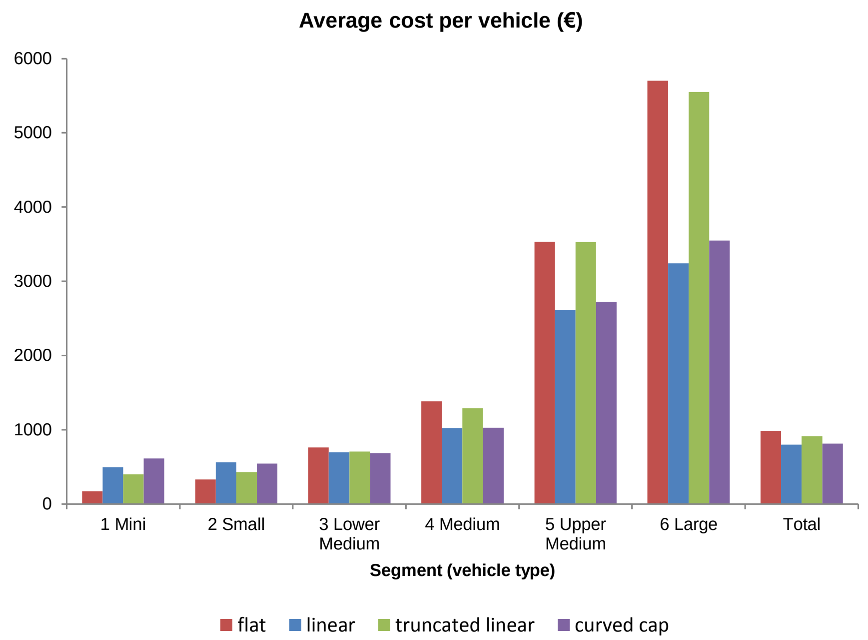
Utility: footprint **Fleet average cap: 120 g/km**	Flat cap	Linear cap	Truncated linear cap	Curved cap
Total sales under cap [-]	5,710,900	4,509,054	4,764,720	4,748,156
% market share under cap	57%	45%	48%	48%
Total sales over cap [-]	4,221,292	5,423,138	5,167,472	5,184,036
% market share over cap	43%	55%	52%	52%
Total cost of reducing CO_2 emissions [€]	3,777,581,930	3,691,618,575	4,089,234,426	3,514,429,197
Average cost of reducing CO_2 emissions [€]	895	681	791	678
Average CO_2 emissions of market after reduction [g/km]	120	120	120	120
Number of vehicles exceeding cap after maximum reduction [-]	105,510	58,308	110,549	58,677
Average exceedance of cap [g/km]	16	15	17	16
Total buyout cost [€]	173,565,067	90,126,113	184,591,583	92,270,074
Average buyout cost per vehicle [€]	1,645	1,546	1,670	1,573



Aim of 115gCO_2/km fleet average emissions, Utility parameter – Footprint

Utility: footprint Fleet average cap: 115 g/km	Flat cap For all M: EL = E1	Linear cap For all M: EL = E1 + a(M - M0)	Truncated linear cap For M ≥ M1: EL = E2 For M < M1: EL = E2 + b(M - M0)	Curved cap For all M: EL = E1 + (E2 - E1) x TANH(M/C)
E1	120	117	47	-70
E2	-	-	122	193
M0	-	3.85	3.85	-
C	-	-	-	0
a	-	29.7	29.7	-

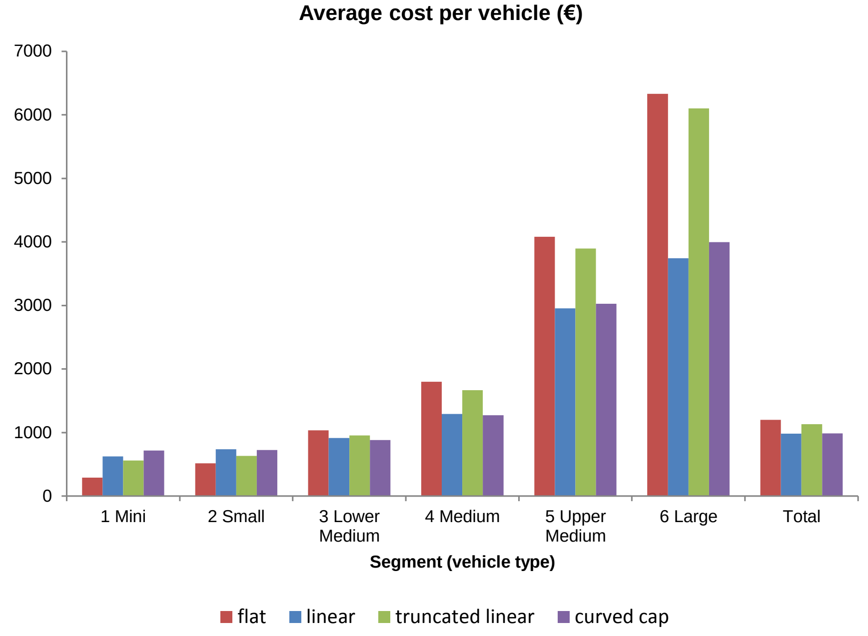
Utility: footprint **Fleet average cap: 115 g/km**	Flat cap	Linear cap	Truncated linear cap	Curved cap
Total sales under cap [-]	3,732,390	2,980,843	3,174,618	2,991,030
% market share under cap	38%	30%	32%	30%
Total sales over cap [-]	6,199,802	6,951,349	6,757,574	6,941,162
% market share over cap	62%	70%	68%	70%
Total cost of reducing CO_2 emissions [€]	6,111,751,646	5,566,752,823	6,181,368,245	5,649,083,029
Average cost of reducing CO_2 emissions [€]	986	801	915	814
Average CO_2 emissions of market after reduction [g/km]	115	115	115	115
Number of vehicles exceeding cap after maximum reduction [-]	214,417	79,795	187,306	85,790
Average exceedance of cap [g/km]	16	17	16	18
Total buyout cost [€]	337,776,423	139,088,790	307,696,901	152,468,956
Average buyout cost per vehicle [€]	1,575	1,743	1,643	1,777



Aim of 110gCO_2/km fleet average emissions, Utility parameter – Footprint

Utility: footprint Fleet average cap: 110 g/km	Flat cap For all M: EL = E1	Linear cap For all M: EL = E1 + a(M - M0)	Truncated linear cap For M ≥ M1: EL = E2 For M < M1: EL = E2 + b(M - M0)	Curved cap For all M: EL = E1 + (E2 - E1) x TANH(M/C)
E1	112	110	47	-70
E2	-	-	115	193
M0	-	3.85	3.85	-
C	-	-	-	0
a	-	29.7	29.7	-

Utility: footprint **Fleet average cap: 110 g/km**	Flat cap	Linear cap	Truncated linear cap	Curved cap
Total sales under cap [-]	2,553,903	1,646,407	2,238,496	1,789,056
% market share under cap	26%	17%	23%	18%
Total sales over cap [-]	7,378,289	8,285,785	7,693,696	8,143,136
% market share over cap	74%	83%	77%	82%
Total cost of reducing CO_2 emissions [€]	8,860,196,758	8,144,061,505	8,698,658,178	8,022,886,850
Average cost of reducing CO_2 emissions [€]	1,201	983	1,131	985
Average CO_2 emissions of market after reduction [g/km]	110	110	110	110
Number of vehicles exceeding cap after maximum reduction [-]	305,147	142,622	277,689	144,903
Average exceedance of cap [g/km]	18	16	18	16
Total buyout cost [€]	557,826,058	230,356,753	489,084,115	232,609,209
Average buyout cost per vehicle [€]	1,828	1,615	1,761	1,605



L Greenhouse gas emissions from production and use of hybrid and electric cars in comparison with petrol equivalents

Table 151 Normalised data on greenhouse gas emissions from production and use of hybrid and electric cars in comparison with petrol equivalents from different studies (kgCO_2 eq.).

Vehicle manufacturing phase (kg)	**Fuel chain emissions (kg)**	**Usage phase (kg)**	**Total (kg)**
Petrol			
3,807	3,621	22,025	29,452
5,740	5,460	33,216	44,416
7,746	7,655	46,566	61,967
Vehicle manufacturing phase (kg)	**Fuel chain emissions (kg)**	**Usage phase (kg)**	**Total (kg)**
Diesel			
4,772	6,054	32,002	42,828
6,431	9,593	50,707	66,731
8,550	13,277	70,176	92,003
Vehicle manufacturing phase (g/km)	**Fuel chain emissions (g/km)**	**Usage phase (g/km)**	**Total (g/km)**
Petrol			
28	26	160	213
33	32	192	257
39	38	234	311
Diesel			
21	27	142	190
21	32	167	220
25	39	204	267

Table 152 Absolute and relative emissions of the vehicle production stage assuming an average vehicle lifetime of 180, 000 km (g CO_2 eq./km).

	petrol		**diesel**	
	g/km	%	g/km	%
Small	21	10%	27	12%
Medium	32	12%	36	14%
Large	43	15%	48	16%

Table 153 Normalised data on greenhouse gas emissions from production and use of hybrid and electric cars in comparison with petrol equivalents from different studies.

		Energy use	**Total GHG, $kgCO_2$ eq.**				
		MJ/km	Production	Battery	Total P+B	Recycling	Use
Samaras 2008*	Petrol CV	2.5	8,500	0	8,500		49,542
	Petrol HEV	1.7	8,500	300	8,660		33,688
	Petrol PHEV 30	1.21	8,500	810	9,310		27,336
	Petrol PHEV 60	0.98	8,500	1,610	10,110		24,504
	Petrol PHEV 90	0.90	8,500	2,420	10,920		23,424
Torchio 2010	Petrol CV	1.89					51,325
	Diesel CV	1.77					49,482
	Petrol HEV	1.63					38,444
	Diesel HEV	1.46					37,217
	BEV	1.11					30,528
AEA 2007	Petrol CV	2.59	3,800	0	3,800	-1,564	30,000
	Diesel CV	2.34	3,817	0	3,817	-1,495	21,804
	Petrol HEV	1.94	3,800	1,491	5,291	-1,189	45,000
	Diesel HEV	1.76	3,817	1,491	5,308	-1,120	34,000
	Petrol PHEV 50	1.28	3,800	2,136	5,937	-1,908	36,000
	Diesel PHEV 50	1.20	3,817	2,136	5,954	-1,839	28,791
	BEV	0.70	3,800	3,150	6,951	-1,389	49,542
Helms 2010	Petrol CV	2.08	4,000	0	4,000		33,688
	Diesel CV	1.74	4,000	0	4,000		27,336
	Petrol PHEV 50	1.33	4,000	1,000	5,000		24,504
	BEV	0.79	4,000	2,500	6,500		23,424

Notes: Use data has been normalised from original sources to the GHG intensity of the EU electricity mix (based on JEC, 2008) and an assumed average EU vehicle lifetime of 238,000 km (based on data from TREMOVE).
** Battery production GHG emissions for Samaras 2008 are for Li-ion batteries. GHG emissions for production of NiMH batteries (currently used in HEVs) were estimated to be roughly double these figures.*
In-use emissions include upstream emissions for fuel production.