Support for the revision of regulation on CO_2 emissions from light commercial vehicles

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Executive Summary

Introduction

The European Union has committed itself to a 20% reduction of its greenhouse gas emissions by 2020 compared to 1990, and of 30% in case other major economies make comparable efforts. Transport is one of the main emitting sectors, and the only one that continues to grow substantially. Road transport is responsible for the majority of the overall transport emissions, and the EU strategy to reduce CO_2 emissions from light-duty vehicles sets out a number of measures to reduce road transport emissions. Regulation (EC) No 443/2009 to reduce CO_2 emissions from passenger cars adopted in 2009 (further referred to as "the cars regulation") is the main tool of this strategy. Regulation to reduce CO_2 emissions from light commercial vehicles (LCVs or vans) – Regulation (EU) 510/2011 further referred to as "the vans regulation", is part of this overall strategy. The vans regulation is a follow-up of the cars regulation and is intended to minimise the regulatory gap between M1 and N1 vehicle categories.

Objective

The vans regulation contains a number of review clauses. Notably, Article 13(1) requires the Commission to carry out an impact assessment to confirm the feasibility of the 2020 target of 147 gCO_2/km and to define the modalities for reaching it in a cost-effective manner and the aspects of implementation of that target, including the excess emission premium. Furthermore, Article 13(6) requires the Commission to publish by 2014 a report on the availability of data on footprint and payload, and their use as utility parameters for determining specific emissions target and, if appropriate, submit a proposal to amend Annex I. Finally, Article 13(4) requires the Commission to set up by 31 December 2011 “a procedure to obtain representative values of CO_2 emissions, fuel efficiency and mass of completed vehicles while ensuring that the manufacturer of the base vehicle has timely access to the mass and to the specific emissions of CO_2 of the completed vehicle”. Furthermore, Annex II part B point 7 defines the framework for such revision, including the procedures to be taken into consideration during this review.

For the review of the 147 gCO_2/km target and suitability of various modalities the following subjects have been addressed:

- Analysis of the 2010 LCV market and comparison to the situation in previous studies
- Development of cost curves for different LCV segments
- The evaluation of utility parameters, i.e. mass in running order, footprint and payload
- Determining other policy options, e.g. the obligated or responsible entity
- Assessment of the additional manufacturer costs and distributional impacts of the 2020 target for various utility parameters
- Penalty or excess premium level assessment
- Comparison with the effort needed to reduce CO_2 emissions from passenger cars to meet the 2020 target
- Impact of electric vehicle penetration
- Total cost of ownership effects and the societal abatement costs of the 2020 target

2010 LCV market

In 2010 39% less LCVs were sold within the big five European countries compared to 2007. In terms of the fractions of total sales for the different LCV weight classes there is a markedly different pattern in 2010 relative to 2007. This is shown in Figure 1. It shows a higher number of smaller LCV sales relative to the numbers of Class III LCVs sold.

This shift in sales has also contributed to the decrease of average CO_2 emissions of approximately 11% (form 203 g/km in 2007 to 181 in 2010). However, besides this shift, other factors have also contributed to this significant decrease, e.g. the fact that for the 2009 study a significant share of CO_2 emission values that to be determined because they were not available in the database. This is discussed in more detail below in the section in which the distributional impacts of this study are compared to those of the 2009 study.

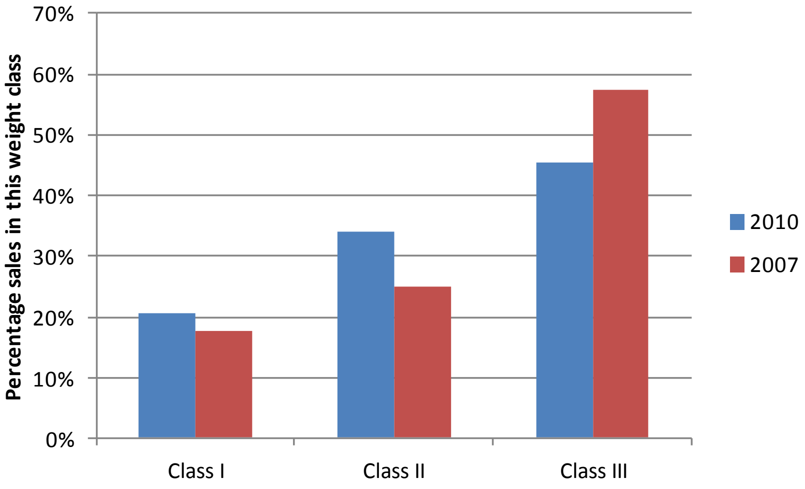

Figure 1 Market shares of different weight classes in the 2007 and 2010 new light commercial vehicle sales

Cost curves

Cost curves for small, medium and large diesel LCVs constructed for this report are based on the minimum costs for combinations of technological CO_2 reducing measures to 2010 baseline vehicles. Selection of CO_2 reduction technologies and assessment of their CO_2 reduction potential and additional costs (relative to the 2010 baseline vehicle) were made on the basis of expert opinion from within the consortium. This differs from the approach taken in [TNO 2011], where literature review was also used because of two reasons, i.e. the assessments for LCVs builds on the analysis from [TNO 2011] for passenger cars and due to contractual limitations. Single point estimates for the costs and CO_2 reduction potential (as measured on the NEDC cycle) were derived for each individual technology to be used as input for the formation of cost curves.

In defining the reduction potential of packages of measures 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.

Several technologies were not taken into account in constructing the cost curves for different reasons. Firstly battery electric vehicles (BEV) and range-extended electric vehicles (REEV) are not taken into account because these are not technologies that can be applied to conventional ICEVs but are rather alternative drive train technologies. Moreover the costs of these technologies are so high that packages including these “technologies” are separated from the rest of the packages. As a result the difference in costs between either applying one of these technologies or not is very big, resulting in a ‘gap’ in the cost curves. Besides BEVs and REEVs several other technologies were not taken into account in constructing cost curves because the cost efficiency of some technologies is very low, e.g. strong lightweighting. As a result some technology packages at the right-upper corner of the cost cloud (excluding BEV and REEV) cost significantly more than other packages lacking these options but add an only very limited amount of CO_2 reductions. In reality it is very unlikely that manufacturers will reduce CO_2 emissions to such high marginal costs.

It can be concluded that for CO_2 emission reductions up to 31% the additional vehicle costs for reaching a given level of reduction are similar for all three segments. From 31% onwards the cost curves predict higher costs for CO_2 emission reductions for small-sized LCVs than for medium-sized LCVs and from 33% onwards costs for small LCVs are also higher than for large LCVs. The maximum reduction potential is found to increase with vehicle size. This is e.g. due to a number of technologies that can be applied to N1 Class III vans, but cannot be applied to

N1 Class I and/or Class II vans (see Table 9), i.e. variable valve actuation, thermo-electric generation and secondary heat recovery cycle and electrical assisted steering.

The fact that the new curves predict lower costs than the earlier indicative curves for 2020 from [Sharpe & Smokers 2009], leads to the conclusion that costs for reaching 147 gCO_2/km will be lower than indicated in the 2009 study. Moreover, since the new cost curves show higher reduction potentials, the likelihood that the 147 g/km target for 2020 will be met is increased.

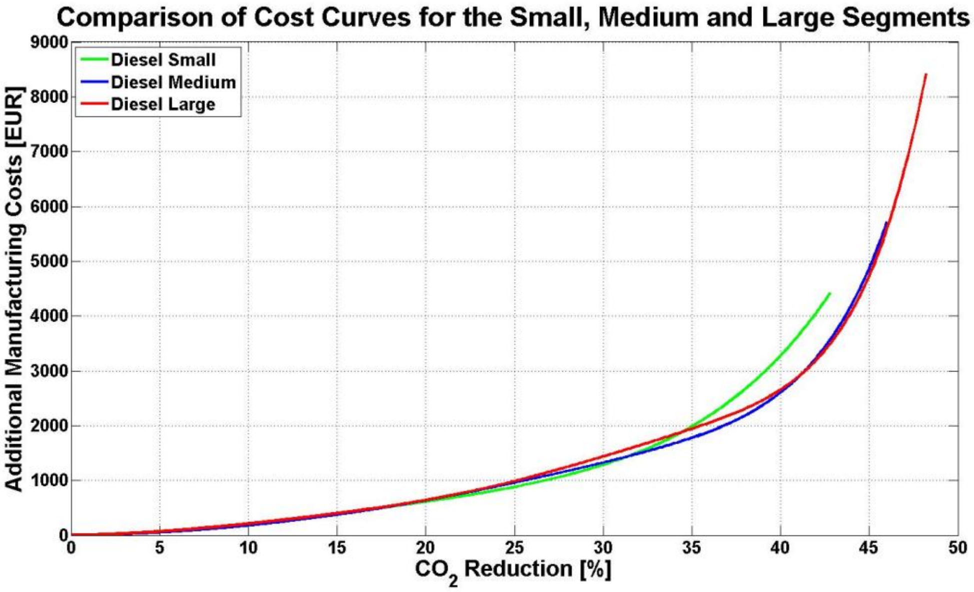

Figure 2 Cost curves for CO_2 emission reductions small-sized, medium-sized and large-sized diesel LCVs in 2020, relative to 2010 baseline vehicles.

Table 1 Coefficient values and end points for 8th order polynomial cost curves for diesel LCVs in 2020, relative to 2010 baseline vehicles

	a_8	a_7	a_6	a_5	a_4	a_3	a_2	a_1	End %	End €
Diesel Small				8.07E+05	-3.30E+05	1.78E+04	1.48E+04	6.87E+02	41.9%	4455
Diesel Medium	2.89E+07	-2.53E+07	6.93E+06	-8.68E+04	-2.95E+05	5.06E+04	1.13E+04	4.48E+02	46.1%	5780
Diesel Large	6.38E+07	-6.13E+07	1.66E+07	5.03E+05	-6.95E+05	5.16E+04	1.58E+04	5.64E+02	48.2%	8475

Evaluation of utility parameters: mass in running order, footprint and payload

The impacts of the 147 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 or requirements with respect to e.g. minimizing additional manufacturer costs for reaching the target, 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.

Results of a qualitative comparison of utility parameters

In this study the suitability is assessed of footprint and payload as alternatives to mass for the utility parameter to be used for the 2020 target. As can be seen in Figure 3, mass in running order correlates better with CO_2 than footprint (Figure 4) and payload (Figure 5). However, mass is not as good a proxy for the utility of a vehicle as footprint or payload. Also mass as a utility parameter to some extent discourages the use of light-weighting as an option for CO_2 reduction. Compared to the situation for passenger cars, however, there is an incentive for LCV manufacturers to reduce the vehicle weight, since lowering vehicle mass can increase payload. Therefore this specific disadvantage of mass as utility parameter is less relevant for LCVs than for passenger cars.
As shown in Figure 3, the gradient of the 2010 sales weighted least squares best fit (0.118) is larger than that for the 2017 limit function (0.1079, [AEA TNO 2008]).

Footprint is a reasonably better proxy for utility as it is a characteristic that correlates with the volume of the load that can be transported. However, from Figure 4 it becomes clear that a linear limit function does not reflect the distribution of LCV CO_2 emissions over the footprint range. Small (up to about $7m^2$) and large (above approximately $9m^2$) LCVs are to a large extent situated under or at the linear best fit, while the vehicles in between are largely above this line (Figure 4). Since the final limit function is derived from this best fit, manufacturers selling LCVs with footprints between approximately $7m^2$ and $9m^2$ would have a relatively large distance to target if footprint were used in combination with a linear limit function. Since (from a societal) perspective there is no reason to discourage vehicles with such footprint, this effect is undesirable. Therefore a non-linear limit function is needed to evenly distribute the effort for meeting the 147 g/km target.

Payload is in principle a good proxy for van utility. However, for vehicles with a maximum GVW (i.e. 3500 kg), the payload decreases when (unladen) weight increases, while in reality such a heavier vehicles would not necessarily be able to bear less mass. Moreover payload (or maximum permissible load) is a declared value that cannot be independently verified. This is a major disadvantage of payload. It can be manipulated by manufacturers. Also the CO_2 impact of vehicle modifications to increase payload could be relatively small. This would offer room for gaming. For mainly the same reasons as for footprint, a non-linear limit function would be needed to evenly distribute the effort over the payload range.

For all assessed utility parameters the CO_2 emissions are found to level off at the upper end of the utility range. This is largely due to discontinuities in the type approval procedure. Various elements of the chassis dynamometer testing procedure, used to determine the CO_2 [g/km] emissions of a vehicle, affect the outcome of the test in such a way that type approval CO_2 emissions become insensitive to increases in vehicle mass (or size) beyond a certain point. The identified elements are listed below:

- The inertia level in the TA test does not increase beyond 2270 kg for vehicles weighing above 2210 kg. Moreover the dynamic coefficients do not change for vehicles weighing above 2610 kg. As a result the relation between size/mass and CO_2 emissions levels off between 2210 kg and 2610 kg. Above 2610 kg the CO_2 emissions are only defined by the efficiency of the engine. Consequently, the CO_2 emissions level off even more.
- Manufacturers have the option to either use simulated inertia and dynamometer load settings depending on the mass class of the vehicle (“cook book values”) or to use inertia and dyno load settings determined from coast down tests with that specific vehicle type. The usage of these “cook book values” tends to result in higher type approval CO_2 emissions values than the usage of the values resulting from the real world road load test for relatively small vehicles (with low air drag and rolling resistance). For relatively large vehicles (with high air drag and rolling resistance) the “cook book values” tend to result in lower type approval CO_2 emission values compared to the use of dyno load test settings derived from coast down testing. As a result, manufacturers tend to use the values the coast down test for small vehicles and the “cook book values” for large vehicles. Therefore the emissions level off towards the upper end of the mass / size range. Moreover, the mass

bins defining the inertia class of a LCV are rather large (up to 230 kg), leading to dynamometer settings that are not representative for the vehicle and resulting in stepwise CO_2 emission increase. These steps are not noticeable in Figure 3 since more vehicle characteristics affect the CO_2 emissions, e.g. engine efficiency.

- Annex 4a of “Agreement Addendum 82: Regulation No. 83 - UNECE” states that for vehicles, other than passenger cars, with a reference mass of more than 1700 kg the dynamometer settings should be multiplied by 1.3. This introduces a step function, increasing the CO_2 emissions when testing LCVs of which the mass in running order is greater than 1700 kg.

The origins of these discontinuities in the test procedure lie in the limited capabilities of mechanical chassis dynamometers at the time when the test procedure was developed. With modern electromechanical chassis dynamometers these limitations no longer exist. In order to improve the basis of CO_2 legislation for LCVs it would therefore be advisable to update type approval test procedures in such a way that especially for larger vans measured CO_2 values become more realistic. Such amendments to the test procedure would reduce a large part of the non-linearity currently observed in the footprint versus CO_2 statistics for LCVs and might thus reduce the need to apply a non-linear limit function. Also when mass is chosen as utility parameter for the 2020 target of 147 g/km, updating the test procedure for CO_2 emission measurement would greatly improve the effectiveness of the regulation and may be expected to have implications for what is the most appropriate limit function. In both cases therefore amendments to the test procedure before 2020 would need to be accompanied by a review and possible revision of the limit function that is now to be selected for defining the modalities for implementation of the 2020 target.

For footprint the levelling off effect is greater than for mass, because the length of light commercial vehicles can be increased (increasing footprint) with only a limited penalty on mass. Especially at the upper end of the spectrum vehicle models are sold with a large number of variants with different lengths. Because of this limited mass increase with increasing length and because the effect on the vehicle’s aerodynamics are diminutive or even positive, CO_2 emissions increase only slightly.

Also for payload, the levelling off effect is significantly greater than for mass. This is largely the result of almost all large (Class III) vehicles having a declared GVW of 3500 kg. For vehicles with this maximum GVW value, the payload decreases with increasing (unladen) weight. As a result, larger, heavier vehicles have a lower payload, while physically the vehicle is not necessarily able to bear less load . The CO_2 emissions are then inversely proportional to the payload. Because of these cons and the ones described above, payload is deemed unfavourable and is not analysed in more detail.

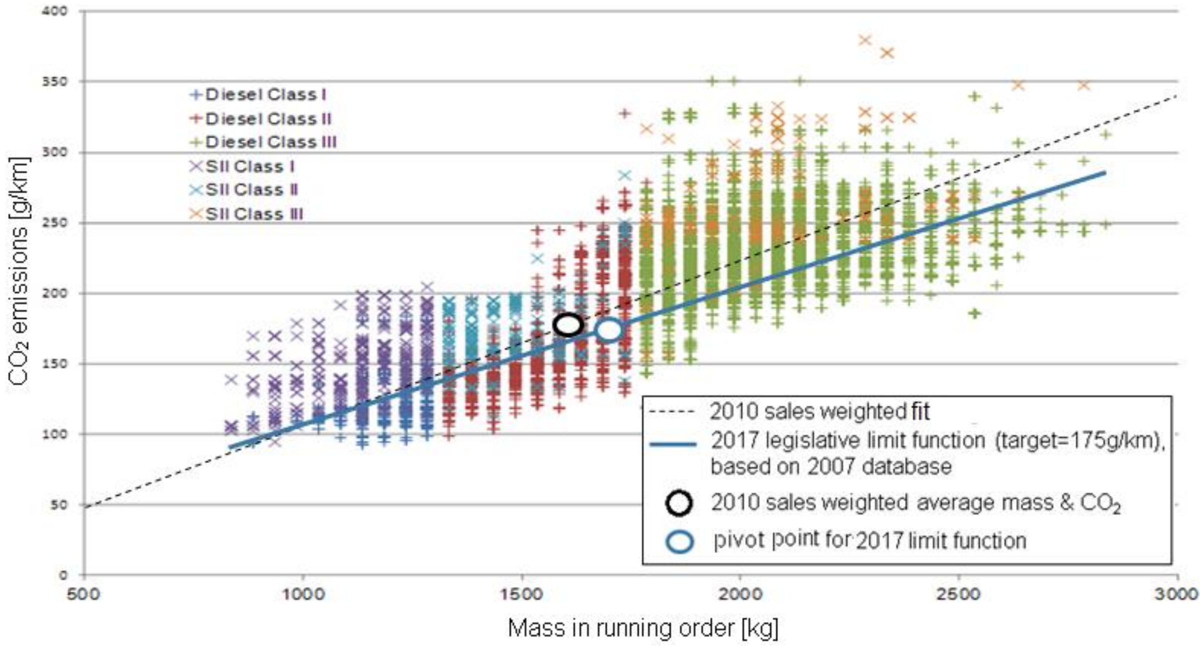

Figure 3 CO$_2$ and mass in running order values of LCV sales in 2010for the six different LCV segments

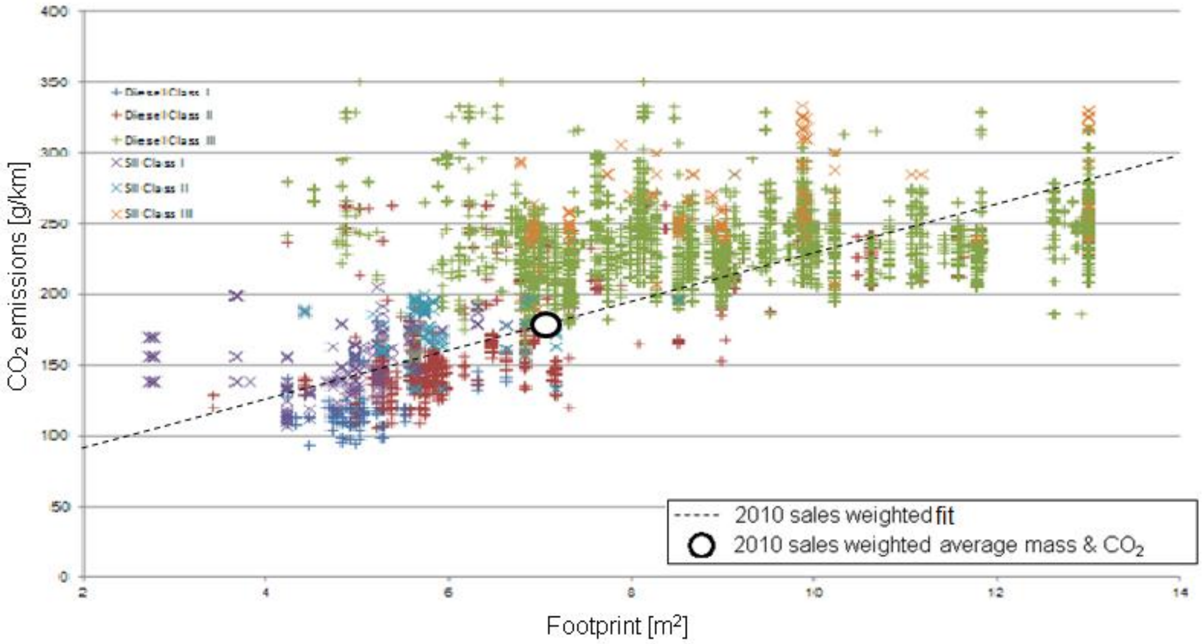

Figure 4 CO$_2$ and footprint values of LCV sales in 2010 for the six different LCV segments

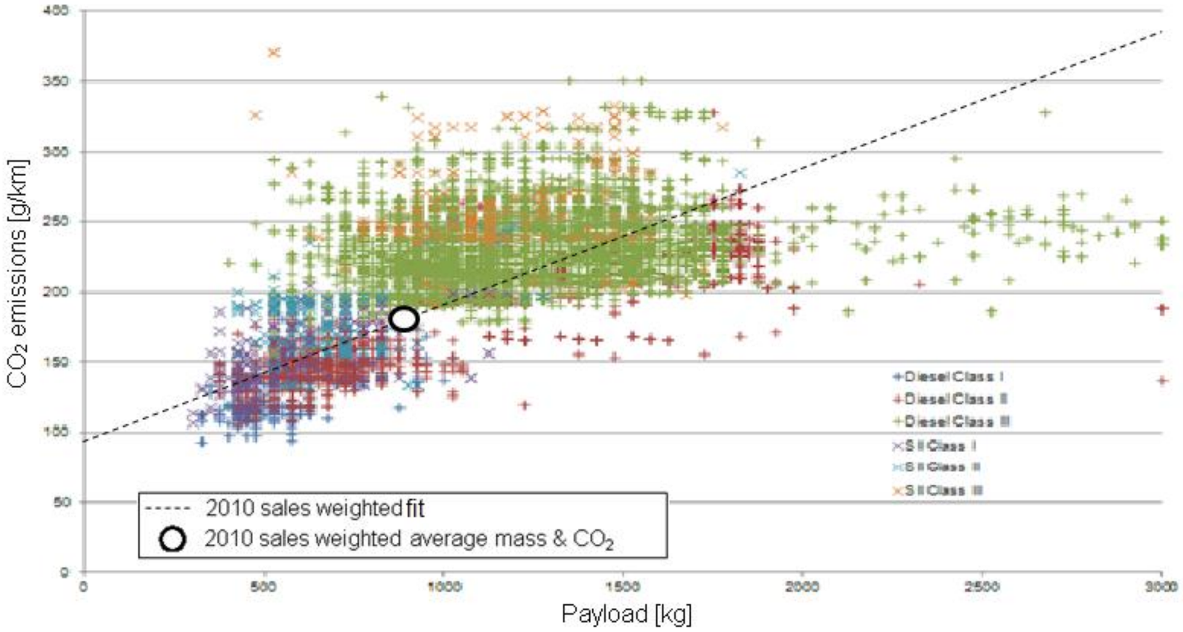

Figure 5 CO_2 and payload values of LCV sales in 2010 for the six different LCV segments

The overall conclusion is that mass seems to be a better utility parameter for vans than footprint or payload. First of all it correlates better with CO_2. Secondly footprint and payload offer room for gaming unless the utility based target slope is chosen very flat, cancelling the objective of the utility based function. Moreover, the payload advantage (see above) of mass reduction (partly) compensates the disincentive generated by assigning more CO_2 credits for heavier vehicles.

Modalities for 147 g/km in 2020

For consistency reasons a number of modalities is proposed to remain unchanged compared to what is used in the legislation currently in place to support the 175 gCO_2/km target for new registrations within the EU27 by 2017. Therefore it is proposed that manufacturer groups remain defined as obligated entities and that the average CO_2 emissions of the total EU sales of manufacturer groups is used as target focus. The main sanction type considered remains an excess premium of penalty per vehicle for every g/km by which manufacturer's average exceeds the manufacturer-specific target.

For simplicity sake a linear utility-based limit function is desirable, provided that the statistics for the selected utility parameter do not indicate a significant non-linear trend in the CO_2 versus utility value data for vehicles sold in the baseline year.

The main choices to be made with respect to the 2020 target for LCVs, therefore, are the utility parameter, the slope of the limit function and the excess premium level.

From the three potential utility parameters assessed, mass was concluded to be a seemingly suitable utility parameter that correlates linearly to the CO_2 emissions rather well. It was therefore analysed in more detail using a linear limit function. Footprint is analysed in more detail using a non-linear limit function, as depicted in Figure 6.

For determining the effects of the modalities on the additional manufacturer costs and the distribution impact is a cost assessment model is constructed. This 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.

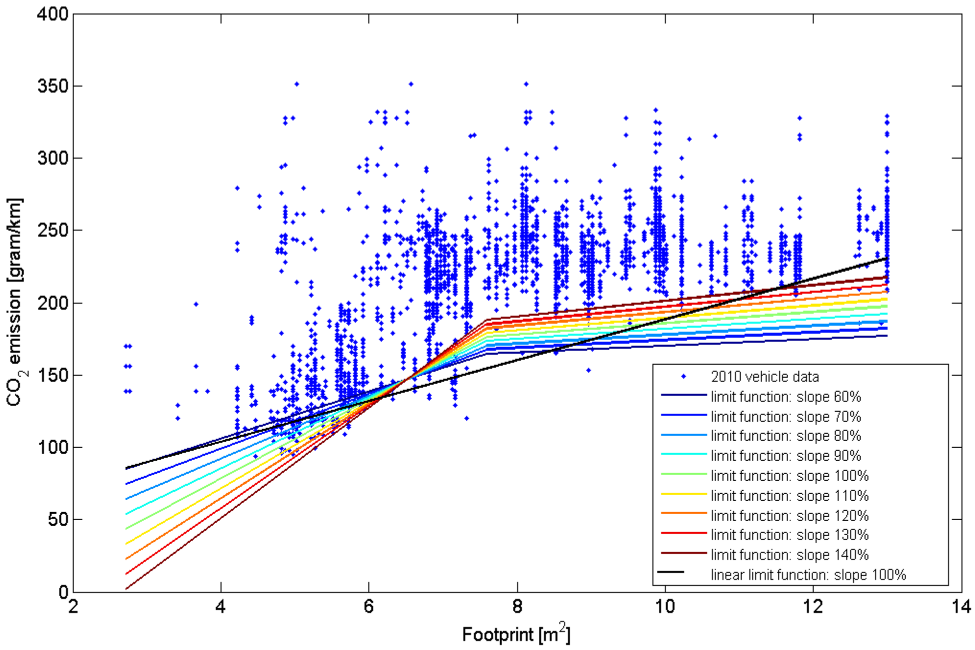

Figure 6 The non-linear equivalent of the 100% footprint-based limit function and a number of alternatives between 60% and 140% slopes. The bending point is 7.6m^2 and the pivot point is 6.5m^2.

Results for mass as utility parameter

Average costs per vehicle for each manufacturer group scale linearly with the slope of the limit function (Figure 7). For manufacturers with a sales-averaged mass below the overall average mass the costs increase with an increase in slope, while for manufacturers with above-average mass the costs decrease with an increase in slope. Sensitivity to changing the 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 also sensitive to the slope of the utility based limit function but here the sensitivity is limited.

The way the additional manufacturer costs and relative price increase are distributed over the segments is heavily influenced by the shape of the cost curves. Though the additional manufacturer cost as function of the relative CO_2 reduction are quite similar for the three segments, the absolute and marginal costs for a given absolute CO_2 reduction are lower for larger vehicles than for smaller vehicles. In the cost assessment model it is assumed that manufacturers strive to minimise the additional manufacturer costs for meeting their average CO_2 emission target. The optimum distribution is characterised by equal marginal costs over the three size segments. Therefore the model predicts that manufacturers are likely to apply larger reductions to the larger vehicles in their sales portfolio than to the smaller vehicles. It should be noted that from this uneven distribution of cost and price increase over segments it can therefore not be concluded that the costs are higher for manufacturers selling relatively many Class III vehicles.

Especially when looking at the additional manufacturer cost increase some manufacturers will be faced with a higher burden than other manufacturers with similar average CO_2 emissions.

- **Daimler**, **Isuzu**, **Iveco**, and to a lower extent **Mitsubishi** and **Toyota** are relatively sensitive to slope changes. The average mass for new registrations for these manufacturer groups is well above average.
- Since the average retail price of **Daimler** and **Iveco** is relatively high, the relative retail price increase is low compared to the additional manufacturer cost increase (Figure 37).
- Since manufacturer groups such as **Fiat**, **General Motors** and **PSA** have relatively low average retail prices, the additional manufacturer costs are high compared to the retail

price. As a result, the relative price increase of these groups is high compared to the additional manufacturer costs (Figure 37).

- The additional manufacturer costs and relative price increase are relatively high for **Mitsubishi**, **Nissan** and **Toyota**. This is a result of a rather long distance to target for these manufacturers. This is especially the case for the costs and price relative to 2010, since a large part of this distance to the 2020 target will already have to be covered to reach the manufacturer specific equivalents of the 175 gCO_2/km target for 2017. It should be noted however, that a large part of the sales of these manufacturers are pick-up trucks and all-terrain vehicles.

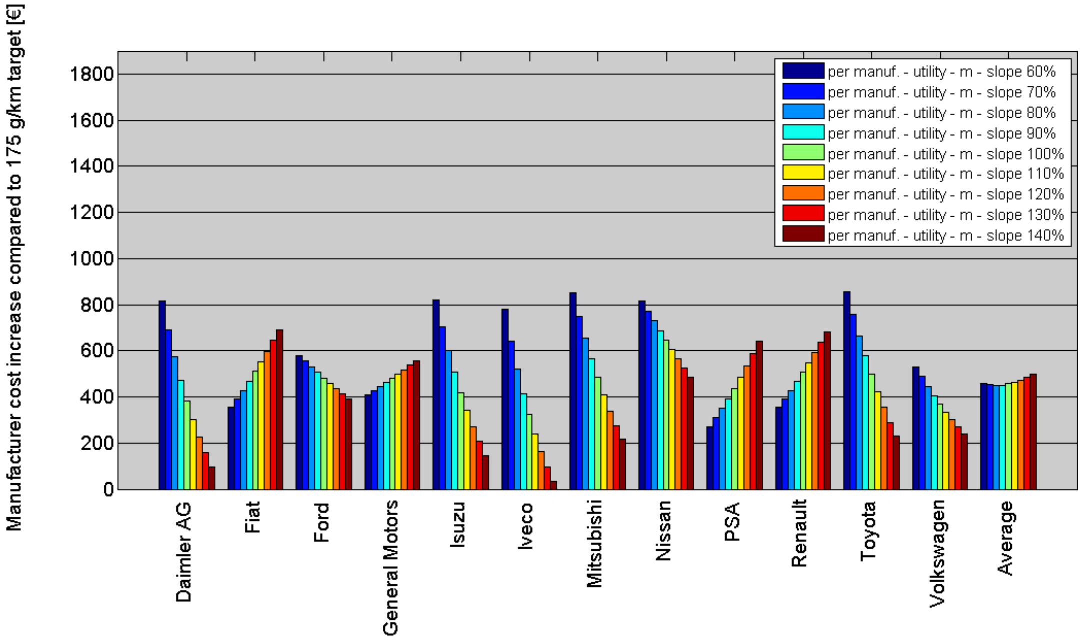

Figure 7 Absolute manufacturer cost increase per manufacturer for mass-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

The average vehicle mass of the 2010 new Tata (incl. Land Rover) registrations is relatively high. As a result, additional manufacturer costs (relative to 2010) are high and the group is relatively sensitive to changes in the slope value. Relative to the 175 gCO_2/km target, additional manufacturer costs are relatively low for low slope values. This is the result of a significant part of the cost to meet their equivalent of the 147 g/km target, have already been made to meet the 175 g/km target. As a result of these costs, the overall average additional manufacturer cost are higher when Tata (incl. Land Rover) is included in the analysis. The impact is limited because of the low sales volume.

Results for footprint as utility parameter

Also for footprint average costs per vehicle for each manufacturer group scale almost linearly with the slope of the limit function (Figure 8). For manufacturers with a sales-averaged footprint below the pivot point (6.5 m^2, not the overall average footprint), the costs increase with an increase in slope, while for manufacturers with a sales-averaged footprint above the bending point the costs decrease with an increase in slope. Sensitivity to changing the slope is very different for the different manufacturer groups depending on the difference between the average footprint of the manufacturer group and the pivot point footprint value. Overall average costs are also sensitive to the slope of the utility based limit function but here the sensitivity is limited.

As also explained for mass as utility parameter the cost optimal way for manufacturers to meet their specific target, under the assumption that additional manufacturer costs are minimised, implies that manufacturers apply larger absolute reductions to the larger vehicles in their portfolio. As a consequence the absolute cost increase for large vehicles will tend to be larger than for small vehicles. Also for the case of footprint it should thus be noted that from an uneven distribution of costs and price increase over segments, it cannot be concluded that the costs are higher for manufacturers selling relatively many Class III vehicles. However, for Iveco, a manufacturer of mostly Class III vehicles, the footprint-based target results in a lower CO_2 target and therefore higher costs compared to a target with a mass-based limit function (Figure 49). This causes the additional manufacturer costs and relative price increase of Class III vehicles to be relatively high (Figure 50). Since these manufacturers will already have to reduce relative much to meet their equivalent of the 175 g/km target, their additional manufacturer costs relative to this 2017 target are comparable to those of other manufacturers.

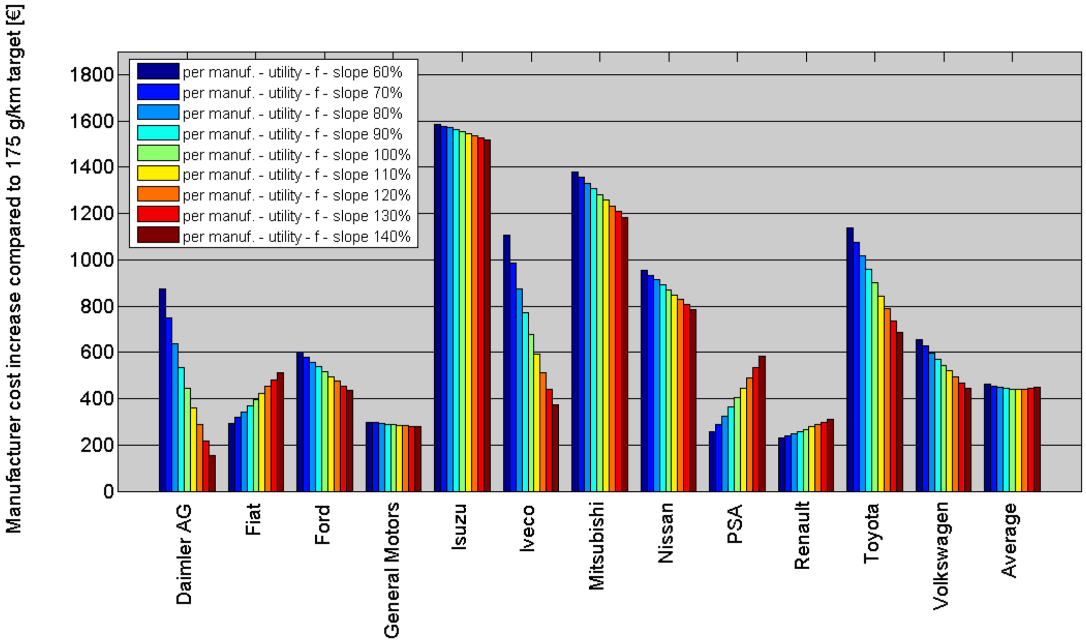

Figure 8 Absolute manufacturer cost increase per manufacturer for footprint-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

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:

- **Mitsubishi**, **Isuzu**, **Nissan** and **Toyota** have relatively high additional manufacturer costs to meet their equivalents of the 147gCO_2/km targets. It should be noted however, that a large part of the sales of these manufacturers are pick-up trucks and all-terrain vehicles
- **Daimler** and **Iveco** are relatively sensitive to slope changes. The average footprint for new registrations for these manufacturer groups is well above average. Since the average retail price of Daimler and Iveco is relatively high, the additional manufacturer costs are low compared to the retail price.
- Since the average footprint of **PSA** is quite a bit lower than the pivot point, this manufacturer group is also relatively sensitive to slope changes. This effect is amplified by the fact that the average footprint is also lower than the bending point; the effect of slope change is larger to the left from the bending point.
- Since manufacturer groups such as **Fiat**, **General Motors** and **PSA** have relatively low average retail prices, the additional manufacturer costs are relatively high compared to the retail price. As a result the relative price increase of these groups is high compared to the additional manufacturer costs.

When footprint is used as the utility parameter, **Tata (incl. Land Rover)** is not able to meet its target. This is the result of the average CO_2 emissions being high compared to their footprint. These emissions are high mostly because of the relatively high mass of these vehicles. Since the sales share of this manufacturer group is less than 1% of all LCV sales, the effect of Tata not being able to meet its target is small. As a result of these costs, the overall average additional manufacturer cost are higher when Tata (incl. Land Rover) is included in the analysis. The impact is limited because of the low sales volume, but higher than with a mass-based utility parameter.

Penalty or excess premium

If the average CO_2 emissions of a manufacturer's new LCV sales exceed its limit value, the manufacturer has to pay an excess emissions premium for each car registered. According to Regulation (EU) No 510/2011, this premium amounts to €95 for every g/km of exceedance from 2019 onwards. This is equal to the excess premium level for passenger cars.

The relative reduction at which the marginal costs are equal to the excess premium level of €95/g/km (which is a proxy for the hypothetical reduction effort after which it could become cheaper to pay the premium) is different for every manufacturer, because the 2010 baseline emission values (on which the relative reductions are based) are different. The average marginal costs for meeting the 2020 target for every manufacturer is just below €30g/km for all slopes analysed. Even for the manufacturer with higher marginal costs for meeting its equivalent of the 2020 target, marginal costs are approximately €40/g/km for a mass-based limit function and €46/g/km for a footprint-based limit function. This is well below the excess premium level from 2019 onwards. Therefore, the current level of excess premium should provide more than enough incentive for all manufacturers to reduce the CO_2 levels of their vehicle fleet rather than paying the penalty for exceeding its limit value.

Comparison of the utility parameters with respect to costs for meeting the target

Compared to footprint, using mass as the utility parameter leads to slightly higher additional manufacturer costs for steeper limit functions. These slightly higher costs are mainly caused by a small number of manufacturers (with a relatively large sales shares) that are more sensitive to the slope of the mass-based limit function than to the slope of the footprint-based limit function.

The additional manufacturer costs are distributed more evenly for mass than for the footprint based limit function. This is mostly due to a limited number of manufacturers selling partly or mostly pick-up trucks with high mass relative to their footprint. Apart from Iveco (relatively high costs for footprint-based limit function), the additional manufacturer costs for footprint and mass are rather similar for manufacturers selling mostly typical vans intended for goods transport.

It should also be noted that the time between the short term target of 175 g/km based on mass (2017) and the longer term 147 g/km target (2020) is only three years. In case footprint is deemed favourable for the 2020 target manufacturers with deviant mass-footprint ratios, might have to severely adapt their CO_2 reduction strategies in a relatively short period.

Favourable slope value for the limit function

Slope values of the limit function affect the distance to target for the various manufacturers. A steep slope leads to a relatively short distance to target (and relatively low costs) for manufacturers producing rather large vehicles and to a relatively large distance to target (and relatively high costs) for manufacturers producing rather small vehicles. On the other hand, a flatter slope leads to a relatively large distance to target (and relatively high costs) for manufacturers producing rather large vehicles and to a relatively short distance to target (and relatively low costs) for manufacturers producing rather small vehicles. Since it is desirable to have LCVs of different sizes, the burden of the 147 gCO_2/km target should in principle be distributed evenly over the utility range. For both mass and footprint as utility parameters, the costs are distributed most evenly over the manufacturer (groups) around the 100% slopes. The distribution of cost impacts over different size segments is found to be uneven while the relative distance to target is more or less constant over the utility range. This is a consequence of the shape of the cost curves for different segments and the optimisation of additional manufacturer costs that manufacturers are assumed to strive for. The cost optimum is generally characterised by higher reductions, and therefore higher costs, for larger vehicles.

The footprint of an LCV can be increased without large negative implications on the CO_2 emissions (nor on the performance). As such changes in vehicle design are much easier to implement in many vans than in passenger cars, gaming with footprint is considered relatively easy for vans. The incentive for gaming is especially strong for vehicles with a relatively low footprint, as the non-linear limit function is relatively steep at this part of the footprint range. As a result vans might be stretched solely for the purpose of increasing the CO_2 target, leading to unnecessarily and undesirably large vehicles. On the other hand, lowering the slope, increases differences in cost impacts especially for the manufacturer groups that sell typical vans rather than pick-ups or all-terrain vehicles and that represent the majority of the market. This trade-off needs to be considered in the choice of slope value for the limit function for footprint.

For mass as utility parameter, the slope of the 100% linear limit function is almost equal to the slope of the limit function used in the CO_2 legislation currently in place for LCVs. In order not to increase the room for gaming, a slope value of 100% or lower is recommendable. Around this 100% slope, the relative price increase (and additional manufacturer costs) is distributed most evenly over the manufacturers in the range.

In [Smokers 2006] a formula was derived to translate the weight increase ΔM into a CO_2-emission increase ΔCO_2 for constant vehicle performance. According to this formula, an 80% slope value should provide enough disincentive against gaming. Taking all these arguments into account, an 80% to 100% slope range is recommendable.

Comparison with results from previous studies

The estimated costs for meeting the 147 gCO_2/km target are significantly lower than expected in [Smokers 2009], for the following reasons:

- The overall average CO_2 emissions based on the 2010 LCV database are significantly lower than those estimated in [Smokers 2009]. This is partly caused by the levelling-off of the CO_2 emissions at the upper range of the utility values that are identified in this study. In [Smokers 2009], this phenomenon was not observed as a result of estimating lacking CO_2 data to fill gaps in the 2007 database. It now seems that these estimated CO_2 emissions were overestimated. Since a significant part of the CO_2 data was lacking at the upper end of the utility range, the overestimated CO_2 values affected the overall average significantly.
- According to Figure 13 the sales share of Class III LCVs (with high CO_2 emissions) has decreased, while the shares of Class II and Class I (with relatively low CO_2 emissions) have increased. This phenomenon has led to a lower overall average CO_2 emission factor. As a result the average distance to target and therefore the costs have decreased.
- Finally, the cost effectiveness of the technologies as determined for this study is in general higher than that of the same technologies mentioned in [Smokers 2009]. This is the result of new studies delivering new insights.

Passenger cars versus vans

Comparing potential limit functions for 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. Therefore, and to simplify the CO_2 regulation for light vehicles, a combined limit function could be desirable.

With mass as the utility parameter, the 100% limit function for LCVs for 2020 is steeper than that of passenger cars (Figure 9), although the CO_2 emissions of passenger cars and LCVs over the mass range appear to be similar. This slope difference is largely due to the fact that the 100% limit function is derived from a sales weighted best fit. For LCVs a large share of the vehicles are sold in Class III, whereas for the passenger cars, the share of heavy vehicles (mass > 1700 kg) is limited. As a result the right part of the LCV sales cloud affects the best fit (and therefore the 100% limit function) more than the right part of the passenger cars sales cloud.

Moreover the depicted LCV limit function is higher than that of the passenger cars over (almost) the total mass range. This is mainly the result of a higher target for LCVs than for passenger cars.

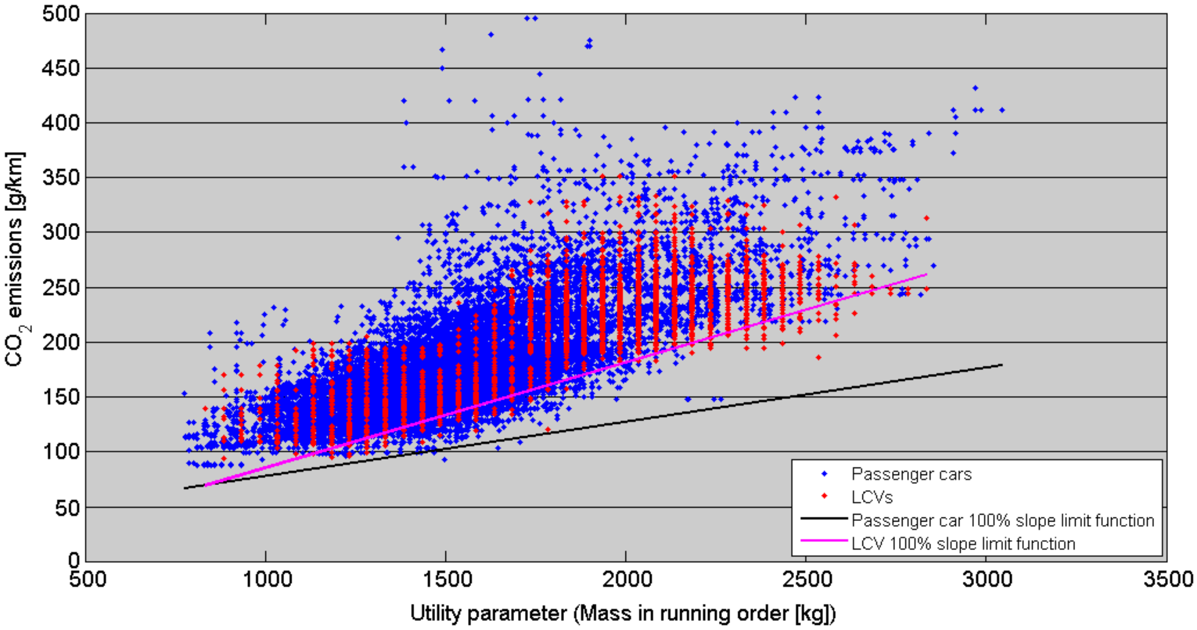

Figure 9 Comparison of 2010 LCV data and 2009 passenger car data, including the mass based 100% slope limit functions for both vehicle types for the 2020 targets.

In contrast to the mass-based situation, the 100% footprint-based limit function for LCVs is below (or right from) the 100% limit function for passenger cars (Figure 10). This results from a generally higher footprint (relative to their mass) for LCVs than for passenger cars. For passenger cars, mass increases significantly with an increasing footprint, while for LCVs (test) mass increases only limitedly with increasing footprint. Moreover the average footprint for LCVs is significantly larger than the average footprint for passenger cars, shifting the limit function to the right.

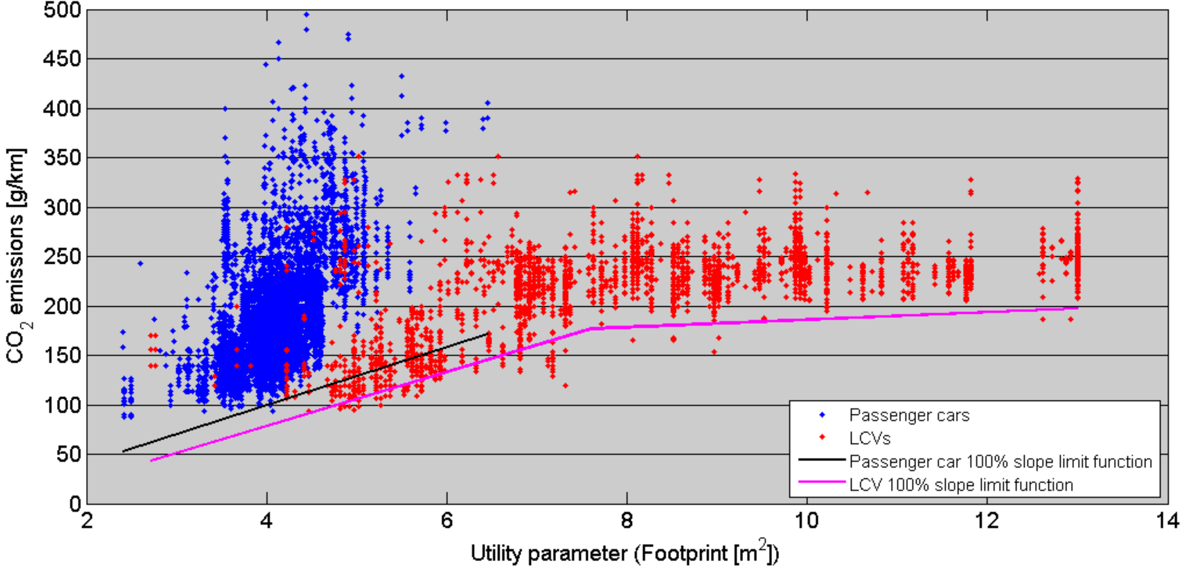

Figure 10 Comparison of 2010 LCV data and 2009 passenger car data, including the footprint based 100% slope limit functions for both vehicle types for the 2020 targets.

Marginal costs for meeting the passenger cars and LCV CO_2 targets

The relatively low additional manufacturer costs that are found in this study, lead to the conclusion that the 147 gCO_2/km target for LCVs is less challenging for the manufacturers than the 95 gCO_2/km target for passenger cars.

Since the CO_2 reducing technologies that can be applied to LCVs are largely similar to the technologies for passenger cars, less technologies have to be applied to LCVs to meet the 2020 target than to passenger cars. In case the target for passenger cars and LCVs would be combined, manufacturers selling both LCVs and passenger cars may decide to divide their effort over both vehicle types, which may delay the introduction of certain more advanced (but less cost effective) technologies. On the other hand, manufacturers of passenger cars that do not make LCVs would not have this advantage. Because of this competitive advantage for manufacturers selling both passenger cars and LCVs, it is undesirable to combine the current targets that are planned for 2020.

In order to eliminate this potential competitive advantage, the marginal costs for the LCV and passenger car target should be equal. In [TNO 2011] it was determined that the average marginal costs for meeting the 95 gCO_2/km passenger car target are € 91/g/km. For LCVs this average marginal cost level is reached at an overall average CO_2 emission of 113.3 gCO_2/km, which is significantly lower than the proposed target of 147 g/km. This comparison, however, should be considered only indicative, as the cost curves for LCVs and passenger cars were not generated simultaneously and with some differences in methodology and data sources, leading to different insights for defining CO_2 reduction potentials and costs of technologies.

Potential shifts between passenger car and LCV sales

Recently COM Regulation No 678/2011 amending Directive 2007/46 (Annex I) came into place, which includes some criteria (e.g. loading space) to more clearly distinguish the vehicle characteristics of the M1 and N1 categories. This will limit the overlap between M1 and N1 and will therefore limit potential CO_2 leakage from vehicles being accounted for in the incorrect CO_2 regulation scheme.

Even if this directive would ensure all vehicles to be correctly categorised (as M1 or N1), CO_2 leakage may still occur in the overlap between vans and cars. In case national authorities allow users to unrestrictedly use M1 vehicles for goods carriage or N1 vehicles for private use, certain financial incentives may be decisive in the type (M1 or N1) of vehicle to be acquired rather than the intended purpose of the vehicle.

Vehicles with certain characteristics (combination of CO_2 emissions and utility parameter value) can have a positive influence on the manufacturer’s average CO_2 emissions in one category (M1 or N1) and a negative effect on the average CO_2 emissions of the other category. For instance, selling a N1 vehicle “between” the two mass-based limit functions (e.g. 2500kg and 200 gCO_2/km), will have a positive effect on the manufacturer’s distance to target for LCVs, while an M1 vehicle with these characteristics will have a negative effect on the distance to the passenger cars target. Therefore a manufacturer may (financially) encourage users to (is available) acquire the N1 variant of a certain vehicle. In case this vehicle is used as a passenger, it is accounted for in the incorrect CO_2 regulation. If this occurs, manufacturers selling both passenger cars and LCVs will have to reduce less CO_2, resulting in CO_2 leakage.

Type approval authorities and national registration authorities play an important role in preventing such CO_2 leakage. It is therefore desirable to define unambiguous European wide guidelines for national registration authorities.

Impact of electric vehicle penetration

In the coming years and decades, electric vehicles are likely to enter the light commercial vehicle fleet. These may be either battery electric vehicles, i.e. vehicles solely powered by batteries and an electric motor, or plug-in hybrid models, which typically have a full electric driving range of several tens of kilometres, but can also be powered with an internal combustion engine.

The number of electric LCVs on offer and in the EU fleet is still very limited, and large scale market uptake still seems to be quite far away. However, the electric light commercial vehicle market can be expected to benefit from efforts currently put into the development of electric passenger cars, and from the incentives provided in the CO_2 and vans regulation. Key conditions for EV uptake in the LCV market are cost, technological developments, availability of charging infrastructure and consumer interest. It is likely that these conditions will be met first in a number of niche markets, and in the lighter LCV categories (Class I).

For estimating the effect of electric LCVs, three uptake scenarios are developed forecasting the electric vehicle share of new LCV sales in 2020 to be between 2.7 to 8.7% in Class I, 1.6 - 3.9% in Class II and 1.0 – 1.5% in Class III LCVs. More than half of these cars are expected to be plug in hybrid electric vehicles.

As the sales of EVs count as zero-emission in the current CO_2 and vans regulation, these sales will impact the emissions of the internal combustion engine vehicles in the LCV fleet. A 10% share of zero-emission vehicles in the sales would allow conventional vehicles to emit somewhat more than 10% more than the target on average, whilst still meeting the target. This impact is enhanced during the years that super-credits are in force.

Currently the costs for manufacturing electric N1 LCVs are so high that it is not likely that manufacturers will actively market EVs as a strategy to meet their CO_2 targets. However, as for some end users, the investment of purchasing an EV at a (probably) relatively high price could be compensated by the relatively low user costs, as electricity is a relatively low cost energy carrier. Moreover such EVs can be fiscally attractive, depending on national policy.

Possible knock-on consequences

The increased purchase price is likely to have an impact on the total amount of N1 vehicles sold. N1 vehicle sales are expected to drop by around 0.7% in 2020 and 0.8% in 2030. In a business-oriented segment as N1 is, very minor changes in costs do not cause major changes in purchase behaviour.

Furthermore a very slight overall increase of transport demand (vkm) is observed as a result of the lower overall cost (the cost decrease due to lower fuel consumption outweighs the purchase price increase in N1, thus transport as a whole becomes cheaper).
This drop also incorporates a move from diesel to gasoline powered vehicles. This is the net effect of a transition to the more expensive fuel type (fuel cost per km decreases, so the importance of this cost in the total goes down), which differs per country. Countries where diesel is relatively cheaper, like France, or Belgium, see a transition to gasoline, whereas the opposite holds for countries like the UK and Denmark, which have higher diesel prices.

The share of fuel cost in TCO decreases as fuel efficiency increases. Ergo, a lower fuel price, as is the case for diesel, would contribute less to the attractiveness of diesel vehicles when consumption is low than when consumption is higher. Ceteris paribus, this would mean that the relative attractiveness of a gasoline vehicle increases, and their share in total vehicle sales would increase.

End user fuel cost savings

Because of the relatively low additional manufacturer costs to meet the 2020 target and the significant fuel (cost) savings, the break even period for the end user is only 0.9 to 1.3 years, depending on the oil price. This is well within the vehicle lifetime and even the average duration of first ownership.

Given that an average CO_2 emissions level of 175 g/km (which is lower than the 2010 average) is already set for 2017, the fuel cost savings relative to this 2017 target are lower than relative to the 2010 average. However, as the additional manufacturer costs and the resulting price increase (end user's additional investment) is also lower, the break even periods are very similar (Figure 11).

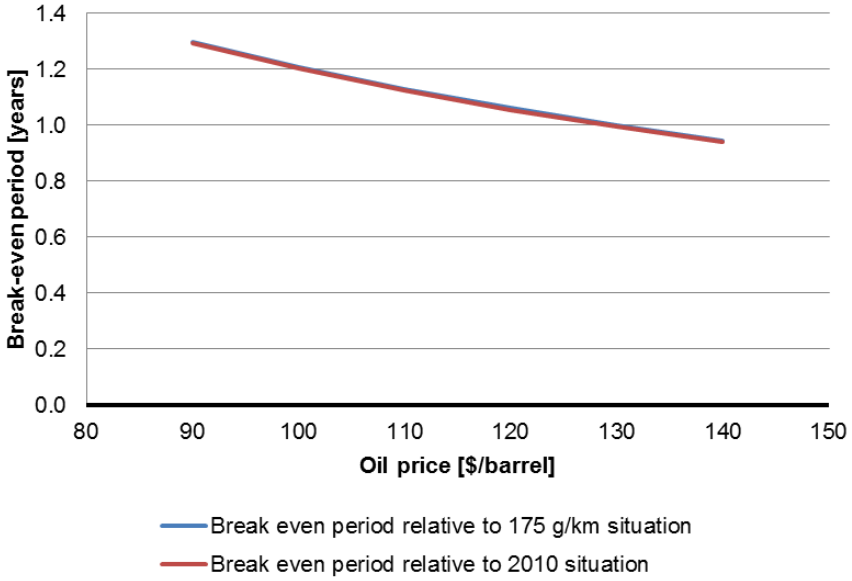

Figure 11 End user break even period as a function of the oil price for the additional vehicle costs resulting from the 2020 CO_2 regulation for LCVs .

Also from a societal perspective, the lifetime fuel cost savings outweigh the additional investment resulting from the 2020 target. This is the case for the situation relative to the 2010 situation and also relative to the 175 g/km target set for 2017. This results in negative abatement costs for society between approximately -170 €/tonne CO_2 and -300 €/tonne CO_2, depending on the oil price (Figure 12). Also for the abatement costs, the higher extra investment of complying with 147 g/km target relative to the 2010 situation, is compensated by the higher fuel cost savings.

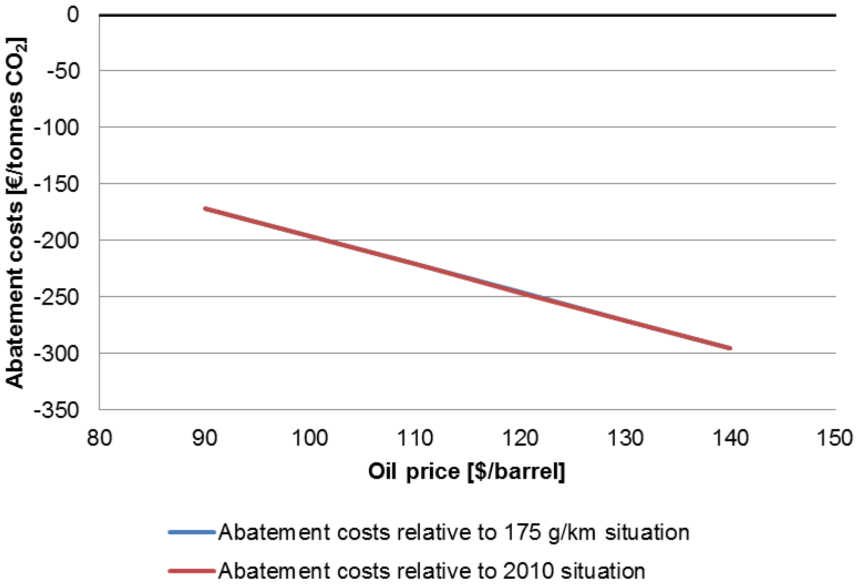

Figure 12 Abatement costs of the 2020 CO_2 regulation in relation to the oil price.

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1 Introduction

1.1 Background

The European Union has committed itself to a 20% reduction of its greenhouse gas emissions, and of 30% in case other major economies make comparable efforts. Transport is one of the main emitting sectors, and the only one that continues to grow substantially. Road transport is responsible for the majority of the overall transport emissions, and the EU strategy to reduce CO_2 emissions from light-duty vehicles sets out a number of measures to reduce road transport emissions. Regulation (EC) No 443/2009 to reduce CO_2 emissions from passenger cars adopted in 2009 (further referred to as "the cars regulation") is the main tool of this strategy. Regulation to reduce CO_2 emissions from light commercial vehicles (LCVs or vans) – Regulation (EU) 510/2011 further referred to as "the vans regulation", is part of this overall strategy as an element of the integrated approach. The vans regulation is a follow-up of the cars regulation and is intended to minimise the regulatory gap between M1 and N1 vehicle categories.

1.2 Objective

The vans regulation contains a number of review clauses. Notably, Article 13(1) requires the Commission to carry out an impact assessment to confirm the feasibility of the 2020 target of 147 gCO_2/km and to define the modalities for reaching it in a cost-effective manner and the aspects of implementation of that target, including the excess emission premium. Furthermore, Article 13(6) requires the Commission to publish by 2014 a report on the availability of data on footprint and payload, and their use as utility parameters for determining specific emissions target and, if appropriate, submit a proposal to amend Annex I. Finally, Article 13(4) requires the Commission to set up by 31 December 2011 “a procedure to obtain representative values of CO_2 emissions, fuel efficiency and mass of completed vehicles while ensuring that the manufacturer of the base vehicle has timely access to the mass and to the specific emissions of CO_2 of the completed vehicle”. Furthermore, Annex II part B point 7 defines further the framework for such revision, including the procedures to be taken into consideration during this review.

1.3 Report structure

For the impact analysis of the 147 gCO_2/km target for LCVs in 2020, a 2010 database was acquired to analyse the current characteristics of the new LCV registrations. The consolidation of this database and some general characteristics are described in section 2. Hereafter in section 3, the CO_2 reduction potential and costs of several CO_2 reducing technologies, that are expected to be applicable to LCVs before 2020, are described. This leads to cost curves, defining the costs for reaching a certain reduction potential within a certain LCV class. In section 4 the suitability of three potential utility parameters is analysed. Other modalities and the distributional impacts of these modalities are described in section 5. Further aspects regarding the 147 g/km target are presented in section 6 (the relation with the CO_2 regulation for passenger cars), 7 (the impact of electrical vehicle penetration) and 8 (some possible knock on consequences of the LCV CO_2 regulation). Finally in section 0 the fuel savings are compared to the additional costs resulting the 147 g/km target from both a societal as well as a consumer perspective.

2 Database consolidation and results

2.1 Introduction

In order to determine the impact of the 147 gCO_2/km target for new N1 registrations by 2020, the current characteristics of the manufacturers are needed to determine the effort they have to put into meeting the 147 gCO_2/km target in 2020. Therefore a 2010 LCV sales database was acquired from JATO, including amongst other things, sales, CO_2 emissions, kerb weight, footprint, payload and price for the largest five EU Member States (Germany, France, UK, Italy, Spain).

During the database consolidation, in particular the consistency of the data was to be checked and obvious errors to be corrected. Furthermore weighted averages for the CO_2 values, the footprint, payload and the mass in running order were calculated.

The most detailed data that JATO could provide for this study was on basis of bins, except for the type approval CO_2 emissions and sales. This means that for every manufacturer, sales are provided of vehicles which characteristics (e.g. price, kerb weight and payload) fit in a certain bin. These upper and lower value of the bins were small enough to do a detailed assessment. Moreover, as CO_2 and sales were not binned, no accuracy was lost on these important parameters.

Since in the calculations values are required, mean values of the bin limits were used as the vehicles' characteristics.

2.2 Deletion steps

- The database contained 25810 vehicles that JATO classified as camper vans, which are out of the scope of Regulation (EU) 510/2011. Those vehicles were deleted from the database.
- Regulation (EU) 510/2011 applies "to motor vehicles of category N1 as defined in Annex II to Directive 2007/46/EC with a reference mass not exceeding 2610 kg and to vehicles of category N1 to which type-approval is extended in accordance with Article 2(2) of Regulation (EC) No 715/2007"[1]. JATO indicated some vehicles having a reference mass higher than 2840 kg. These were deleted[2].
- For numerous small volume manufacturers a three-tiered deletion step was executed based on the completeness of data, low number of registration and manufacturers not producing N1 vehicles.

2.3 Data filling

15% of vehicles did not have a CO_2 value within the JATO database. Therefore the Polk LCV file from 2009 was taken as a basis for the data work of the JATO data:

1) Data source: POLK LCV COMBINED FILE from Service Request 1 (2009 Data):

   Working steps:

---

[1] The Article 2(2) of R715/2007 reads: "2. At the manufacturer's request, type approval granted under this Regulation may be extended from vehicles covered by paragraph 1 to M1, M2, N1 and N2 vehicles as defined in Annex II to Directive 70/156/EEC with a reference mass not exceeding 2 840 kg and which meet the conditions laid down in this Regulation and its implementing measures.

[2] Furthermore several vehicles had a reference mass between 2610 kg and 2840 kg. They were marked within the database for further assessments by the consortium.

    a. Identification of the vehicles comprising information about CO_2 value, kerb weight, capacity, fuel type on version level and per manufacturer.
    b. Aggregation of 1a) into the categories per manufacturer using the JATO kerb/capacity banding, as well JATOs fuel type nominations
    c. Calculation of the respective CO_2 value per row of 1b) per manufacturer
2) Data source: JATO Database from Service Request 3 (2010 data):
    a. Identification of manufacturers missing the CO_2 value but comprising information regarding kerb weight/capacity categories and fuel type
    b. Inserting the carbon emission values calculated in 1c) into the rows with corresponding kerb weight/capacity categories and fuel type (per manufacturer)
    c. Recalculating the CO_2 value with the original and filled data

After this treatment step 98% of all vehicles were equipped with a CO_2 value as opposed to 85% before.

2.4 Additional data work

2.4.1 Kerb weight

JATO delivered a column named “kerbweight” which is defined as “the published kerb weight of the vehicle in the official documentation. I.e. according to JATO, without any extra addition or deletion of drivers weight etc. The value is taken regardless if it includes driver weight or not.

Based on earlier data work it was decided that kerb weight as indicated by JATO + 60 kg is an appropriate approximate definition for reference mass and mass in running order and a respective column was inserted and filled with data.

2.4.2 Payload

JATO provided two columns for the payload, (Payload allowance and Payload incl. driver) and an additional column named “Payload incl. driver” containing Y/- or no entry. After analysing these columns it became obvious that the drivers weight would be double counted in a number of cases as the mass in running order (kerbweight + 60kg) already contains the drivers’ weight. For those cases 75 kg were deducted from the payload values.

2.4.3 Impact of M1 vehicles

In order to assess the impact of potential remaining M1 vehicles within the JATO database in particular for large volume manufacturers, the Polk LCV data of 2009 was taken for comparison as it comprises more detailed data.

In order to distinguish M1 and N1 the type approval directive 2007/46/EC defines in Annex II A 3. some basic parameters for N1 vehicles:

> *“The number of seating positions excluding the driver’s seating position shall not exceed 6 in the*
>
> *case of N1 vehicles [...]. Vehicles shall show a goods-carrying capacity equal or higher than the person-carrying capacity expressed in kg. For such purposes, the following equations shall be satisfied in all configurations, in particular when all seating positions are occupied:*
> *(a) when $N = 0$:*
> *$P – M \geq 100$ kg*
> *(b) when $0 < N \leq 2$:*
> *$P – (M + N \times 68) \geq 150$ kg;*
> *(c) when $N > 2$:*

P – (M + N × 68) ≥ N × 68;
where the letters have the following meaning:
"P" is the technically permissible maximum laden mass;
"M" is the mass in running order;
"N" is the number of seating positions excluding the driver's seating position."

When executing the formula most of the average CO_2 values would increase if vehicles which do not comply with the N1 criteria would be removed from the database. Most notably for the manufacturers Toyota, Peugeot, Fiat, VW, Piaggio, Seat, Kia and Volvo.

The key fields used in this report are:

- Sales
- CO_2 emissions
- Mass in running order
- Payload
- Footprint
- (Fuel and N1 class).

2.5 General results from the database

This overview of LCV sales in 2010 is undertaken using the same methodology and format as that used in the analysis of the 2007 LCV sales [AEA TNO 2008]. This both provides an overview of LCV sales, and enables direct comparisons to be made to the earlier study.

It has already been noted that the consolidated database had been cleaned so that it contained only N1 LCV, i.e. it did not contain any minibuses or camper vans. Table 2 presents an overview of the shares in total sales of vehicles from different classes and fuels in the consolidated JATO 2010 database. Totals for the share of different fuels is given in Table 3, together with the equivalent data from the analysis of the 2007 database.

Table 2 Shares of total LCV N1 sales of different vehicle types / classes / fuel from the JATO 2010 database

Fuel	Class I	Class II	Class III	Unknown	total
Compressed natural gas	1.25%	0.52%	0.09%	0.02%	1.87%
Diesel	17.56%	32.82%	44.78%	0.80%	95.96%
E85	0.004%	0.002%		0.000%	0.01%
LPG	0.33%	0.06%	0.03%	0.02%	0.44%
Petrol (premium unleaded)	1.20%	0.32%	0.09%	0.05%	1.66%
Electric	0.010%	0.036%	0.000%	0.015%	0.06%
TOTALs	**20.35%**	**33.75%**	**44.99%**	**0.91%**	**100.00%**

In 2007 sales were dominated by diesel LCVs, with petrol sales accounting for just over 2% of total sales, and other fuels adding up to less than 0.6% (although there were around 0.6% whose fuel type was not known). In 2010 again diesel LCVs dominate sales, with petrol sales accounting for under 2% of total sales, and other carbon fuels adding up to around 2.3%, around 1.4 times the number of petrol sales.

It is unhelpful either to ignore these increasingly important alternative fuels, or to expand the earlier analysis to contain five groups of three, i.e. 15 columns, covering each fuel type and weight class. Consequently the compressed natural gas, E85, LPG and premium unleaded petrol fuelled vehicles were aggregated to give data for fuels used in spark ignition engines. This was analysed as one fuel group, and diesel (or compression ignition) engines comprised the other group. Electric vehicles were kept separate because their lack of direct CO_2 emissions potentially merely confuses any analysis of CO_2 emissions considered against a utility parameter. However, whilst these are not included in the utility parameter analysis, their inclusion is vital when assessing the average CO_2 emissions of the vehicles made by individual manufacturers, or the overall average CO_2 emissions. Table 4 provides a list of the sales of LCV in 2010, sub-divided by mass class and fuel.

Table 3 Share of different fuels in LCV N1 sales for 2010 compared with 2007

Fuel	Total for 2010	Total for 2007
Compressed natural gas	1.87%	0.50%
Diesel	95.96%	96.71%
E85	0.01%	0.00%
LPG	0.44%	0.03%
Petrol (premium unleaded)	1.66%	2.13%
Electric	0.06%	0.00%
Unknown	0.00%	0.63%
TOTALs	**100.00%**	**100.00%**

Table 4 Numbers of LCV N1 sales for different vehicle types / classes / fuel from the JATO 2010 database

	Class I	Class II	Class III	Unknown	total
Diesel fuelled LCV	189,566	354,271	483,438	8,683	1,035,948
SI engined LCV	30,007	9,722	2,230	970	42,929
Electric vehicles	112	387	2	158	659
TOTALs	219,685	364,380	485,670	9,811	1,079,536

This is quite a different market to 2007, where, from Table 3.4 of Reference 1, 1,747,145 LCV with ICE were sold, 165% of the 2010 sales figure. In terms of the fractions of total sales for the different weight classes (calculated using only sales where the weight class is known) there is a markedly different pattern in 2010 relative to 2007. This is shown in Figure 1. It shows a higher number of smaller LCV sales relative to the numbers of Class III LCVs sold.

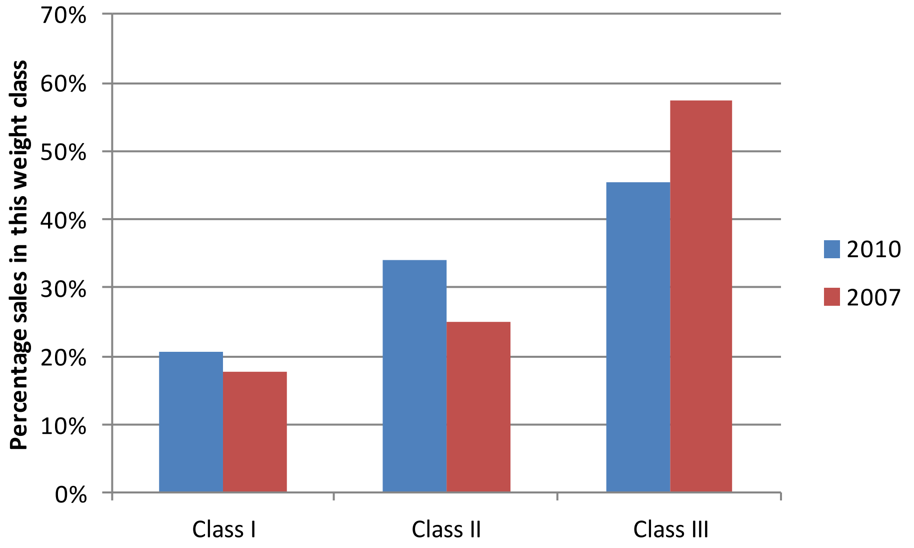

Figure 13 Market shares of different weight classes in the 2007 and 2010 new light commercial vehicle sales

Not all the key data fields, i.e. CO_2 emissions, mass, footprint or payload were available for each model. The table below gives an overview of the database entries and those missing key parameters.

Table 5 An overview of the data provided and missing in the 2010 JATO database for key parameters

Key Parameter	Category	Database entries
CO_2 emissions	Number of sales with CO_2 data provided	919,415
	Number of sales to which CO_2 data was added	142,675
	Number of sales missing CO_2 data	17,457
Mass in running order	Number of sales with mass data provided	1,060,786
	Number of sales missing mass data	18,761
Footprint	Number of sales with footprint data provided	1,011,174
	Number of sales missing footprint data	68,373
Payload	Number of sales with payload data provided	1,040,178
	Number of sales missing payload data	39,369

2.6 Technical feasibility check of the 147 gCO_2/km target

In order to check the technical feasibility of the 147 g/km target, an algorithm is developed early in the project to calculate the indicative specific emissions of CO_2 from LCVs of different masses relative to a 2020 target aiming at a sales average of 147 gCO_2/km. This was based on the equivalent algorithm for the 175 gCO_2/km target published in the Regulation (EU) 510/2011.

From this algorithm the gap between the actual (type approval) emissions performance of different LCV segments (diesel fuelled or SI engined N1 Class I, II or III) and the 2020 target was calculated from the sales weighted actual emissions performance of LCVs sold in the EU in 2007 and 2010 (using JATO LCV sales databases).

The cost curves and assessment methodology described in AEA (TNO) 2009 when combined with the actual performance of LCV sales in 2007 (AEA (TNO) 2008) concluded the 147 gCO_2/km target was considered feasible.

Relative to 2007 the average CO_2 emissions in 2010 had reduced for all LCV segments, though by varying amounts. Extrapolation of the reduction seen during the three years indicated that at this rate of reduction all LCV segments would meet the 2020 CO_2 emissions target, appropriate for that sector's weight, except for diesel N1 Class III vehicles.

The scope for further reductions from the 2010 values was evaluated using updated cost/CO_2 reduction curves which were defined relative to a 2010 vehicle baseline. Relative to the situation based on 2007 sales and cost curves, the updated cost curves show a greater reduction potential, and lower costs.

The combination of the smaller reduction to be achieved, and the updated cost curves indicate that the 147 gCO_2/km can be achieved at lower costs than expected from the earlier study reported in AEA (TNO) 2009.

The timeframe over which this reduction would need to occur is 10 years. This is longer than the development phase for LCV, as described by ACEA, which is stated as being around 7 years.

Further reviews of costs are likely to lead to a further lowering of the cost estimates required to reduce CO_2 emissions. Consequently, this first iteration feasibility study concluded it is feasible to meet the 147 gCO_2/km average emissions target by 2020.

3 Cost curves for LCVs

3.1 Introduction

This section describes the development of cost curves for CO_2 reduction in LCVs by means of technical measures aimed at achieving CO_2 emissions of 147 g/km for new LCVs in 2020. The approach is similar to the method developed for [Smokers 2006] and applied in the [IEEP 2007] study in support of the Commission's Impact Assessment for the CO_2 legislation for passenger cars[3], as well as in the impact analysis for the 95 g/km target for passenger cars in 2020 [TNO 2011].

In [AEA TNO 2008] a simplified approach was used to derive cost curves for light commercial vehicles for the purpose of assessing average costs and impacts on different manufacturers of possible targets for the short term[4]. The same simplified approach was used in [Sharpe & Smokers 2009] to provide an indicative assessment of the feasibility of meeting various target levels for LCVs in 2020.

This Service Request aims to perform a detailed assessment of the feasibility of the 147 gCO_2/km target for newly registered LCVs in 2020. For that reason a detailed review is carried out of the reduction potentials and costs of CO_2 reducing technologies available for LCVs around 2020, e.g. improvements of engine and powertrain efficiency and reduction of vehicle weight and resistance factors. Such individual technical measures can be combined into packages of technologies. On the basis of these packages, cost curves are constructed that describe the costs for various levels of CO_2 emission reduction in LCVs. Therefore, this study uses the more detailed methodology that was also used in the above mentioned studies for passenger cars, e.g. [TNO 2011].

These cost curves are subsequently used in a cost assessment model that calculates the average costs for meeting the target as well as their "distributional impacts", i.e. the cost impacts for different manufacturer groups with different positions in the market and the cost impacts for different vehicle segments.

In section 3.2 the methodological aspects are explained in more detail, including clarifying assumptions and definitions. In section 3.3 the technological options and the corresponding reduction potentials and costs are presented. Finally, the resulting cost curves are presented in section 3.3.7.

3.2 Methodology for developing cost curves

3.2.1 Approach

The methodology starts with the definition of baseline vehicles for the three vehicle segments, N1 Classes I, II and III. Characteristics of the vehicles were defined on the basis of the highest selling vehicles in each class in 2010, where sales figures were derived from the JATO project database.

Selection of CO_2 reduction technologies and assessment of their CO_2 reduction potential and additional costs (relative to the 2010 baseline vehicle (see section 3.3.3)) were made on the basis of expert opinion from within the consortium. This differs from the approach taken in [TNO 2011], where literature review was also used because of two reasons, i.e. the assessments for LCVs builds on the analysis from [TNO 2011] for passenger cars and due to contractual limitations. Single point estimates for the costs and CO_2 reduction potential (as measured on

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[3] http://ec.europa.eu/clima/policies/transport/vehicles/docs/report_ia_en.pdf
[4] http://ec.europa.eu/clima/policies/transport/vehicles/docs/2008_co2_lcv_en.pdf

the NEDC cycle) were derived for each individual technology to be used as input for the formation of cost curves.

Subsequently, all possible packages of technical measures were 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 reference) and additional manufacturer costs (in [€]) of each possible package have been determined.

Finally the improved cost curve approach from [TNO 2011] 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 (Class I), medium-sized (Class II) and large (Class III) LCVs running on diesel. Non-diesel powered vehicles were not considered in the present study because they represent less than 4% of the analysed EU market (section 2.5), while timing and budget were strongly limited from the onset of the study.

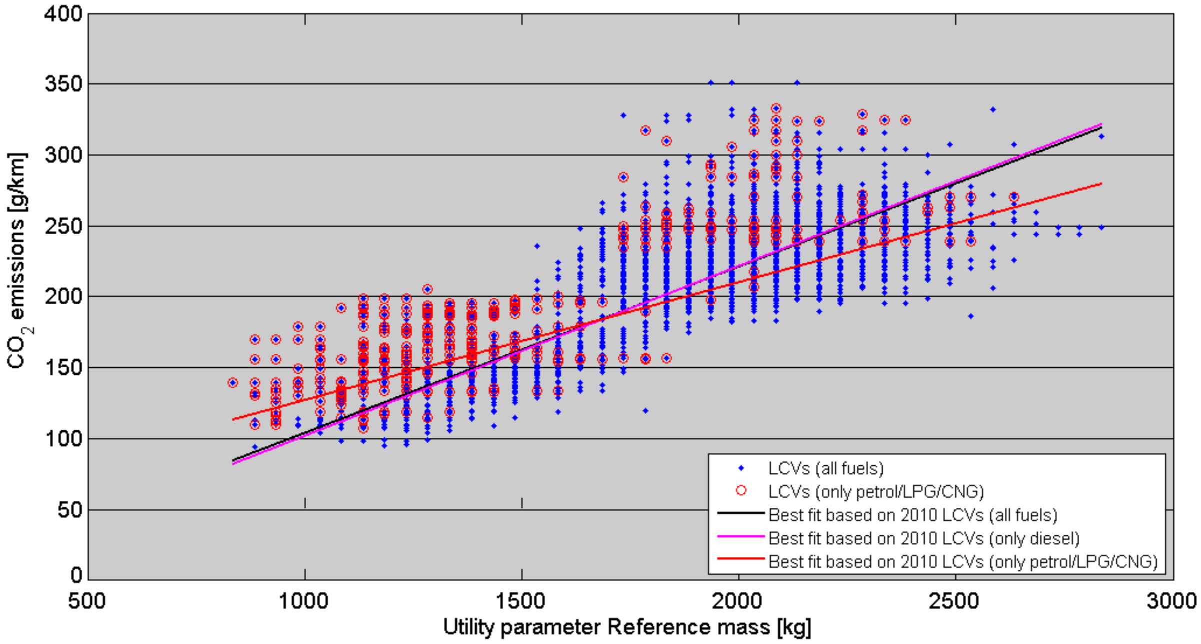

Figure 14 Sales weighted best fits through LCVs with different fuel types

The effect of not taking the non-diesel LCVs on the total average additional manufacturer costs for meeting the 147 gCO_2/km is very limited. As can be seen in Figure 14 the sales weighted best fit of the non-diesel vehicles (red line) is less steep than that of the diesel vehicles (pink line). However, the number of non-diesel vehicles (red circles) is so limited that their influence on the weighted average is very small. The best fit through the diesels is very close to the best fit through all vehicles (black line). The majority of non-diesel LCVs are relatively light and emit relatively much compared to their mass. For the individual manufacturers the error on the average additional manufacturer costs is also small as only one manufacturer (with sales above 3000 LCVs) sells a significant share of non-diesels, i.e. Fiat. This manufacturers sells approximately 17% non-diesels, which are mainly car derived Class I vehicles. The CO_2 reduction of these vehicles will partly benefit from the CO_2 reductions realised under the 95g/km target for passenger cars.

3.2.2 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 / user costs = retail price including applicable taxes

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 previously stated, 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. This is the same approach as was used for the assessment of the cost of passenger car technologies in [TNO 2011].

3.2.3 Definition of CO_2 emission reduction potential

The 147 gCO_2/km target as defined for 2020 for LCVs relates to the average emissions of new LCVs 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 study does not consider the impact of the new World Harmonised Test Procedure (with new drive cycle) that is expected to be implemented in 2020. The new change in average road load required is likely to affect the CO_2 measured over the cycle. However, at the current time the cycle is not defined with sufficient certainty to allow analysis of the effect.

The real-world (RW) emissions and fuel consumption of vehicles can differ significantly from the values measured on the Type Approval (TA) test, which are generally lower. 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]. The relation between RW and TA may change as a result of CO_2 reducing technologies which target for example either part-load or full load efficiency of the powertrain. This aspect is difficult to quantify within the aggregated approach of this study and is therefore excluded. The issue may require further study in a future project. The limited availability of hybrids and other advanced powertrains for LCV does not yet allow a statistically sound identification of a possible difference in the translation factor from type approval to real-world (see e.g. [Ligterink 2010]) between these advanced vehicles and vehicles with more conventional power trains.

Typical duty cycles for LCVs are likely to differ from that of passenger cars which may also affect the relationship between real world and NEDC CO_2 emissions. For example, a city delivery vehicle may have significantly more stop-start behaviour than an average passenger car duty cycle. Therefore, a hybrid powertrain would provide an increased level of CO_2 reduction for an LCV with this type of duty cycle as compared to a passenger car application. Furthermore, for commercial vehicles the mass of the vehicle varies significantly with payload, whereas NEDC type approval tests are conducted with low payload.

3.2.4 General considerations

In the assessments presented in section 3.3 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 cannot be accounted for in detail in this CO_2 focussed study. Instead, cost data have been derived under the assumption of high volume production.

- 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 Euro 6 diesel vehicles it is assumed that additional energy losses caused by the applied NO_x after treatment 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.

3.3 Technical options to reduce fuel consumption at the vehicle level

3.3.1 Technological options for reducing CO_2 emissions from LCVs

In [Sharpe & Smokers 2009] a list of technical options was identified which can be used to improve the fuel economy and reduce CO_2 emissions for petrol and diesel vans in the period up to 2020. In this study this list has been updated to include the most recent insights on the various. Some options have been added that have recently become available for the time period up to 2020, and date for the technologies were more specifically tailored for application in LCVs.

The following changes in the selected technological options have been made for LCVs compared to the technologies selected for passenger cars in 2020 in Service Request 1 [TNO 2011]:

- Baseline applications vehicles were considered to have already undergone a level of downsizing. For this reason, strong downsizing (>=45%) is not considered to be feasible for the baseline vehicles in this study without some form of hybridisation and is therefore excluded as an independent option.
- Improvements in engine friction (involving such technologies as piston coatings, lubricants, piston ring design) are considered to already be present on the baseline vehicles and so additional CO_2 reductions are not included for these technologies. Improvements in driveline (transmission) friction are included separately for this study for LCVs.
- In Service Request 1 both variable valve timing and lift were considered feasible options for passenger cars, whereas for this study we now consider that the cost of variable valve lift is likely to be prohibitive for the limited benefit gained on diesels.
- Series range-extended electric vehicles (REEV) are included in this study because this technology is emerging in demonstrator LCVs, so is expected to reach the market in the time period up to 2020. However, these REEVs are not taken into account in the final cost curves for reasons explained in section 3.3.7.
- Contrary to Service Request 1, Battery Electric Vehicles (BEV) and hybrid vehicles are included in the list of CO_2 reducing technologies. For passenger cars, up to date manufacturer cost data for BEVs, HEV and REEVs only became available during the execution of Service Request 1. Since such cost information was required for Service Request 3, but not available, costs for these technologies are determined in this study. Similar to the REEVs, also BEVs are not taken into account in the final cost curves for the reasons explained in section 3.3.7.
- CVT is excluded since it is not expected to be an option for the European market in the timescale of the study.
- Aerodynamic improvements are split into two categories for LCVs:
    - Minor - parts not affecting styling to give 10% reduction in drag coefficient (Cd), e.g. modified under tray;
    - Major - electro mechanical systems such as air shutters and changes to body-in –white (BIW) to give 15% improvement in Cd;
- Auxiliary systems improvements are split into three categories for LCVs:
    - Auxiliary thermal systems improvements: including more effective coolant and oil pumps, valves and electric thermostat.

  - Other auxiliary systems improvements: including more effective lubrication and vacuum pumps and FIE improvements.
  - Electrical assisted steering (EPS EPHS): only available in the large segments.

3.3.2 Baseline Vehicles

The CO_2 reduction potential and cost of each technology option were assessed relative to baseline vehicles which were defined as the highest selling vehicles in each of three segments in 2010: N1 Classes I, II and III. Due to the banded nature of the JATO project database it was not possible to select the baseline vehicles using this database alone. An approach was therefore used which utilized data from a number of sources (the JATO database, UK Vehicle certification agency database and OEM vehicle data) using the following process:

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- The manufacturer and CO_2 emissions figures for the highest selling vehicle in each vehicle class (N1 Class I, N1 Class II and N1 Class III) were identified using the JATO database
- The UK vehicle certification agency (VCA) database of van CO_2 emissions is then used to identify which vehicle model has the specified CO_2
- Where a number of vehicle variants are found with the same CO_2 emissions figure on the VCA database, in particular where different power ratings are found, OEM published information was used to determine which vehicle fits within in the data ranges specified by the JATO database (for example, kerb weight).

The specification of the baseline vehicles is shown below in Table 6 and Table 7.

Table 6 Specifications of 2010 baseline LCVs

Parameter	Diesel N1 Class I	Diesel N1 Class II	Diesel N1 Class III
Total CO_2 (g/km)	115	140	222
Vehicle kerb weight (kg)	1045	1251	2200-2249
Power (kW)	50	63	95
Engine capacity (cc)	1461	1461	2143
Length (m)	4.0	4.2	5.9
Width (m)	1.7	1.8	2.0
Height (m)	1.5	1.8	2.4
Volume (l*w*h m^3)	10.4	17.8	28.5

** Average calculated from lowest weight in range*
Source: developed from JATO project database

Table 7 Baseline LCV technologies

	Diesel N1 Class I	Diesel N1 Class II	Diesel N1 Class III
Engine layout	4 cylinder in-line	4 cylinder in-line	4 cylinder in-line
Fuel system	Common rail direct injection	Common rail direct injection	Common rail direct injection
Gearbox	5 speed manual	5 speed manual	6 speed manual

Source: OEM product information

3.3.3 Reference vehicles

As explained in section 3.3.2, the three selected baseline vehicles (the vehicle models most sold within every segment) are used as a basis to define the relative CO_2 reduction potential and manufacturer costs of every technology. It is assumed that these baseline vehicles are representative for the 2010 LCV sales; homogeneity in applied technologies is assumed. Therefore every CO_2 reducing technology (based on 2010 baseline vehicles) listed in [TNO 2012] is assumed to be applicable to every LCV model available in the assessed 2010 LCV database.

Besides these ‘baseline vehicles’, the term ‘reference vehicles’ is used to indicate the manufacturer-specific starting point for CO_2, from which they start ‘climbing’ the cost curves at the present moment. They are defined as the average of the vehicles sold by every manufacturer (group) within every segment in which a manufacturer (group) sells vehicles.

In previous studies for passenger cars, e.g. [Smokers 2006] and [TNO 2011], the year 2002 was defined as the baseline year. The average vehicles per manufacturer group per segment of that year were used as reference vehicles, because of homogeneity in applied technologies and absence of identifiable CO_2 reduction technologies. In previous vans studies, e.g. [Smokers et al. 2009], 2002 data was created by back casting 2007 data, because 2002 data were not available.

Dissimilar to these previous studies, 2010 was selected as the baseline year for the current study. The 2010 data were decided to be preferable over previously acquired LCVs data because it is believed to be more much complete and reliable. This data is used assuming homogeneity in applied technologies; every LCV model within its segment is assumed not to have any of the identified CO_2 reduction technologies applied.

3.3.4 CO_2 reduction potential and costs of individual options

CO_2 reduction technologies are grouped into the following categories in the discussion below:

- engine technologies
- lubrication and thermal management technologies
- transmission technologies
- hybridisation and electrification
- lightweighting
- rolling resistance reduction
- aerodynamic improvements
- driveline friction reduction.

Note: contrary to passenger cars studies, not all technologies aiming at improving the efficiency of auxiliaries are included in this study – e.g. electric power steering for Class I and Class II LCVs. The reasons for this are described in detail in the corresponding section below.

Engine technologies

It is expected that CO_2 legislation and need for common powertrains for production cost reasons will drive the application of similar technology into both passenger car and LCV vehicles. The key engine technology areas of combustion, air system, structural design, friction, lubrication, thermal, and ancillaries will all be progressively improved.

Whilst technically the Small (N1 Class I) applications may not require NO_x after treatment to meet Euro 6 NO_x regulations as combustion advances alone will be adequate, it is likely that such technology will be used in conjunction with a low activity exhaust NO_x trap (otherwise known as a Lean NO_x Trap [LNT]). In general for Medium (N1 Class II) and Large (N1 Class III) vehicles, NO_x control via Selective Catalytic Reduction (SCR) is expected to be applied, particularly in applications with lower engine displacement / vehicle weight ratio. However, it is plausible that a single OEM will select a single technology across all vehicle platforms in order to minimise development costs.

For the purposes of this study it is assumed that small segment LCVs use LNT while medium and large LCVs are assumed to be fitted with SCR systems. While the medium segment baseline vehicle has the same engine specification as the small segment vehicle, the vehicle mass is relatively larger, leading to higher engine out NO_x necessitating the use of SCR for this class of vehicle. The cost for Euro 6 compliance has not been included and it is assumed the exhaust system has been optimised to result in no net CO_2 penalty

Engine CO_2 reduction technologies considered were as follows:

- Combustion enhancement including, for instance, the application of Low Pressure EGR
- In line with Service Request 1, improvements in engine friction (involving such technologies as piston coatings, lubricants, piston ring design) are considered to already be present on the baseline vehicles and so additional CO_2 reductions are not included for these technologies. Improvements in driveline (transmission) friction are included separately
- Mild and Medium downsizing including down-speeding.
    - Mild downsizing assumes 15% engine capacity reduction with enhancement of the single turbo system and combustion systems
    - Medium downsizing assumes 30% engine capacity reduction with two stage series sequential boosting technology using fixed geometry turbochargers.
    - As the inertia and rolling resistance of the vehicle increases, the potential gain of downsizing reduces due to the NO_x penalty and drivability limitations incurred by higher load operation.
- Variable valve actuation - For LCV applications it is assumed that exhaust phasing will be applied for aftertreatment temperature enhancement in applications with SCR. It is considered that because small LCVs require minimal NO_x aftertreatment using LNT, they will not benefit so strongly from aftertreatment temperature enhancement. This technology is therefore included as an option for large and medium segment LCVs only. Also only variable valve actuation is now considered as the cost of variable valve lift is likely to be prohibitive for the limited benefit gained on diesels.

Lubrication, thermal management and ancillary technologies

The following technology categories are included in the analysis for lubrication and thermal management technologies: auxiliary thermal systems improvements, other thermal management technologies, thermo electric generation, secondary heat recovery and electric power steering. These technologies are described in the following paragraphs.

Auxiliary systems improvement technology includes variable coolant and lubrication pumps. A variable lubricating pump enables to limit the mechanical power absorbed by the oil pump during engine warm-up or during thermal steady-state operations as the oil pump is sized mainly for low engine speed operations (piston cooling jets at maximum torque for example). A variable cooling pump enables reduction in the amount of power absorbed by the pump during engine warm-up when the engine is not requesting any coolant flow rate but also while the engine is operating at low and mid-load during thermal steady-state operations – coolant pump is sized mainly for the rated power operating condition. The absence of any coolant flow rate in the engine during warm-up helps also to reduce the fuel consumption by increasing the temperature of the metal within the engine at a faster rate than if coolant flow is allowed during warm up. Similarly, parasitic power to drive the oil pump can be reduced if account is taken of the need for oil at different locations in the engine where friction is occurring. Furthermore, the heat transfer from the combustion chamber to the coolant can be reduced which is improving the combustion efficiency.

Further solutions to control engine warm up which are expected to come to the market before 2020 are included in the other thermal management category. This technology includes:

- A heat storage system to better control the thermal behaviour of the engine and especially to reduce the fuel consumption during its warm-up. This system works by storing hot coolant for several hours, the hot coolant is then used when engine is started after a long stop (several hours) in order to bring the engine to its nominal temperature as quickly as possible.

- Engine encapsulation used to maintain a nominal engine temperature even after a long vehicle stop and exhaust heat recovery used for improving the engine warm-up

Thermoelectric generation using the Seebeck effect and secondary heat recovery via a Rankine cycle are included for medium and large LCVs but not for small LCVs because less exhaust heat is available from the smaller vehicle with a lower powered engine which leads to the technology having a relatively small benefit.

Electric assisted steering, both EPS (Electrical Power Steering) and EPHS (Electrical Power Hydraulic Steering), can give fuel economy benefits because the pump runs only on demand. However, EPS is already present on the small and medium baseline vehicles and is therefore not included as a CO_2 reduction technology. Electric hydraulic steering (EPHS) technology is not currently applied to large vans, but is expected to appear in the 2020 timeframe and is therefore included in the analysis.

Transmission technologies

As low speed torque for LCV engines increases, it is possible to optimise gear ratios to allow the engine to operate at lower engine speeds, thereby allowing a small reduction in CO_2 emissions in addition to that provided by the engine.

Clutch micro-slip control can be used in conjunction with Dual Mass Flywheel (DMF) deletion to reduce CO_2 emissions. Clutch micro slip systems were originally developed for autoclutch systems and dual clutch transmissions (DCTs). It allows the clutch to slip a small amount (c.20 to 50 rpm) during normal driving which improves the shift response of these systems and provides a degree of torsional damping. The slip control provided significant torsional damping and allowed the deletion of the DMF thereby reducing the driveline inertia and improving fuel consumption. In real world driving conditions, the effect of the improved torsional mapping provided by the slip controlled clutch was that the drivers adapted and allowed the engine to run down to lower speeds before downshifting to enable further CO_2 reductions . However, as shift points are fixed for manual transmissions in the NEDC test procedure, potential benefits are reduced because only the effect of the reduced inertia that will contribute to the CO_2 emissions results. Trials have been reported using slip control on a large LCV equipped with a diesel engine and a manual transmission

Automated Manual Transmissions (AMTs or ASG) provide the benefits of the efficient manual transmission with the lowest cost automation. Automating the shift points enables improvements on the NEDC cycle which also tend to apply in the real world as the system is more likely to be in the correct gear for a given condition. Adding the new generation of slip control to an AMT and then adjusting the shift points to take advantage of this, could yield the best CO_2 figures for LCVs with a lower on cost than other types of automated transmission.

Dual clutch transmissions (DCTs or DSG) have been in use in passenger cars for some time and are beginning to appear in light trucks. Dry clutch DCTs give the best CO_2 reductions of the technologies on offer but have limited torque capacity therefore the development of this type of transmission is generally being limited to passenger cars up to C-segment. This technology is therefore included for small and medium LCVs but it is considered unlikely that there will be a suitable dry clutch DCT available for the large LCV segment. These transmissions can approach the CO_2 reductions for an equivalent AMT but will always have slightly higher CO_2 emissions due to increased inertias and weights, and are significantly more expensive than an AMT. It is expected that this technology will be more expensive than for a passenger car with similar torque due to more demanding duty cycle.

Hybridisation and electrification

The hybrid and electric vehicles included in the technology options have assumed the following specifications:

Table 8 Specifications of hybrid and electric vehicles included in the technology options

Vehicle type	Battery system	Technology
Stop start	12 V PbA	Stop start only
Micro hybrid	12+ V PbA	Stop start and light regenerative braking
Mild hybrid	~1 kWh NiMH/Li-ion	Manual transmission, torque boost, increased regenerative braking, stop-start, engine optimisation
Full hybrid	1-3 kWh NiMH/Li-ion	As mild plus AMT and EV mode expected 20-30 mile range
Series range extender	12 kWh Li-ion	As full with larger EV range, expected 40-50 mile range
Electric vehicle	30 kWh Li-ion Class I and 2 40-45 kWh Li-ion Class III	75 – 100 mile range, part laden

The benefits of hybridisation in the LCV segment are most clearly demonstrated in use cases/drive cycles that involve duty cycles with high levels of stop-start traffic. LCVs are frequently used in delivery applications and drive through dense traffic areas – in these cases, since all forms of hybridisation support stop-start this can have a very high impact on CO_2 reduction. The NEDC improvements shown in Table 3 are modest but in the real-world delivery cycles, much higher levels would be expected.

A significant difference between passenger cars and LCVs is the availability and cost impact of automated transmissions – some hybrid solutions can only be implemented with an automated transmission, whilst others can achieve higher savings if some form of automated transmission is used. To achieve the maximum CO_2 reductions for a hybrid an automated transmission is required and is therefore assumed for full hybrid.

The applicability of stop-start to LCVs is affected by engine displacement and nature of the vehicle use. So while stop start is applicable to the reference Class III vehicle in this study as it has a 2.2L engine, LCVs with larger engine displacements (e.g. >2.4l) require more robust enhanced-starter motors which are not yet readily available. As the trend for stop-start increases in the diesel passenger car market this problem is expected to be addressed but it is not expected that stop start systems will be available in the 2020 timeframe for LCVs with engine capacities > 2.4L.

The more predictable nature of some LCVs, particularly in fleet operators does allow for the introduction of EV and series range extender EVs (REEVs); many LCVs complete relatively low mileage in cities and for these an EV or RE-EV can be a very efficient way to significantly reduce CO_2.

Lightweighting

Reducing vehicle inertia reduces the energy required to propel the vehicle thus providing improvements in fuel economy and CO_2. Major benefits are realised when the reduced tractive efforts to propel the lighter vehicle reach a point where a downsized powertrain can be employed. Achieving Body-in-White (BIW) weight reduction involves the application of novel materials and processes which can affect vehicle attributes such as crash safety, NVH, stiffness and durability. For the purpose of this assessment, it is assumed that the BIW will have very similar attribute performance for each level of weight reduction. “BIW lightweighting” for this report includes the closures (doors, bonnet). For the small LCVs segment, CO_2 reduction by lightweighting is less cost effective than for comparable passenger cars. The reason is that although many characteristics of LCVs within this segment are comparable to those of passenger cars, e.g. engine, body and chassis, there is less potential to reduce weight without affecting performance, because there is less of the “first choice items” (e.g. seats, noise reducing materials) to remove and/or lightweight. Therefore, it is more costly to reduce the same weight. Medium and large LCVs have relatively greater rolling resistance and aerodynamic losses resulting in lower relative inertia losses, therefore the effects of BIW weight reduction are reduced.

Four levels of lightweighting are considered:

- 10% LCV BIW weight reduction - this can be achieved by the implementation of advanced steels with higher mechanical strength properties enabling thinner sections and panels in the structure. These improvements would incur relatively moderate engineering, raw material and production costs
- 25% LCV BIW weight reduction – this would typically require a multi-material approach using advanced high strength steels and aluminium. The high strength steel would be applied in strength critical areas such as front and side crush zones with larger unstressed areas such as the roof, side panels and bonnet ideally suited for aluminium. The joining of aluminium and steel introduce engineering and production complexities hence a higher cost increase
- 40% BIW weight reduction - this would involve more radical material and structural approaches such as composites and aluminium spaceframe technologies. A significantly higher cost impact is anticipated due to the raw material costs, requirements for “clean” production environments and lower production rates when using composites. With such high reductions in BIW weight, it should be noted that “secondary” weight benefits become viable which are not included in this evaluation. A lower vehicle inertia may enable a lighter, downsized powertrain to be specified. Also, the forces acting in the vehicle chassis will be lower, hence downsized (lighter) suspension wheel and tyre components may be specified. A lower vehicle weight will reduce the load on the tyres enabling further improvements in tyre rolling resistance
- LCV lightweighting other than “BIW” involves reducing the weight of vehicle suspension and powertrain systems. A “moderate” approach of applying steels and aluminium alloys for lightweighting of these systems is assumed for this study.

Cost estimates for lightweighting have been revised to be in line with analysis that was performed for the SuperLIGHT-CAR car project for BIW mass reduction[5].

Rolling resistance reduction

The rolling resistance force produced by a tyre is dependent on the vertical load, vehicle (wheel) speed, contact patch area and the properties of the rubber compound and tread. Tyre rolling resistance is usually in direct conflict with NVH, wet/dry grip and tyre wear characteristics. Recent improvements in tyre rolling resistance have been achieved by advances in the rubber compound, in particular the introduction of silica. Tyre suppliers are demonstrating more radical ways of reducing rolling resistance by modifying the wheel and tyre size. Narrower tyres have a reduced contact patch area but suffer compromised grip. Changing the tyre radial velocity by wheel diameters can also benefit but at the expense of challenging styling issues. For the purpose of this study, improvements in rubber compound and tread and moderate changes in tyre widths are considered. The costs for these tyres are estimated since the technology is emergent, but it is considered that they will be significantly higher than current low rolling resistance tyres.

Aerodynamic Improvements

Minor aerodynamic features are considered to be changes that would not affect the overall styling and shape of the vehicles, such as active front grilles, wheel fairings and underbody treatments to improve localised airflow. The improvements and costs for small and medium LCV’s are assumed to be similar to passenger car values. Minor improvements to large LCVs are more challenging given the large frontal area, driven by the requirement for these vehicles to accommodate standard pallet sizes.

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[5] http://www.superlightcar.com/public/index.php

Major aerodynamic features involve changes to the overall vehicle shape and could only be incorporated as part of a major model update. Again, aerodynamic improvements to the larger classes of LCVs are deemed to be more challenging due to requirements for carrying standard pallet sizes.

Driveline friction reduction

For transmissions designed for similar torque levels, the higher the input torque level, the higher the efficiency, as the torque independent (spin) losses tend to dominate. As the LCV size increases, the GVW increases faster than the powertrain torque, so the larger vehicles tend to run at higher proportional torque levels. However the largest LCVs are normally rear axle driven, which requires the addition of a comparatively inefficient bevel gear drive, which partially offsets the efficiency increase due to higher torque levels. Based on similar transmissions and vehicle weights, an average efficiency of 80% is assumed for the small LCV, 82% for the medium LCV and 83% for the large LCV.

For a mild reduction in transmission loss, lower viscosity lubricant with additional additives, moderately reduced friction in seals and bearings, and optimised gear and casing design is assumed. It is estimated that a 10% friction reduction is possible with this. For a high reduction in transmission loss, oil churning losses are removed by changing the transmission design to a dry sump, with oil pumps, jets and filters required to achieve this. Gear superfinishing is applied, in conjunction with low viscosity oil with an advanced additive pack. A ‘next generation’ of oil seals and bearings are used. It is estimated that a 50% reduction in transmission loss is possible, with the greatest proportion from the elimination of oil churning. As the engine efficiency decreases at lower loads, the overall CO_2 reduction is less than the transmission loss reduction.

Cost estimates for mild friction reduction technology includes increased unit costs of the lower friction components, while the cost estimate for high friction reduction technology includes the additional component costs for oil pumps and filters, increased manufacturing costs due to the additional gear finishing process, and casing features to allow for a dry sump and oil jet lubrication.

3.3.5 Analysis procedure

A final data set has been constructed based on the analysis of experts from within the consortium describing the assumed CO_2 reduction potential and additional costs (in 2011 Euros) of the various individual technologies studied in this chapter. These data, listed in 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 147 g/km.

Some technologies listed in Table 9 cannot be combined with other technologies. These mutually exclusive technologies are listed in Annex G.

The cost data presented in Table 9 are additional manufacturer costs compared to the 2010 baseline vehicle. CO_2 reduction percentages are relative to the CO_2 emission of the 2010 baseline vehicle in each segment. 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 and are therefore used for this analysis.

3.3.6 Stakeholder feedback

Once the data set had been constructed using analysis by experts from within the consortium, feedback to validate these results was sought from the following groups:

- Vehicle manufacturers chosen to represent different technological focus and market positions
- Manufacturer’s associations ACEA, JAMA and KAMA
- Automotive suppliers chosen to represent different technological focus and market positions
- The supplier association CLEPA and possibly other relevant trade associations

Feedback from these sources was then reviewed and the results revised as considered appropriate by consortium experts.

Table 9 Diesel LCV CO_2 reduction potential and costs

	Technology options for diesel LCVs	**Small LCV**		**Medium LCV**		**Large LCV**	
	Description	CO2 reduction potential [%]	Cost [EUR]	CO2 reduction potential [%]	Cost [EUR]	CO2 reduction potential [%]	Cost [EUR]
base engine	Combustion improvements	3.0	90	3.0	90	3.0	90
	Mild downsizing (15% cyinder content reduction)	4.0	50	4.0	50	3.0	50
	Medium downsizing (30% cylinder content reduction)	7.0	290	7.0	290	6.0	170
	Variable valve actuation	N/A	N/A	1.0	50	1.0	50
transmission	Optimising Gearbox ratios/downspeeding	1.0	0	1.0	0	1.0	0
	Improved M/T Transmission	0.5	0	0.5	0	0.5	0
	Downspeeding via slip controlled clutch and DMF deleted	3.0	120	3.0	120	3.0	120
	Automated manual transmission	6.0	300	6.0	300	6.0	500
	Dual (dry) clutch transmission	4.0	900	5.0	1100	N/A	N/A
Hybridisation/EV	Start stop	4.0	175	4.0	200	5.0	225
	Micro -hybrid (including regenerative braking)	6.0	350	7.0	375	8.0	400
	Mild hybrid (Torque boost for downsizing)	11.0	1400	11.0	1500	11.0	1600
	Full Hybrid (EV only mode)	25.0	2550	25.0	3050	25.0	4250
	Series Range extender with 40-50kW engine	45.0	10000	45.0	11000	45.0	11500
	Electric vehicle	100.0	30000	100.0	32000	100.0	33000
Driving resistance reduction	BIW lightweighting - mild (~10% reduction)	1.5	150	1.0	175	1.0	325
	BIW lightweighting - medium (~25% reduction)	4.0	750	2.5	875	2.5	1625
	BIW lightweighting - strong (~40% reduction)	6.5	2400	4.0	2800	4.0	5200
	Lightweight components other than BIW	1.5	150	1.0	175	1.0	325
	Aerodynamics improvement - minor	1.5	50	2.0	100	1.5	100
	Aerodynamics improvement - major	3.0	150	3.0	200	3.0	250
	Low rolling resistance tyres	4.0	150	5.0	200	5.0	300
	Reduced driveline friction (mild reduction)	1.0	80	1.0	80	1.0	90
	Reduced driveline friction (high reduction)	3.0	210	3.0	220	3.0	250
Other	Thermo-electric generation	N/A	N/A	2.5	300	4.0	400
	Secondary heat recovery cycle	N/A	N/A	4.0	400	5.0	600
	Auxilliary (thermal) systems improvement	2.5	70	2.8	80	3.2	80
	Auxilliary systems improvement (lubrication, vacuum, FIE)	2.8	85	3.5	100	3.7	115
	Other Thermal management	1.5	80	2.2	120	2.5	170
	Electrical assisted steering (EPS, EPHS)	N/A	N/A	N/A	N/A	3.0	150

3.3.7 Generation of cost curves for packages of technical measures

Using the methodology as described in [Smokers 2006] and [TNO 2011] from the lists in Table 9 those options that are technically compatible can be combined into packages of measures. This yields a large number of possible packages, each with a different overall CO_2 reduction potential and different overall costs.

The overall CO_2 emission $E_{package}$ 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 be 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 $(1 - \gamma)$, applied to the reduction potential defined by the cost curve, 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.

A safety margin $\gamma = 5\%$ (correction factor 0.95) was applied to the end point. This 5% margin is based on a balance between safety margins applied in earlier studies (resulting from previously acquired knowledge) and new consortium insights.

Two technology options listed in Table 9, i.e. battery electric vehicles and range-extended electric vehicles are not taken into account for constructing the curves because these are not technologies that can be applied to conventional ICEVs but are rather alternative drive trains. Moreover the costs of these technologies are so high that the packages including these "technologies" are separated from the rest of the packages (Figure 15). As a result the cost difference between either applying one of these technologies or not is very big, resulting in a 'gap' in the cost curves. An extra argument for neglecting the BEVs is that adding other CO_2 reducing technologies does not yield a type approval CO_2 reduction since that is already zero.

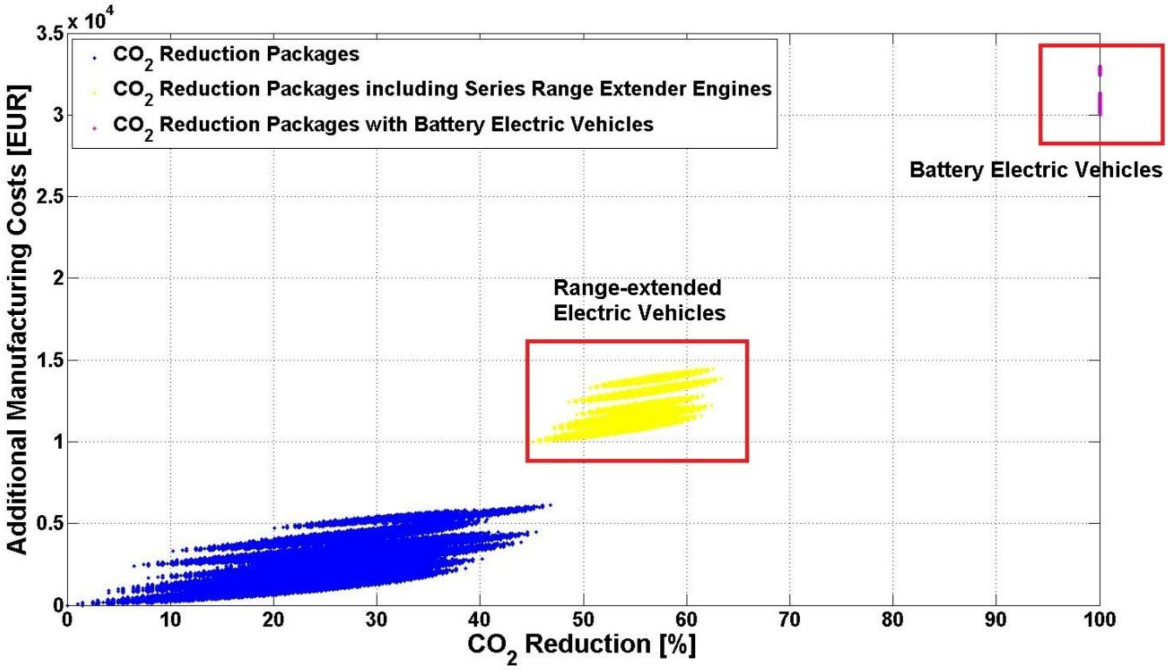

Figure 15 Costs of CO_2 reducing technology packages for small diesel LCVs including range extended electric vehicles and battery electric vehicles.

Unlike in previous studies e.g. [Smokers 2006], [AEA TNO 2008] and [Sharpe & Smokers 2009] the technology package used for determining the end point of the cost curve is not the package containing all technologies listed in Table 9. This is because the cost efficiency of some technologies is very low, e.g. strong lightweighting. As a result some technology packages at the right-upper corner of the cost cloud (excluding BEV and REEV) cost significantly more than packages lacking these technologies but add only a very limited amount of CO_2 reduction As a result the cost curve slope would become very steep at the end if these technologies were taken into account. In reality it is very unlikely that manufacturers will reduce CO_2 emissions to such high marginal costs

In Figure 16 the blue dots represent the costs (based on manufacturer cost estimates) vs. CO_2 reduction of the various feasible packages. The magenta line represents the outer envelope of the cloud of data points indicating costs and reduction potentials of all feasible technology packages. The green lines represent the constructed cost curves. Starting point for the x-axis and y-axis in these figures are the 2010 baseline vehicles for the different classes, 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 C.

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, top 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 criterion that the 1st and 2nd derivative are positive in the range of reduction levels that are relevant for the assessment.

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

$$y = \sum_{i=1}^{8} a_i \cdot x^i$$

with x the CO_2 reduction in [%][6] and y the additional manufacturer costs in [€]. For the different size classes 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 diesel LCVs in 2020, relative to 2010 baseline vehicles

	a_8	a_7	a_6	a_5	a_4	a_3	a_2	a_1	End %	End €
Diesel Small				8.07E+05	-3.30E+05	1.78E+04	1.48E+04	6.87E+02	41.9%	4455
Diesel Medium	2.89E+07	-2.53E+07	6.93E+06	-8.68E+04	-2.95E+05	5.06E+04	1.13E+04	4.48E+02	46.1%	5780
Diesel Large	6.38E+07	-6.13E+07	1.66E+07	5.03E+05	-6.95E+05	5.16E+04	1.58E+04	5.64E+02	48.2%	8475

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[6] 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.

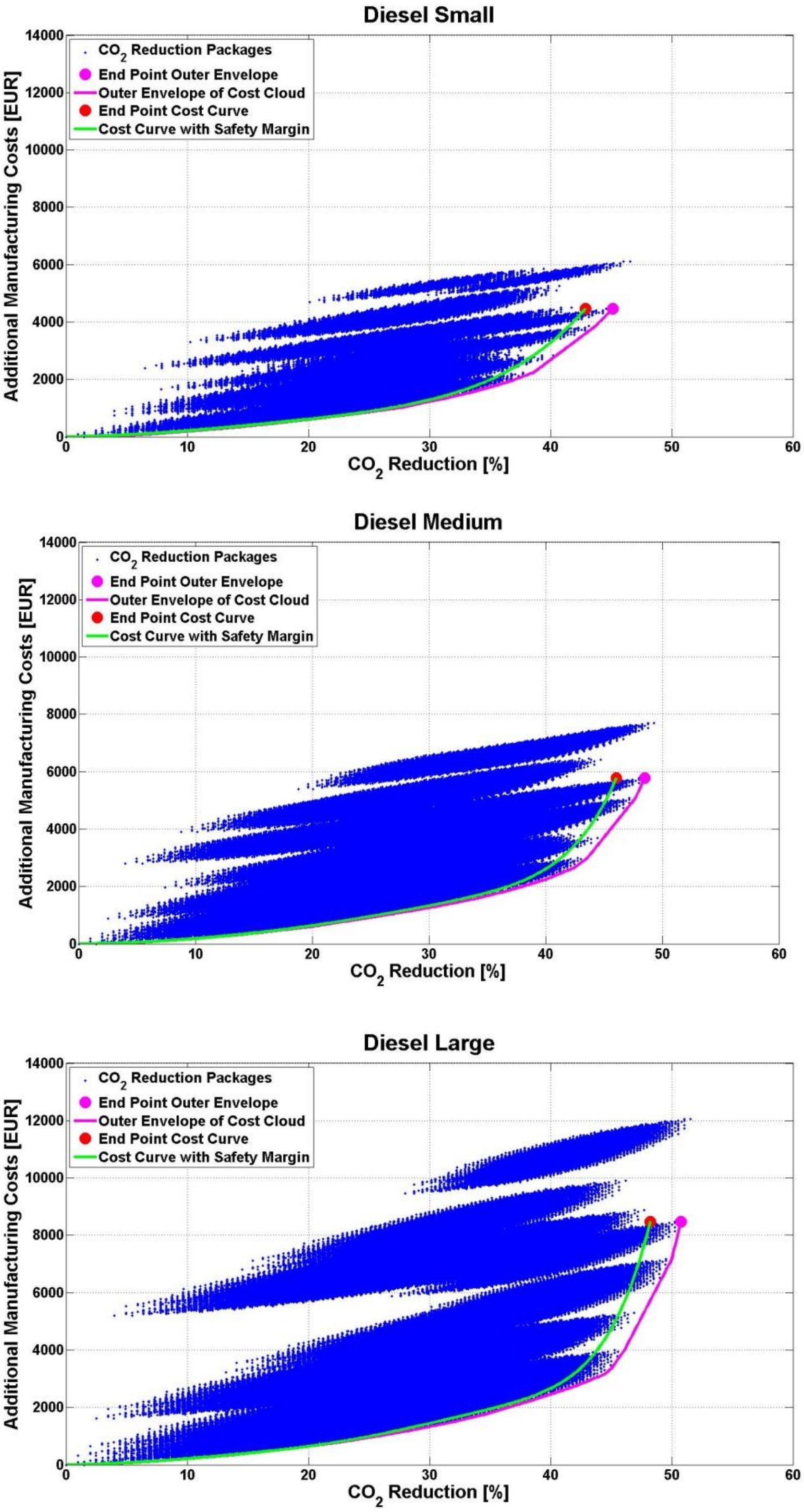


Figure 16 Development of cost curves for diesel LCVs in the small, medium and large segments. The red dot indicates the maximum reduction potential for the assessed measures at the lowest cost. The baseline CO_2 values are 120.5 g/km Class I, 161.4 g/km for Class II and 223.1 g/km for Class III diesel LCVs.

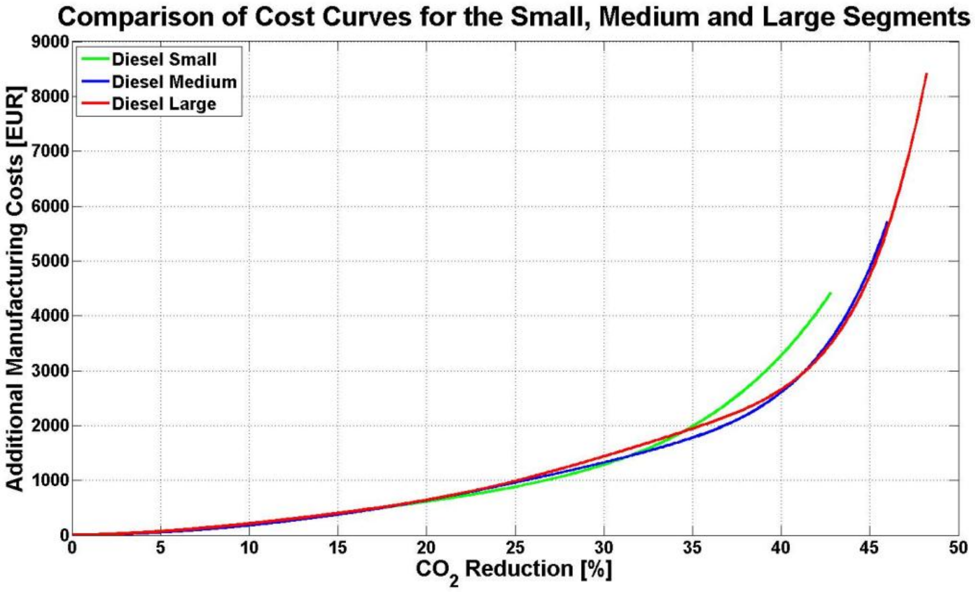


Figure 17 Cost curves for CO_2 emission reductions small-sized, medium-sized and large-sized diesel LCVs in 2020, relative to 2010 baseline vehicles.

Including the safety margin, the maximum CO_2 reduction potential using the assessed measures for small, medium and large diesel LCVs is respectively 41.9%, 46.1% and 48.2% (Table 9). These reductions combined with the costs of the technology packages on which these maximums are based (calculated as the sum of the costs of all technologies in the package) generate the end point of the cost curve, indicated as red dots in Figure 16. An overview of the resulting cost curves for the small, medium and large segments is presented in Figure 3.

From these figures it can be concluded that for CO_2 emission reductions up to 31%, equal relative CO_2 emission reductions can be achieved at the same costs for all three segments. From 31% onwards the costs for CO_2 emission reductions for small-sized LCVs become higher than for medium-sized LCVs and from 33% onwards higher than for large-sized LCVs. A similar observation can be made for medium-sized LCVs, for which the costs of CO_2 emission reductions from 41% onwards become higher than for large-sized LCVs. This is due to a number of technologies that can be applied to the N1 Class III reference van, but cannot be applied to the N1 Class I and/or Class II reference vans (see Table 9), i.e. variable valve actuation, thermo-electric generation and secondary heat recovery cycle and electrical assisted steering.

In the current study reductions are presented as relative values on the x-axis, while absolute reductions were used in [AEA TNO 2008] and [Sharpe & Smokers 2009]. As a result the cost curves of the three segments are closer together in this report (see Annex C for the cost curves in absolute emission reductions). 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.

3.4 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. However, both the 2008 analysis, assessing short term targets for LCVs based on cost curves for the 2012-2015 timeframe [AEA TNO 2008], and the 2009 study, assessing the feasibility of and costs for achieving further CO_2 emission reductions in LCVs in the longer term up to 2020 [Sharpe & Smokers 2009], used a simplified approach to generate cost curves for LCVs. For the current study, which is intended as a detailed review of the results of previous, more indicative assessments for the 2020 target for LCVs, it was decided to follow the detailed approach that was also used to generate cost curves in studies for the passenger car targets. In addition modifications to this approach have been made to better reflect specific issues for the LCV market.

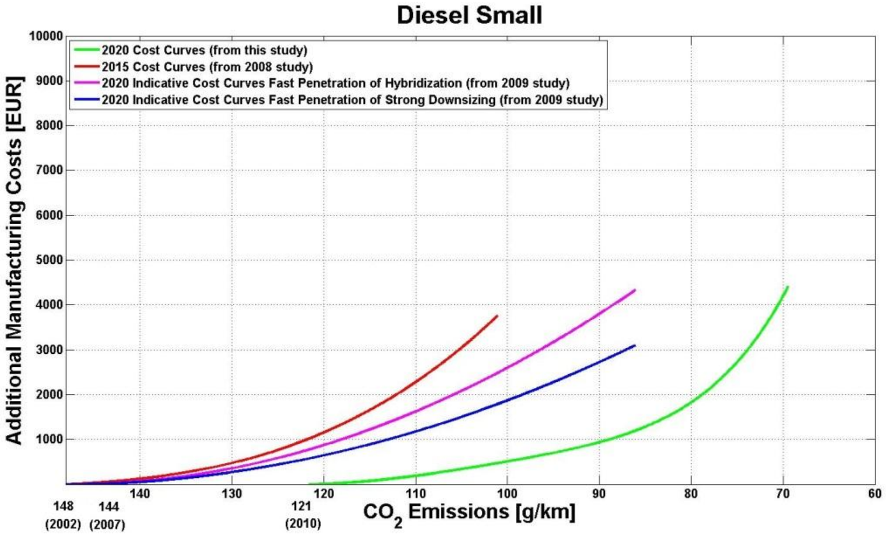
In order to compare the current estimates of costs of CO_2 reduction by 2020 with previously estimated costs, cost curves from the previous reports are depicted side by side with the current cost curves in Figure 18. Since in the 2009 report, cost curves were presented for two scenarios (strong engine downsizing and hybridisation) the figures below show two 2009 cost curves per segment. Also, since the previous studies used 2002 as baseline year, compared to 2010 for this study, the cost curves have “different origins”. For the previous cost curves the sales weighted average CO_2 emissions in 2002 was used as origin, while the new cost curves from this study the 2010 sales weighted average CO_2 emissions have been used.

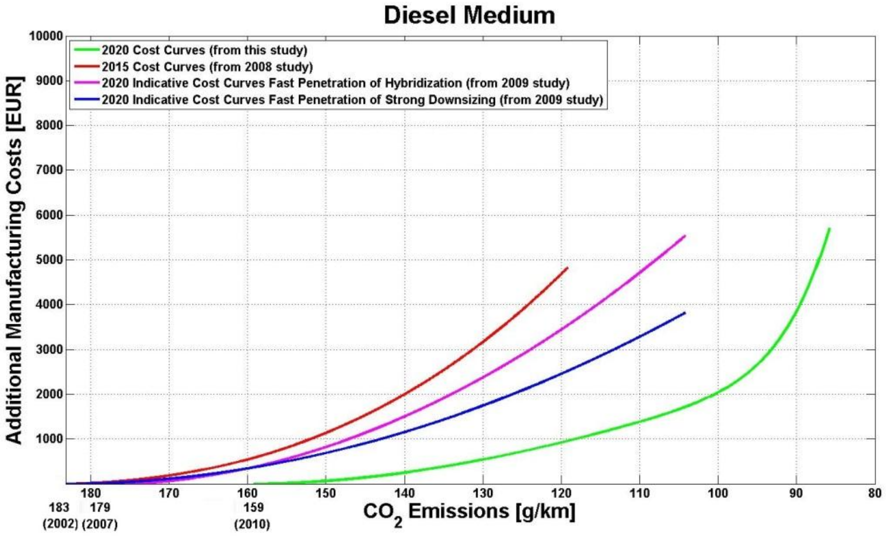
In these figures it can be seen that the new cost curves (valid for 2020 and beyond) are all below the previous curves valid for the 2012-2015 respectively the 2015-2020 timeframe, implying that the currently estimated costs for the application of available technologies at maturity are significantly lower than previously expected. Moreover, the maximum reduction potential according to the new 2020 curves is higher. Beyond the maximum potential indicated by the earlier cost curves for 2020 the new cost curves display a sharp upward bend, indicating that the additional potential is available at relatively high marginal costs.

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:

- Significant emission reduction efforts have taken place between 2002 and 2010. Especially for the small and medium segment. Part of this achievement can be attributed to technologies that where present in the 2008 and 2009 study but are excluded from the current technology table, because they are already applied in the baseline vehicles, such as electric assisted steering for the small and medium segment. Besides this reduction by means of implementation of CO_2 reducing technologies, reductions in the Type Approval CO_2 emissions have also been realised by relatively small technological changes not listed in this or previous studies and by developments not related to technology.
- In the 2009 study strong downsizing (relative to the baseline year of that study, i.e. 2002) 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. Part of what was defined as ‘strong downsizing’ in the 2009 study, has already been applied to the baseline vehicles of the current study. The new cost curves do not include strong downsizing as a feasible package in the same technology set as hybridisation. However, the technology listed as mild downsizing in the current study is more or less equal to what was defined as ‘strong downsizing’ in the 2009 study.
- For large reduction potentials the new cost curves are well below the indicative curves from the 2009 study.

Differences between the indicative 2020 cost curved from [Sharpe & Smokers 2009] and the new cost curves from the current study only partly relate to the fact that the earlier curves were indicative and based on a simplified methodology. The main origin of the difference is the fact that for the new curves the inputs with respect to costs and potentials of CO_2 reduction 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 3.3.7) 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 the new curves predict lower costs than the earlier indicative curves, leads to the conclusion that costs for reaching 147 gCO_2/km will be lower than indicated in the 2009 study. Moreover, since the end point of the cost curves is set at a higher reduction, the likelihood that the 147 g/km target for 2020 will be met is increased.





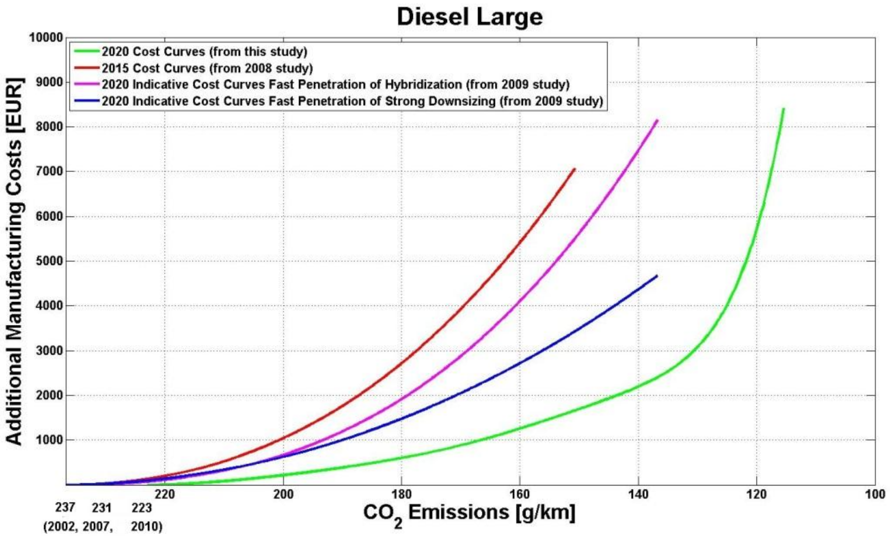


Figure 18 Current cost curves for diesel LCVs in 2020 compared to cost curves presented in [AEA TNO 2008] and [Sharpe & Smokers 2009] .

3.5 Conclusions

Cost curves for small, medium and large diesel LCVs were constructed for this report. They are based on the minimum costs for combinations of technological CO_2 reducing measures to 2010 baseline vehicles. In defining the reduction potential of packages of measures 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.

Several technologies were not taken into account in constructing the cost curves for different reasons. Firstly battery electric vehicles (BEV) and range-extended electric vehicles (REEV) are not taken into account because these are not technologies that can be applied to conventional ICEVs but are rather alternative drive train technologies. Moreover the costs of these technologies are so high that packages including these “technologies” are separated from the rest of the packages. As a result the difference in costs between either applying one of these technologies or not is very big, resulting in a ‘gap’ in the cost curves. Besides BEVs and REEVs several other technologies were not taken into account in constructing cost curves because the cost efficiency of some technologies is very low, e.g. strong lightweighting. As a result some technology packages at the right-upper corner of the cost cloud (excluding BEV and REEV) cost significantly more than other packages lacking these options but add an only very limited amount of CO_2 reductions. In reality it is very unlikely that manufacturers will reduce CO_2 emissions to such high marginal costs.

It can be concluded that for CO_2 emission reductions up to 31%, achieving equal relative CO_2 emission reductions is at the same costs for all three segments. From 31% the cost curve predicts higher costs for CO_2 emission reductions for small-sized LCVs than for medium-sized LCVs and from 33% higher than for large-sized LCVs. A similar observation can be made for medium-sized LCVs, for which the cost curves predict higher costs for CO_2 emission reductions from 41% than for large-sized LCVs. This is due to a number of technologies that can be applied to N1 Class III vans, but cannot be applied to N1 Class I and/or Class II vans (see Table 9), i.e. variable valve actuation, thermo-electric generation and secondary heat recovery cycle and electrical assisted steering.

The fact that the new curves predict lower costs than the earlier indicative curves for 2020 from [Sharpe & Smokers 2009], leads to the conclusion that costs for reaching 147 gCO_2/km will be lower than indicated in the 2009 study. Moreover, since the end point of the new cost curves is set at a higher reduction, the likelihood that the 147 g/km target for 2020 will be met is increased.

4 Utility parameters

In this section, the LCV sales database for 2010 is analysed to provide data on the sales weighted average for all LCV, and for the individual LCV segments. The principal objective is to investigate aspects of utility parameters. Those considered are:

- Mass in running order (the current utility parameter specified in Regulation (EU) 510/2011)
- Footprint
- Payload.

In each case the manner the CO_2 emissions (gCO_2/km) changes with the utility parameters is assessed and analysed. In addition, the average CO_2 emissions of the LCVs sold by individual manufacturers is analysed and compared against the “sales weighted least square fit” through all LCV sales.

4.1 Mass in running order as utility parameter

4.1.1 Size of the sample that was analysed

In this and the following sections where footprint and payload are considered as potential utility parameters, the principle adopted is **to use as much of the database as possible**. This leads to using any line of sales data in the database that records **both CO_2 emissions and vehicle mass data**. These criteria lead to 1,060,285 LCV being included, and 18,592 sales being excluded as missing one, or both, vital pieces of information.

4.1.2 Analysis of sales weighted average CO_2 emissions for the different weight classes

The sales weighted average mass in running order, and CO_2 emissions were calculated for all the 1,060,258 LCVs, and for the six engine type-weight class LCV segments. These data are given in Table 11. The corresponding data for the analysis of the 2007 JATO database are given in the lower portion of the table for comparison.

Table 11 Average CO_2 emissions and mass in running order per vehicle segment for 2010 (and 2007)

	Spark ignition			**Diesel**			**Average**
	Class I	**Class II**	**Class III**	**Class I**	**Class II**	**Class III**	
Mass in running order (kg)	1158	1457	2075	1174	1502	1988	1654
CO_2 emissions (gCO_2/km)	137.7	167.8	240.4	120.5	161.4	223.1	181.4
Sales with both data fields	28,837	9,711	1,972	189,195	352,993	477,577	1,060,285
2007 data for comparison							
Mass in running order (kg)[7]	1,085	1,430	1,933	1,166	1,531	1,950	1,706
CO_2 emissions (gCO_2/km)	165	198	271	144	179	231	203
Sales	20,992	6,590	3,761	287,710	429,805	998,287	1,747,145

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[7] In the 2007 emissions analysis the data provided was “Reference Mass”. These data have been converted into “Mass in running order” eo enable a direct comparison to be made. Reference Mass is defined as the mass of the vehicle in running order less the uniform mass of the driver (taken as being 75 kg) and increased by a uniform mass of 100 kg. Hence, Mass in running order = Reference Mass – 25 kg.

Inclusion of the 659 electric vehicles, which have no tailpipe CO_2 emissions, reduces the average emissions for all LCVs from 181.4 to 181.3 g CO_2/km.

For all six LCV segments the average CO_2 emissions have reduced, though by varying extents for the 2010 data relative to the 2007 data. This is despite the average weight of vehicles increasing for all segments except the Class II diesel LCV. Further comments on the mass in running order-CO_2 emissions relationship, how it has changed since 2007, and the implications for successfully meeting the 2020 147 gCO_2/km target are discussed in section 4.1.

4.1.3 Analysis of sales weighted average CO_2 emissions as a function of mass in running order

Section 2.5 of this study considered the changes in CO_2 emissions from LCV since 2007 and the average emissions. Specifically it considered the feasibility of the average emissions meeting the 147 gCO_2/km 2020 target, assessed using mass in running order as the utility parameter (as per Regulation (EU) 510/2011). In contrast, this section assesses and analyses the relationship between the CO_2 emissions (gCO_2/km) and the different potential utility parameters (mass in running order, footprint and payload). This section analyses the relationship between CO_2 emissions (gCO_2/km) and mass in running order.

Figure 19 shows a scattergram of the CO_2 emissions (/km) as a function of mass in running order for all 1,060,285 LCVs. Relative to earlier graphs where the databases from which they were drawn contained continuous values of mass, the banded nature of the weights provided in the 2010 JATO database is evident, with mass in running order only able to take discrete values, 50 kg apart.

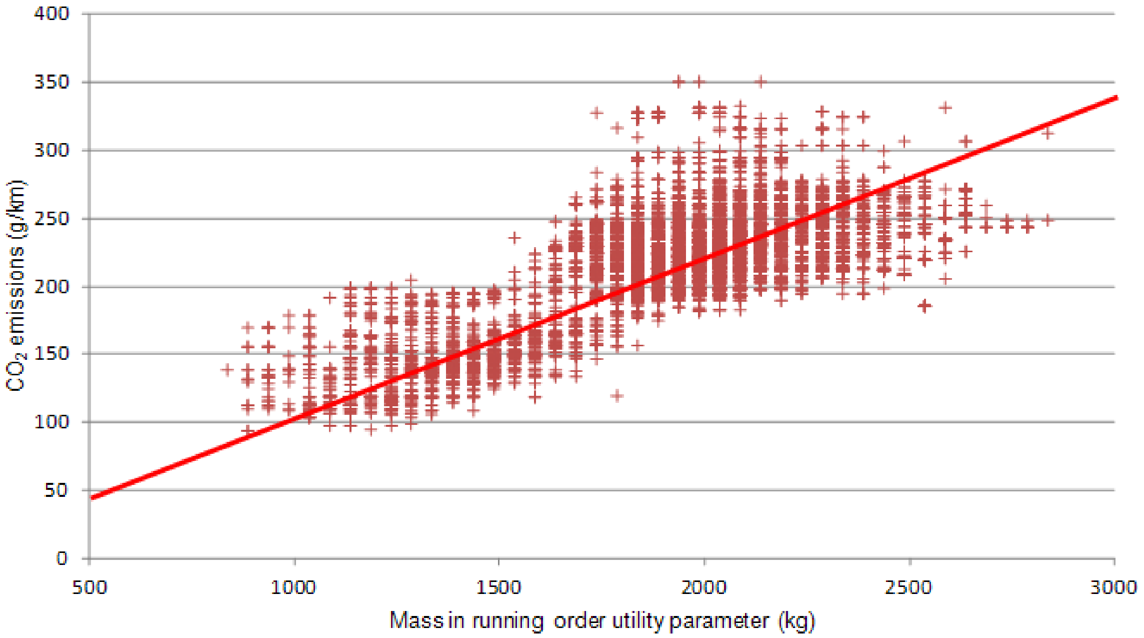

Figure 19 CO_2 and mass in running order values of LCV sales in 2010, and the sales weighted least squares fit through the data

In part, some details of Figure 19 are a consequence of the testing procedure. In particular, two aspects of the procedure (more details in Annex E), as defined in Annex III, Type I test, affect the CO_2 emissions.

Various elements of the chassis dynamometer testing procedure, used to determine the CO_2 [g/km] emissions of a vehicle, affect the outcome of the test in a way that is inconsequential for different vehicles. The identified issues are listed below.

- **Issue:** In Annex 4a of "Agreement Addendum 82: Regulation No. 83 - UNECE", the table of power and load settings for the dynamometer is presented (see Annex E). According to this table the inertia to be set does not increase beyond 2270 kg for vehicles weighing above 2210 kg, and the dynamic coefficients do not change for vehicles weighing above 2610 kg. This can be seen in Table 42 in which the road load settings for LCVs are depicted.
  Effect on Type Approval CO_2 emissions: Between 2210 kg and 2610 kg, dynamometer settings only change by means of and increasing dynamic coefficients. As a result the relation between size/mass and CO_2 emissions levels off. Above 2610 kg, the dynamometer settings do not change at all and the CO_2 emissions are only defined by the efficiency of the engine. Consequently, the CO_2 emissions level off even more.
- **Issue:** Manufacturers have the option to either use simulated inertia and dyno loading settings depending on the mass class of the vehicle ("cook book values", see Table 42) or to use inertia and dyno loading settings determined from coast down tests with that specific vehicle type.
  Effect on Type Approval CO_2 emissions: The usage of values listed in Table 42 tends to result in higher type approval CO_2 emissions values than the usage of the values resulting from the real world road load test for relatively small vehicles (i.e. low air drag and rolling resistance). For relatively large vehicles (i.e. high air drag and rolling resistance) the values listed in Table 42 tend to result in lower type approval CO_2 emission values compared to the usage of road load test settings derived from coast down testing. As a result, manufacturers tend to use the values resulting from the real world road load test for small vehicles and the values from Table 42 for large vehicles. As a result, the emissions level off towards the upper end of the mass / size range. As the mass bins defining the inertia class of a LCV are rather large (up to 230 kg), leading to a stepwise increase of CO_2 emissions (that is not noticeable in Figure 19 since more vehicle characteristics affect the CO_2 emissions, e.g. engine efficiency).
- **Issue:** In Annex 4a of "Agreement Addendum 82: Regulation No. 83 - UNECE" is stated that for vehicles, other than passenger cars, with a reference mass of more than 1700 kg the dynamometer settings should be multiplied by 1.3.
  Effect on Type Approval CO_2 emissions: Introduction of a step function increasing the CO_2 emissions when testing LCVs of which the mass in running order is greater than 1700 kg.

These factors may well be influencing the shape of the data in Figure 19. It is also anticipated that they will have a significant impact for other utility parameters, but that these will occur as a less sharp point because of the lack of a direct relation between the dynamometer settings and the vehicle's footprint, or payload.

The sales weighted least squares fit through these data is also shown. Its equation, when written in a format that is directly comparable with that defined in Regulation 510/2011[8] (Annex I) is:

$$\text{Indicative specific emissions of } CO_2 = 0.118\,M - 14.0 \qquad \text{Eqn 1}$$

where M = mass of the vehicle in running order in kilograms (kg).

Written relative to an average mass in running order of 1,706 kg, for the 2007 LCV average, this becomes:

$$\text{Indicative specific emissions of } CO_2 = 187.7 + 0.118 \times (M - M_0) \qquad \text{Eqn 2}$$

where:

M = mass of the vehicle in running order in kilograms (kg)
M_0 = 1 706.0 kg

An entirely equivalent expression can be written in terms of the 2010 average mass in running order, i.e.

$$\text{Indicative specific emissions of } CO_2 = 181.4 + 0.118 \times (M - 1654)$$

---

[8] This includes using mass in running order, rather than reference mass, and a reference mass of 1,706 kg for LCV

The sales-weighted least squares fit through all the 2010 LCV models, calculated as a function of mass in running order, Equation 1, can be lowered to meet the average 147 g/km for an LCV with the average utility value in such a way that the relative reduction is equal over the utility range. In this manner the “100% slope” base limit function is defined as the limit function for which the burden of CO_2 reduction between 2010 and 2020 is evenly distributed over the range of utility values.

In essence, this involves scaling the two coefficients in Equation 1 above by the factor:

New target/ (2010 average CO_2 emissions), i.e. 147/181.4, which is 0.8104

The values for the gradient and intercept for the 100% slope base function is:

Gradient = 0.0957
Intercept = -11.4

Therefore the target 100% slope line for these data are:

$$147 \text{ Target specific emissions of } CO_2 = 0.0957\ M - 11.4 \qquad \text{Eqn 3}$$

where M = mass of the vehicle in running order in kilograms (kg).

Shape of the limit function

For the implementation of an average single value target, the shape of the function relating the target CO_2 emissions value to a utility parameter is an important aspect of the overall regulation. The current regulation, (EU) 510/2011, has a linear limit function, similar to the format given in Equation 2, relating the mass in running order with CO_2 emissions. The shapes of limit functions considered included:

- linear sloped line targets,
- linear sloped line targets with a horizontal cut off at the upper or lower end,
- non-linear functions, e.g. quadratics, cubic or higher order polynomials.

Purely pragmatically, the linear line shown in Figure 19 appears quite a reasonable approximation given the scatter of the data. Further, the objective is to implement a new utility based target function that is methodologically as close to the 2015 function (and the 2020 car function) as possible. Therefore switching from a linear function to a non-linear function is undesirable. Therefore no further functions were considered for mass in running order.

It was investigated how this sales weighted relationship might vary for the six different LCV segments. Figure 20 is a revised version of Figure 19 where different markers are used for the six different segments. Table 12 gives the gradient and intercepts from sales weighted least squares fit to each segment.

The “best fit” functions for the individual LCV segments were found to vary widely. The reasons for these variations are:

- the limited range of mass in running order values for individual segments, which, when combined with the large range of CO_2 emissions values for each mass band, leads to poorly defined changes in CO_2 emissions over a smaller mass range than when the whole database is considered.
- the wide range of CO_2 emissions for different models.

Examination of Figure 20 illustrates this. The different least squares fit equations for the different LCV segments are understandable given the wide range of CO_2 emissions for different models within each segment. These six equations are shown graphically below, over the mass in running order range appropriate to each LCV class. This graph is deliberately plotted using the same ranges of values for the axes as was used in Figure 20, but the individual data points are omitted.

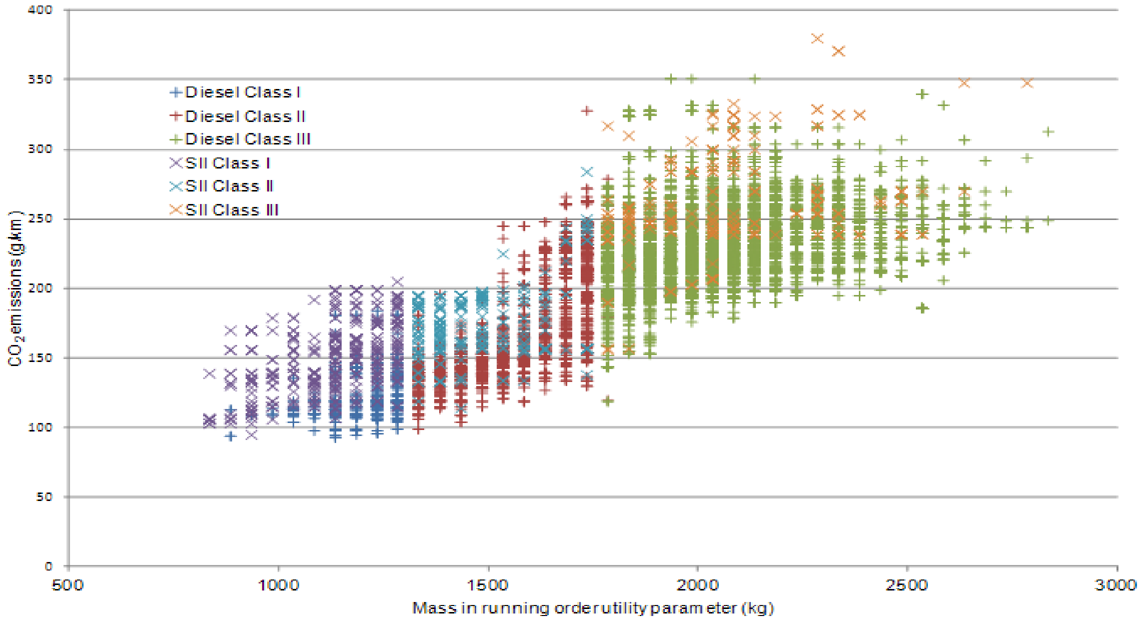

Figure 20 CO$_2$ and mass in running order values of LCV sales in 2010, for the six different LCV segments

Table 12 Sales weighted least squares fit parameters from analysis of 2010 LCV sales, calculated for each segment

Vehicle segment	Gradient	Intercept	Segment's average CO$_2$ emissions
All vehicles	0.118	-14.0	181.4
SI Class I	0.001	136.8	137.7
SI Class II	-0.029	209.4	167.8
SI Class III	0.057	122.23	240.4
Diesel Class I	0.044	68.33	120.5
Diesel Class II	0.180	-108.5	161.4
Diesel Class III	0.050	124.7	223.1

For the three diesel classes the lines for the three segments could be used to construct a non-linear limit function because their intercepts are quite well aligned with the mass boundaries between classes. Alternatively, it could be argued that the low gradients for Class I and III diesel LCVs (0.044 and 0.050) relative to the larger value for the Class II diesel LCVs could justify a floor and ceiling to the CO$_2$ emissions – mass utility function relationship.

Overall, it is concluded that the equations calculated for the whole database, Equations 1 and 2, are the most useful expression as to how CO$_2$ emissions vary with mass in running order. Based on Equation 3, the 147 g/km 2020 target 100% slope line is the most useful for comparing how different manufacturers compare relative to the 2020 target.

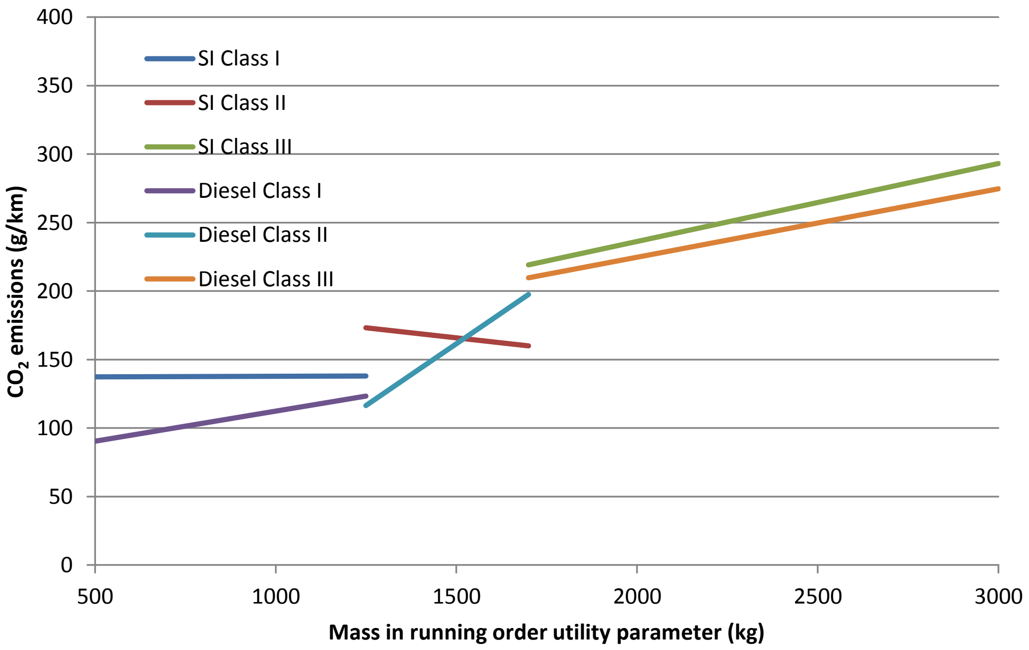

Figure 21 Sales weighted best fist of different segments

4.1.4 *Analysis of sales weighted average CO_2 emissions as a function of mass in running order for individual manufacturers.*

The 1,060,285 LCV sales for which both CO_2 emissions and mass in running order were known were then reanalysed using the “Vehicle Make” field to define categories. From the data sales weighted averages of CO_2 emissions, and of mass in running order, were calculated. The following three steps were then applied:

- vehicle makes with < 500 sales in 2010 were not analysed further;
- some “Vehicle Makes” specified in the JATO database were combined, see Table 13;
- the number of electric vehicles sold by each make was added to the total, thereby reducing the average CO_2 emissions for all LCVs manufactured by the specific makers.

Table 13 Details of combinations of "Vehicle Makes"

JATO database Makes combined	Manufacturer name
Peugeot & Citroen	PSA
Renault & Renault Trucks & Dacia	Renault
Vauxhall & Opel	GM (General Motors)
Mitsubishi & Mitsubishi Faso	Mitsubishi
VW & Skoda	VW

This approach generates a list of 17 vehicle manufacturers. The data is summarised in Table 14. This gives the sales weighted average CO_2 emissions and mass in running order, together with sales figures for each of the six ICE vehicle segments, and for electric vehicles.

Table 14 Average CO_2 emissions and mass in running order for the different LCV manufacturers, and their sales for different LCV segments

Manufacturer	Average		Sales of SI vehicles			Sales of diesel vehicles			Sales of electric vehicles	TOTAL
	CO_2 g/km	Mass in running order kg	Class I	Class II	Class III	Class I	Class II	Class III		
Daimler	226.2	2,039	12	2	265	18	4,690	84,112	50	89,149
Fiat	159.9	1,513	16,893	3,077	449	26,362	33,658	38,056	73	118,568
Ford	201.9	1,757	94	8	223	7,836	46,549	64,866	7	119,583
GM	172.6	1,584	638	874	102	13,400	18,208	20,510		53,732
Hyundai	219.7	2,086	6			31	82	1,803		1,922
Isuzu	223.8	1,986					91	6,224	1	6,316
Iveco	229.0	2,135			162		641	33,509		34,312
Land Rover	276.9	2,028			9			7,064		7,073
Mazda	247.1	1,937			1			693		694
Mitsubishi	225.1	1,937	12	2			181	12,112		12,307
Nissan	214.1	1,769	52	131	8	135	12,016	14,056	1	26,399
PSA	157.9	1,486	2,356	2,089	184	81,977	115,656	59,258	162	261,682
Piaggio	135.5	1,007	3,436						324	3,760
Renault	167.2	1,519	4,427	1,361	84	56,139	84,544	61,203	16	207,774
Ssangyong	222.7	2,019						1,067		1,067
Toyota	215.3	1,867	123	4	1	501	804	12,381	22	13,836
Volkswagen	192.4	1,808	491	2,163	256	2,796	35,847	59,751	2	101,306
Other small LCV volume manufacturers			297		228		26	912	1	1464
TOTAL			28,837	9,711	1,972	189,195	352,993	477,577	659	1,060,944

The sales weighted averages for each manufacturer are graphically illustrated as a bubble graph in Figure 22. Also included in Figure 22 is the sales weighted least squares fit displayed in Figure 19 and described in Equation 1. Table 15 contains the summary data from Table 14 together with the difference above or below the current sales weighted least squares fit calculated using the sales weighted mass in running order and Equation 1. This provides a quantification of each manufacturer's current LCV characteristics relative to the average. The three columns on the right of Table 15 give the corresponding average CO_2 emissions and weight from the analysis of the 2007 LCV database.

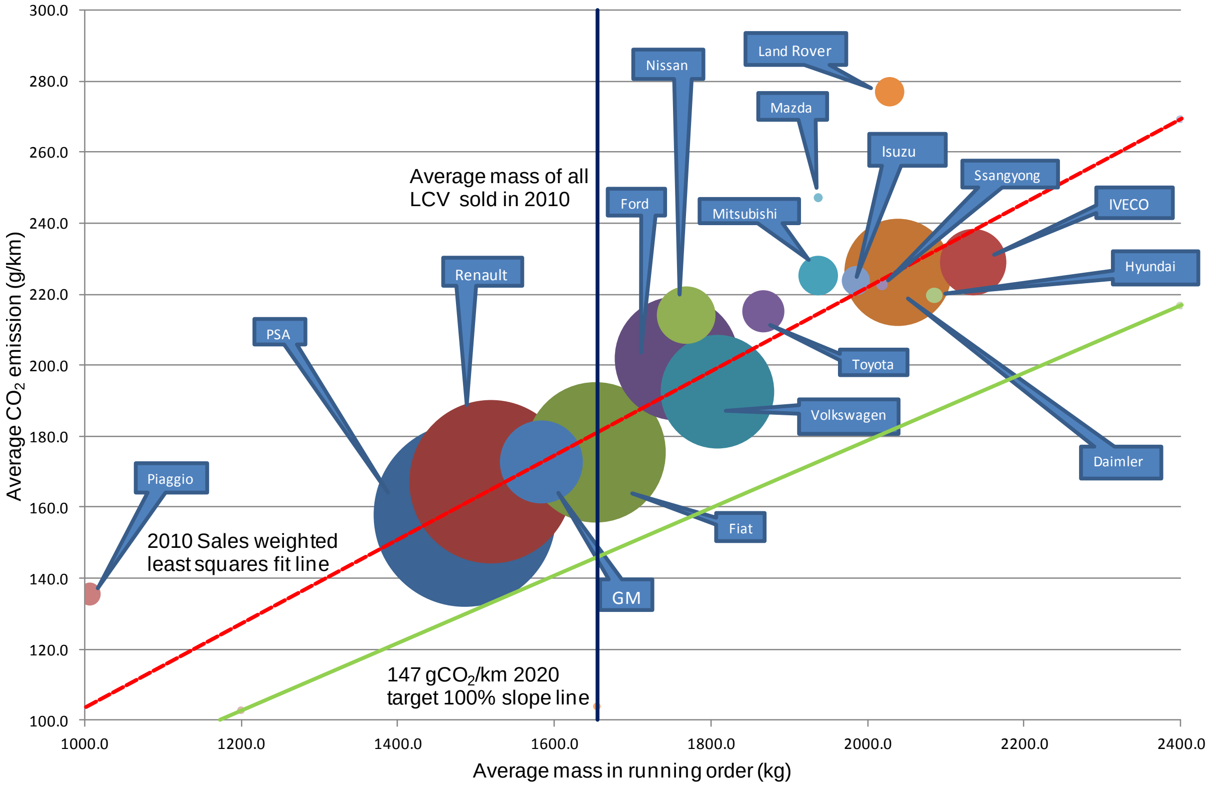

Figure 22 Average CO2 emissions as a function of mass in running order for various manufacturers selling LCV in Europe. The size of the bubbles indicates the sales volume.

Comments of the data in Table 15:

- Most of the large volume manufacturers lie quite close to the least squares best fit line.
- The average emissions for Land Rover are high – but Land Rover was not analysed as a separate group in the 2007 study.
- There are other manufacturers that were not in previous study, e.g. Piaggio and Ssangyong.

In terms of the distance of manufacturers from the 2010 sales weighted least squares fit line, the gradient of the 2010 sales weighted least squares best fit (0.118) is larger than that for the 2007 sales weighted least squares best fit (0.1079, [AEA TNO 2008]). This difference is greater if allowance is made for the different average CO$_2$ emissions values (203 g/km in 2007 and 181.4 in 2010). This change in gradient has meant that some manufacturers furthest from the 2007 sales weighted least squares fit line (based on their 2007 LCV sales characteristics), e.g. PSA and Daimler, appear closer to the 2010 sales weighted least squares fit line. The above comment is from the perspective of the distance of individual manufacturers' averages from the sales weighted least squares fit line. It should be remembered the new 2010 fit is a direct consequence of the distribution of emissions with weight for the new, 2010, database.

Table 15 Average CO_2 emissions and mass in running order for the different LCV manufacturers, and the deviations of these from the 2020 target 100% slope line, and a comparison with the analogous sales data for LCV in 2007

Manufacturer	Analysis of 2010 LDV database					Analysis of 2007 LDV database		
	CO_2 g/km	Mass in running order kg	Total LCV sales	CO_2 from 2020 target 100% line	Distance to 2020 target 100% slope line	Average CO_2	Mass in running order	TOTAL LCV sales
Daimler	226.2	2,039	89,149	182.5	-43.6	243.0	2024.0	156,700
Fiat	159.9	1,513	118,568	145.7	-14.2	196.0	1770.0	279,541
Ford	201.9	1,757	119,583	155.6	-46.3	207.0	1748.0	235,507
GM	172.6	1,584	53,732	139.2	-33.4	181.0	1592.0	128,245
Hyundai	219.7	2,086	1,922	186.9	-32.8	227.0	1897.0	9,054
Isuzu	223.8	1,986	6,316	177.4	-46.3	230.0	1969.0	11,549
Iveco	229.0	2,135	34,312	191.7	-37.4			
Land Rover	276.9	2,028	7,073	181.5	-95.5			
Mazda	247.1	1,937	694	172.8	-74.3	246.0	1799.0	6723.0
Mitsubishi	225.1	1,937	12,307	172.8	-52.3	233.0	1946.0	34675.0
Nissan	214.1	1,769	26,399	156.8	-57.3	238.0	1932.0	82,163
PSA	157.9	1,486	261,682	129.9	-28.0	181.0	1539.0	317,266
Piaggio	135.5	1,007	3,760	84.3	-51.2			
Renault	167.2	1,519	207,774	133.0	-34.2	193.0	1595.0	233,872
Ssangyong	222.7	2,019	1,067	180.6	-42.1			
Toyota	215.3	1,867	13,836	166.1	-49.1	223.0	1868.0	53,239
Volkswagen	192.4	1,808	101,306	160.5	-31.9	207.0	1793.0	190,664
TOTAL			1,059,480					1,739,198*

* The 2007 database also includes the manufacturer LDV, whose data are not included here because production stopped in 2008.

4.2 Footprint as utility parameter

4.2.1 Size of the sample that was analysed

Following the methodology used in the previous section, again we analyse **as much of the database as possible**. This leads to using any line of sales data in the database that records **both CO_2 emissions and vehicle footprint data**. These criteria lead to 1,001,085 LCV being included, and 77,792 sales being excluded as missing one, or both, vital pieces of information. For the most part, it was missing vehicle footprint data that led to them not being usable for this portion of the analysis.

4.2.2 Analysis of sales weighted average CO_2 emissions for the different weight classes

The sales weighted average vehicle footprint, and CO_2 emissions was calculated for all the 1,001,085 LCVs, and for the six engine type-weight class LCV segments. These data are given in Table 16.

The corresponding data for the analysis of the 2007 JATO database are given in the lower potion of the table for comparison.

Table 16 Average CO_2 emissions and vehicle footprint per vehicle segment for 2010 (and 2007)

	Spark ignition			Diesel			Average
	Class I	Class II	Class III	Class I	Class II	Class III	
Vehicle footprint (kg)	4.82	5.74	8.76	5.12	6.21	8.69	7.08
CO_2 emissions (gCO_2/km)	138.0	167.7	240.5	120.7	159.2	223.2	180.3
Sales with both data fields	28,084	9,540	1,885	189,195	352,993	477,577	1,001,085
2007 data for comparison							
Pan area	6.7	7.7	9.7	7.0	8.4	10.6	9.4
CO_2 emissions (gCO_2/km)	165	198	271	144	179	231	203
Sales with both data fields	20,992	6,590	3,761	287,710	429,805	998,287	1,747,145

Because there was very little data on footprint available, in the analysis of the JATO 2007 database the utility parameter analysed was “pan area”, which is the vehicle’s length multiplied by its width. These are the values given in the table above.

However, it is appreciated that pan area is not an ideal utility parameter. Better is potentially the vehicle footprint, the product of the vehicles average track width and its wheel base (This is inevitably smaller than the vehicle pan area). In the JATO 2010 database, footprint was calculated from the raw data JATO had available, and were reported in the database as bands of vehicle footprint. Discussions between JATO and TNO confirmed that the algorithm used was:

footprint = wheel base x (front axle track width + rear axle track width)/2.

Unfortunately, there is no simple correlation/correction that can be made between vehicle pan area values and their footprint values. Therefore it is difficult to draw any meaningful quantitative comparisons between the footprint/pan area analyses of the 2007 and 2010 databases.

4.2.3 Analysis of sales weighted average CO_2 emissions as a function of footprint

Figure 23 shows a graph of the CO_2 emissions (/km) as a function of vehicle footprint for all 1,001,085 LCVs.

It was noted that a preliminary version of Figure 23 was provided in Figure 80 of the final report of Service Request 1 [TNO 2011]. As is expected for these two graphs drawn from the same database, the LCV (red) data of Figure 80 of [TNO 2011] and the data in Figure 23 here appear identical despite there being some minor differences because the data used in this report has been subject to further cleaning and consolidation.

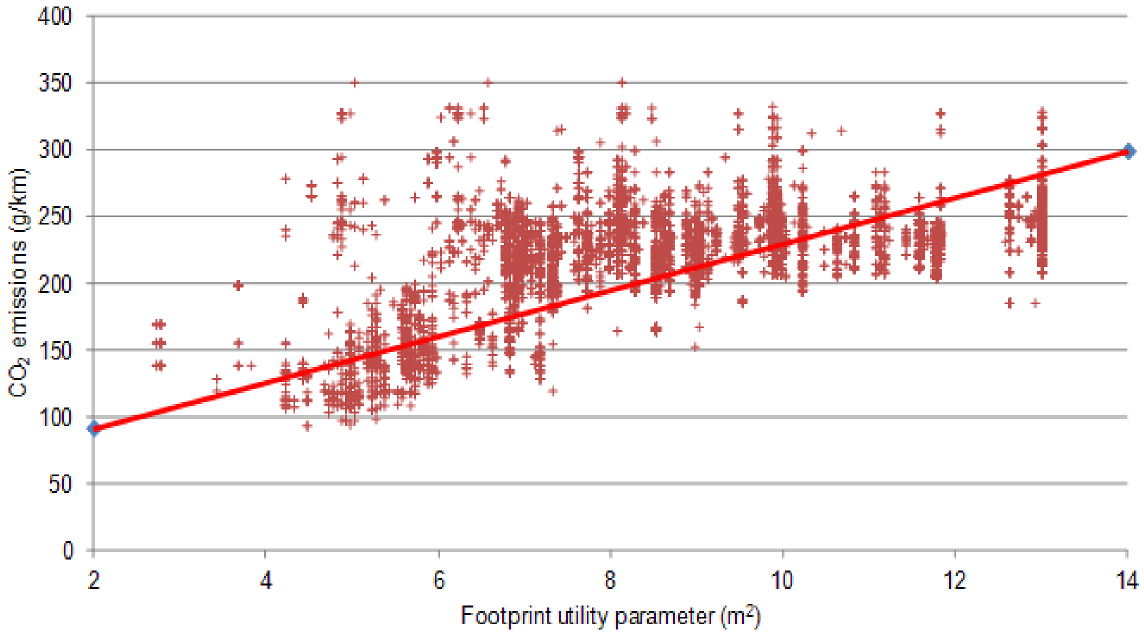

Figure 23 CO_2 and footprint values of LCV sales in 2010, and the sales weighted least squares fit through the data

As was noted in section 4.1.3, some details of Figure 23 are most probably partially a consequence of the testing procedure (as described in section 4.1.3). In particular:

- a step function increasing the CO_2 emissions when testing LCV whose mass in running order is greater than 1,675 kg probably accounts for some of the step increase seen around a footprint of 6 to 7 m^2, and
- the use of the same dynamometer inertia setting for vehicles weighing above 2,210 kg and the same dynamometer resistance factor settings for vehicles weighing above 2.610 kg accounts for some of the levelling off of the emissions seen for vehicles with a footprint above around 8 m^2.

Besides the testing procedures, there are other (mainly physical) elements that lead to the levelling off of CO_2 emissions for larger LCVs. An increasing footprint affects the energy use and CO_2 emissions indirectly via mass increase (extra body work means extra mass) and shape changes affecting c_w (extra length generally reduces c_w [CE 2008]). LCVs with higher footprints are generally fitted with larger engines. As a result, CO_2 emissions may increase much with increasing footprint more than is to be expected solely on the basis of how mass increases with increasing footprint. However, especially at the upper end of the footprint range, vehicle models are available with the same engine and a different length (and wheelbase) as can be seen in Figure 23 at the cost of performance. As can be seen in Table 43 and Table 44 (in Annex E) the mass increases only limitedly with an increasing footprint (100 – 150 kg/m^2). As a result real world mass increases relatively little for vans with an increasing footprint. This results in limited CO_2 increase with an increasing footprint. Since for large/heavy LCVs the mass bins, defining the inertia classes, are rather large (up to 230 kg), a stretched vehicle with an increased footprint of 1.5m^2 could theoretically be attributed the same inertia settings as the 'unstretched' vehicle. From this we can concluded that the levelling-off of the CO_2 emissions with increasing footprint is not only caused by the test procedure issues discussed above, but also by the type of LCVs sold at the upper end of the footprint range, i.e. stretched LCVs.

N.B. the 'extra-long' version has quite a bigger cargo area and cargo volume, but the same footprint as the 'long' version. This indicates that footprint is not a perfect proxy for utility.

The sales weighted least squares fit through the LCV footprint data (using a format similar to Equation 1, and mimicking that used in Regulation 510/2011, Annex I) was found to be:

Indicative specific emissions of CO_2 = 17.3 FP + 57.5 Eqn 4

where FP = the vehicle footprint (track-width x wheel base) in square metres.

Written relative to an average footprint of 7.08 m^2 this becomes:

$$\text{Indicative specific emissions of } CO_2 = 180.3 + 17.32 \times (FP - FP_0) \qquad \text{Eqn 5}$$

where:

FP = the vehicle footprint in square metres
FP_0 = 7.08 m^2.

The sales-weighted least squares fit through all the 2010 LCV models, calculated as a function of footprint, Equation 4, can be lowered to meet the average 147 g/km for an LCV with the average utility value using the methodology described for mass in running order. For footprint, given Equation 4, the average CO_2 emissions for LCV sales for which footprints can be calculated within the 2010 LCV database (180.3 gCO_2/km) and the 147 g CO_2/km target, the values for the gradient and intercept for the 100% slope base function are scaled by a factor of 0.8153. From this the target 100% slope line for these data are:

$$\text{147 Target specific emissions of } CO_2 = 14.1\ FP + 46.9 \qquad \text{Eqn 6}$$

where FP = the vehicle footprint (track-width x wheel base) in square metres.

Shape of the limit function

Some general comments regarding the importance of this consideration, and some options considered, are given in Section 4.1.3. It was noted that for mass in running order as the utility parameter, target CO_2 emission values are reasonably described by a simple linear line.

For footprint as a possible utility parameter the linear line shown in Figure 23 is not such a good fit. The gradient and form of the line are strongly influenced by the groups of vehicles whose footprints lie up to 6 m^2 (49% of sales), and above 12 m^2 (approximately 2% of sales). The resulting sales weighted best fit linear line lies below most of vehicles whose footprint lies between 7 and 9m^2. However, the analysis of sales share as a function of footprint indicates that only 15% of sales are realised within this range. For this utility parameter a simple linear line may not be optimal. Rather, some function with a horizontal cut-off at the high end may be better. An overview of the sales distribution for the different footprint ranges is given in Figure 24.

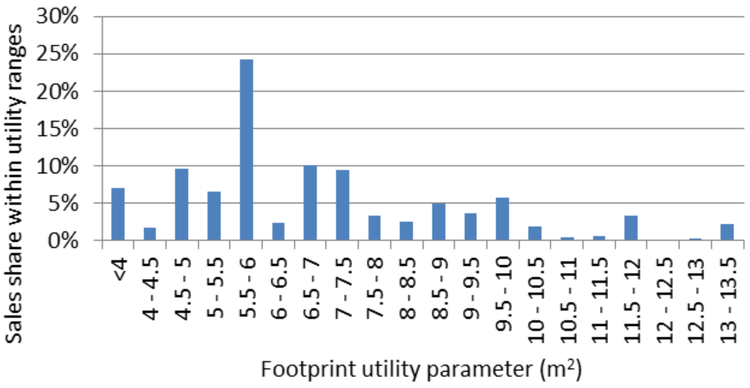

Figure 24 Overview of sales share within footprint ranges

The relationship between the sales weighted LCV footprint and CO_2 emissions was investigated for the six different LCV segments. Figure 25 is a revised version of Figure 23 where different marker options are used for the six different segments. “x” are used for the SI segments, and “+” for the diesel segments, with different colours denoting the different mass classes.

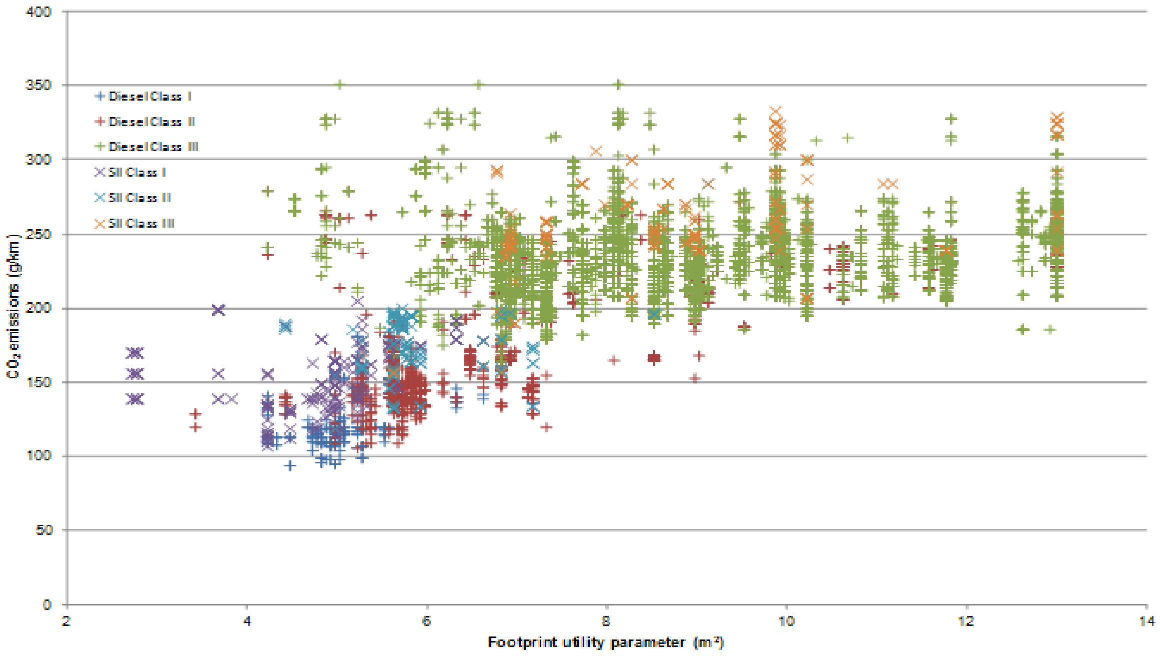

Figure 25 CO_2 and footprint values of LCV sales in 2010, for the six different LCV segments

The gradient and intercepts from sales weighted least squares fit to each segment were even less consistent than the vehicle segment – mass in running order analysis. That analysis concluded that overall disaggregating to vehicle segment level was not useful. That is emphasised for footprint against CO_2 emissions, and the individual results are not tabulated.

4.2.4 Analysis of sales weighted average CO_2 emissions as a function of footprint for individual manufacturers.

The 1,001,085 LCV sales for which both CO_2 emissions and footprint were known were then reanalysed using the “Vehicle Make” field to define categories. From the data sales weighted averages of CO_2 emissions, and of mass in running order, were calculated. The three steps described in section 4.1.4 were then applied to generate manufacturer average data for 16 vehicle manufacturers.

The data is summarised in Table 17 which gives the sales weighted average CO_2 emissions and footprint, together with sales figures for all ICE and electric vehicles for each manufacturer. Data calculated for the different LCV fuel/weight class sectors are not given because the general sales trends are as in Table 14.

The average CO_2 emissions/km, column 2 of Table 17, are generally very close to those given in Table 14. However, they are not identical because the number of vehicles included in the average generally differs slightly. There are some manufacturers who provide markedly less footprint data than mass data (though it is emphasised that provision of footprint data is discretionary). Most notably, Ford, where some 45,000 fewer LCV sales (37% of their total sales) have no footprint data. This leads to the average CO_2 emissions from sales where both CO_2 and footprint data are available being 7.7 g CO_2/km less than when averaged over sales data for which both CO_2 and mass data are available.

Table 17 Average CO_2 emissions and footprint for the different LCV manufacturers, and their sales for different LCV segments

Manufacturer	CO_2 g/km	Footprint	Sales of ICE vehicles	Sales of Electric vehicles	TOTAL
Daimler	226.3	9.31	87,507	50	87,557
Fiat	160.0	6.65	118,218	73	118,291
Ford	194.2	7.51	74,535	7	74,542
GM	173.1	6.99	53,295	0	53,295
Hyundai	222.3	7.68	1,844	0	1,844
Isuzu	223.5	6.59	6,157	1	6,158
Iveco	229.0	9.11	34,143	0	34,143
Land Rover	278.7	5.57	6,770	0	6,770
Mazda	249.4	6.71	661	0	661
Mitsubishi	226.0	6.75	11,766	0	11,766
Nissan	213.6	6.86	25,481	1	25,482
PSA	158.7	6.27	256,871	162	257,033
Piaggio	135.5	3.00	3,436	324	3,760
Renault	167.3	6.91	206,584	16	206,600
Ssangyong	222.9	6.48	1,049	0	1,049
Toyota	222.2	7.09	12,774	22	12,796
Volkswagen	193.2	7.45	98,934	2	98,936
Other small LCV volume manufacturers			1,060	1	1,061
TOTAL	180.3	7.08	1,001,085	659	1,001,744

The other manufacturer where a large difference in average CO_2 emissions is seen compared to the mass-based analysis is Toyota. For this manufacturer around 7.5% of sales had to be excluded from the analysis because of a lack of footprint data. This leads to an increase in average CO_2 emissions of around 7 g/km.

The sales weighted averages of CO_2 emissions and vehicle footprint for each manufacturer are graphically illustrated as a bubble graph in Figure 26. So too is the sales weighted least squares fit displayed in Figure 23. Table 18 contains the summary data from Table 17 together with the difference above or below the current sales weighted least squares fit calculated using the sales weighted footprint and Equation 4. This provides a quantification of each manufacturers current LCV characteristics relative to the average. The three columns on the right of Table 15 give the corresponding average CO_2 emissions and weight from the analysis of the 2007 LCV database.

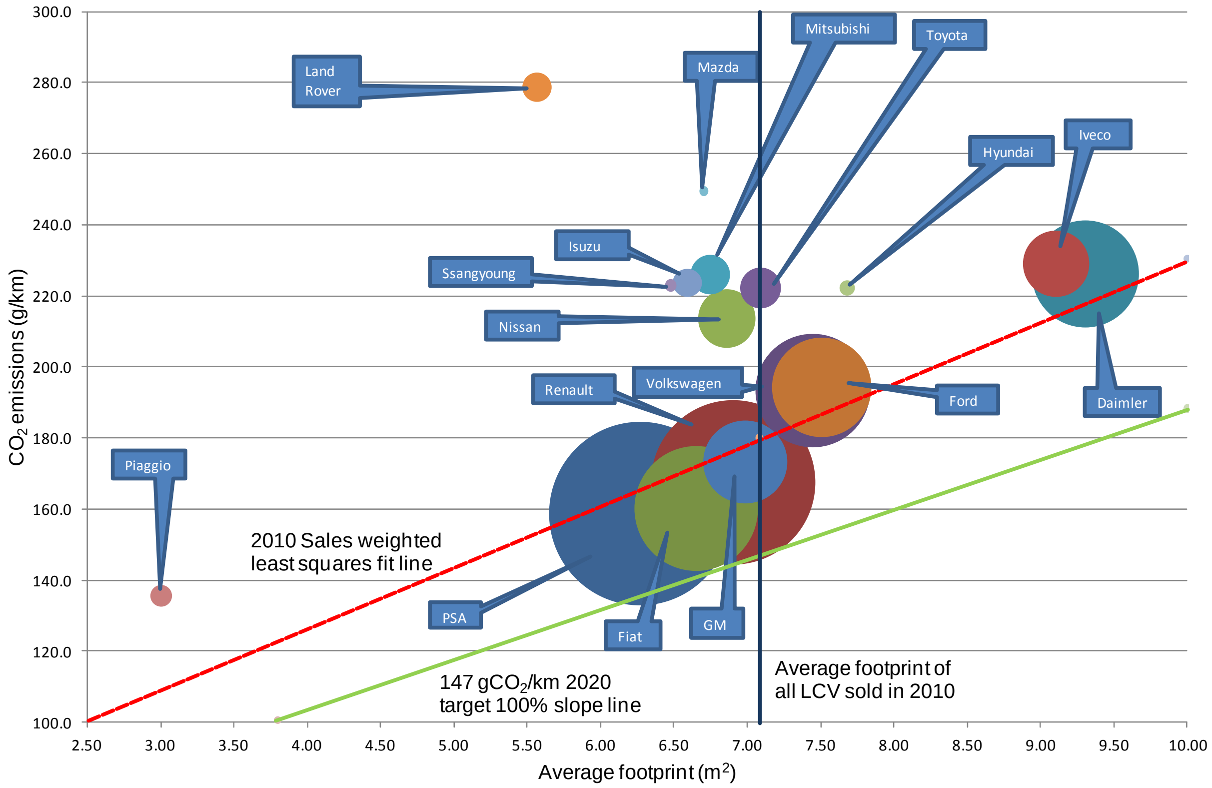

Figure 26 Average CO_2 emissions as a function of vehicle footprint for various manufacturers selling LCV in Europe. The size of the bubbles indicates the sales volume.

Comments on the data in Figure 26 and Table 17

- Six of the seven largest volume LCV manufacturers have an average footprint that spans only 1.25 m^2, i.e. the average footprint of all their LCVs sales are similar.
- For the smaller volume LCV manufacturers, their average CO_2 emissions are above the sales weighted least squares fit line.
- This “systematic” difference arises because many of these smaller volume LCV manufacturers only make LCV with a narrow range of footprints, in the region 6 – 9 m^2. Figure 23 shows how the best fit linear utility function lies below the vast majority of vehicles with this footprint.
- The average emissions of Land Rover are high relative to its average footprint and most other vehicles.
- Daimler is the only manufacturer of the 7 largest volume LCV manufacturers whose average LCV footprint is markedly different. At 9.3 m^2 this is some 30% above the average footprint for all LCVs. Similarly, the average footprint of Iveco LCVs is markedly above the average footprint of all LCV sold in 2010. Therefore, Daimler and Iveco are particularly impacted by the choice of gradient of this line.

Some further analysis was undertaken to better understand this. It seems from Figure 23 that vehicles sold with footprint of less than 6m^2 are largely below the best fit, just as vehicles > 11 m^2. If a manufacturer selling mainly within these ranges has an average footprint of 9.3m^2 it could well be below the best fit. Analysis of the distribution of the footprints of Daimler’s LCV sales, see Figure 27, shows that Daimler mainly sells vehicles in the range of 8 – 10.5 m^2. This is an argument for why Daimler is “impacted by the choice of gradient of the limit function”.

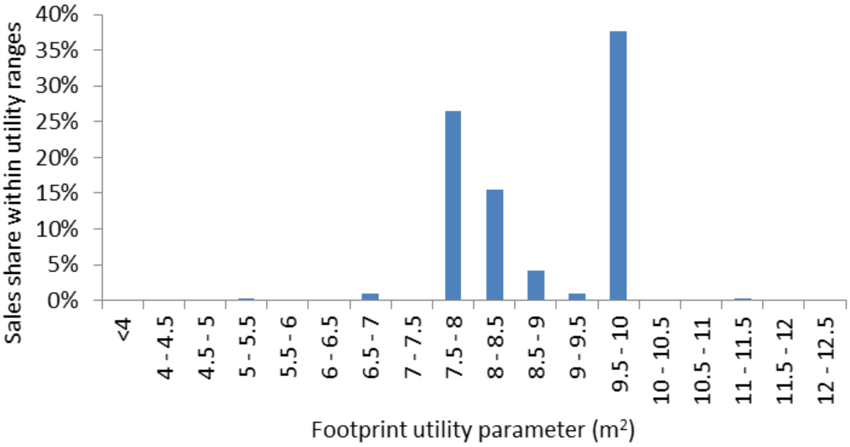

Figure 27 Analysis of distribution of footprint ranges for Daimler LCV sales

Table 18 Average CO_2 emissions and footprint for the different LCV manufacturers, and the deviations of these from the 147 2020 target 100% slope line, and a comparison with the analogous sales data for LCV in 2007

	Analysis of 2010 LDV database					Analysis of 2007 LDV database		
Manufacturer	CO_2 g/km	Average footprint m^2	TOTAL LCV sales	CO_2 from 2020 target 100% line	Distance to 2020 target 100% slope line	CO_2 g/km	Pan area m^2	TOTAL LCV sales
Daimler	226.3	9.31	87,557	178.5	-47.8	243.0	10.9	156,700
Fiat	160.0	6.65	118,291	141.0	-19.0	196.0	9.9	279,541
Ford	194.2	7.51	74,542	153.1	-41.1	207.0	9.7	235,507
GM	173.1	6.99	53,295	145.7	-27.4	181.0	8.6	128,245
Hyundai	222.3	7.68	1,844	155.5	-66.8	227.0	9.0	9,054
Isuzu	223.5	6.59	6,158	140.1	-83.4	230.0	9.2	11,549
Iveco	229.0	9.11	34,143	175.6	-53.4			
Land Rover	278.7	5.57	6,770	125.6	-153.1			
Mazda	249.4	6.71	661	141.7	-107.7	246.0	9.1	6723.0
Mitsubishi	226.0	6.75	11,766	142.3	-83.7	233.0	9.2	34675.0
Nissan	213.6	6.86	25,482	143.9	-69.7	238.0	9.6	82,163
PSA	158.7	6.27	257,033	135.6	-23.1	181.0	8.6	317,266
Piaggio	135.5	3.00	3,760	89.4	-46.1			
Renault	167.3	6.91	206,600	144.6	-22.8	193.0	8.8	233,872
Ssangyong	222.9	6.48	1,049	138.5	-84.4			
Toyota	222.2	7.09	12,796	147.1	-75.1	223.0	9.3	53,239
Volkswagen	193.2	7.45	98,936	152.2	-41.0	207.0	9.4	190,664
TOTAL			1,000,683					1,739,198*

* The 2007 database also includes the manufacturer LDV, whose data are not included here

4.2.5 Potential changes in strategic behaviour or safety in response to changing utility parameter to footprint.

Strategic behaviours by manufacturers to respond to change in utility parameter
The vehicle manufacturers operating in the European market are likely to display a change in their strategic behaviours as a consequence of a changing of utility parameter to vehicle footprint. Of course the exact changes of their strategy change remain unknown, but discussions with automotive industry stakeholders indicate that there are several potential strategic directions that manufacturers could pursue. Those directions deemed more suitable and potentially cheaper to implement then pursuing technology changes, or easier to implement as they cause less disruption to existing product planning and manufacturing operations are reviewed below.

Changes to existing vehicles and technology
Modifying existing vehicles and technologies to better suit the new requirement are of course one option available to the manufacturer. But in reality the manufacturers would like to keep vehicle modifications to a minimum due to long lead-times and modification costs. Hence it is deemed unlikely that existing vehicles will change their dimensions, however what could be changed on existing vehicles is the pursuit of further engine downsizing initiatives resulting in smaller capacity engines featuring lower power outputs which would further reduce the CO_2 values of the vehicles, but of course it could also potentially affect the suitability of the vehicle for commercial purposes due to power and engine torque restrictions. A further modification pursued by manufacturers could be the introduction of speed limiters, which could imply that eventually the overall engine power output could be reduced as outright vehicle speed and performance is no longer deemed a priority. However this could impact the suitability of the vehicle for commercial purposes as it might affect the engine torque on offer. Another possible strategy change could include to further pursuit of alternative powertrains, such as electric drive, as these new generation powertrains are likely to be exempt of the overall regulation. But once again it needs to be further investigated if this does not limit the commercial utility on offer.

New vehicle architectures
An alternative option available for the manufacturers could be to reconsider the current light commercial vehicle (LCV) offering and start engineering and design activities on smaller LCV vehicles, which could likely be based upon smaller passenger car vehicles which are already subjected to strict CO_2 regulation. So effectively the LCV could transform into a so-called car derived van (CDV) and would effectively result in a smaller sized commercial vehicle solution. This is considered an attractive option for the manufacturers, as it is highly compatible with their operational and manufacturing base, but the question remains if this will be acceptable for the commercial user of the vehicle, as the overall utility provided by the vehicle is affected.
At the other end of the scale the manufacturers could explore the possibility of potentially introducing larger commercial vehicle offerings which could –depending the size- potentially be excluded from the car category and consequently not be affected by the change of utility parameter. Although this could have an impact in terms of driver’s licence requirements in order to legally drive the larger vehicle. In reality a split of the existing LCV category into 2 separate categories such as CDV and larger CV could be an interesting solution to the manufacturer. While selected manufacturers could consider the introduction of little quadra-cycle based vans, either electric or not, which could create an entire new urban utility segment of smaller sized non-car based commercial vehicles.

Strategic behaviours by fleet-owners to respond to change in utility parameter
Overall any fleet-owner behavioural changes are thought to be rather limited due to the fact that the CO_2 compliance liability lies squarely with the manufacturers, hence any behavioural change will mostly be a function of the strategy changes pursued by the manufacturers. Although some behavioural change could be anticipated due to corporate social responsibility (CRS) policies adopted by selected fleet-owners.

Those fleets that are likely to react in response to the utility parameter change are most likely to pursue alternative powertrain choices, in the understanding that these will be exempted from the regulation and provide them with additional ‘green marketing’ capabilities. This opinion comes from stakeholder feedback that if fleet owners should change their behaviour, it will be primarily driven by corporate social responsibility (CRS) policies adopted by selected fleet-owners. Those fleets who value CRS qualities are determined to display green initiatives which they can incorporate into their marketing initiatives, as well as generating consumer goodwill (and also shareholder goodwill). It is also completely within their expectations that these ‘alternative powertrain choices’ will be subjected to favourable legislative treatment/recognition as these historically have been rewarded for their ‘green qualities’ either through incentives or tax benefits.

While a change in LCV vehicle-type will be out of the question for many fleets due to potential loss of vehicle utility required to perform their commercial activities. However some portion of fleets could potentially switch over to either smaller or larger commercial vehicles depending on the mission profile required. These partial fleet changeovers will likely be governed by the legal driver's licence requirements for larger commercial vehicles (licences obtained after 1st January 1997 are restricted to nothing heavier than 3.5-ton in selected EU countries).

Implications of behaviours in terms of emissions and safety

The overall implications of any of these strategic changes remain unclear, but stakeholder discussions do hint that unless alternative powertrain choices are pursued the emissions outcome could potentially work out neutrally due to a polarisation of the LCV market with demand heading towards either car-derived vans (CDV) or towards the heavy-van end with less demand for the currently popular middle-of-the-road LCV vehicles. So while the CDV vehicles will likely reduce the emissions impact, these reductions could be off-set by the increase in heavy-vans which are differently regulated. While the possible introduction of small quadra-cycle based vans will reduce the overall emissions impact theoretically, but in reality these new vehicles will also feature emissions that will however be regulated differently. However if the introduction of this new parameter will be introduced jointly with exceptions for electric drive systems, then the overall implication could potentially turn positive.

It has to be noted that any behavioural changes could result in some short-term distortion of the emissions implications as increasingly many small and medium enterprises (SME) appear to favour used LCVs as their preferred mode of business transport as new LCV vehicles are currently beyond their financial reach. Consequently it is not unlikely that new LCV sales could be initially further negatively impacted by this change in utility parameter, and that the consequent emissions impact of this change would appear more favourable then is the case. This distortion is expected to correct itself beyond an initial introductory phase.

As for the safety implications of the proposed utility change the expected impact is rather negative due to the likely polarisation of the LCV market. The implication being that the market will experience an increase in both smaller and larger vehicles, which from a crash-impact point of view are deemed less compatible with each other. While the possible introduction of small quadra-cycle based vans, vehicles which are exempt from car-like safety systems adoption, is expected to further negatively impact the overall market safety situation.

Implication of various bodyworks

Overall the impact upon the bodyworks is very uncertain, as LCV operators have very specific needs and requirements for their commercial activities, hence the current high demand for LCV vehicles. Hence it would appear unlikely that manufacturers would pursue bodywork modifications as these could prove undesirable for the commercial customer base. If their commercial activities can be handled by means of different bodyworks then the question remains as to why this is currently not the case. Especially since the European market recently witnessed more sales of pick-up vehicles (PUP) in countries such as Spain due to some selected taxation loopholes, and yet this mainly impacted passenger car sales and not LCV sales. While the likely polarisation of the LCV market is also expected to negatively affect the overall bodyworks market, since smaller CDV vehicles will be unable to feature various bodyworks, while the larger heavy-vans could accommodate some bodyworks but this is currently not a common feature. Hence the overall bodyworks impact is deemed to be minimal.

4.3 Payload as utility parameter

4.3.1 Size of the sample that was analysed

Again we analysed **as much of the database as possible**. This leads to using any line of sales data in the database that records **both CO_2 emissions and vehicle payload data**. These criteria lead to 1,029,620 LCV being included, and 49,257 sales being excluded as missing one, or both, vital pieces of information. The number of sales that cannot be included is intermediate between the smaller number for mass in running order, and the larger number for vehicle footprint.

4.3.2 Analysis of sales weighted average CO_2 emissions for the different weight classes

The sales weighted average vehicle payload, and CO_2 emissions was calculated for all the 1,029,620 LCVs, and for the six engine type-weight class LCV segments. These data are given in Table 19. The corresponding data for the analysis of the 2007 JATO database cannot be included, because no analogous analysis was undertaken.

Table 19 Average CO_2 emissions and vehicle payload per vehicle segment for 2010

	Spark ignition			Diesel			Average
	Class I	Class II	Class III	Class I	Class II	Class III	
Vehicle payload (kg)	543	633	1104	529	786	1207	928
CO_2 emissions (gCO_2/km)	138.0	167.7	239.8	120.9	162.5	223.1	182.7
Sales with both data fields	28,089	9,576	1,956	177,718	338,070	473,166	1,029,620

4.3.3 Analysis of sales weighted average CO_2 emissions as a function of payload

Figure 28 shows a graph of the CO_2 emissions (/km) as a function of vehicle footprint for all 1,029,620 LCVs.

The sales weighted least squares fit through these data is was found to be:

Indicative specific emissions of $CO_2 = 0.100\ PL + 90.0$ Eqn 7

where PL = the vehicle payload in kg.

Written relative to an average payload of 928 kg this becomes:

Indicative specific emissions of $CO_2 = 182.7 + 0.100 \times (PL - PL_0)$ Eqn 8

where:

PL = the vehicle payload in kg
PL_0 = 928 kg.

The sales-weighted least squares fit through all the 2010 LCV models, calculated as a function of payload, Equation 7, can be lowered to meet the average 147 g/km for an LCV with the average utility value using the methodology described for mass in running order. For footprint, given Equation 6, the average CO_2 emissions for LCV sales for which payload is (indirectly) declared within the 2010 LCV database (182.7 gCO_2/km) and the 147 g CO_2/km target, the values for the gradient and intercept for the 100% slope base function are scaled by a factor of 0.8046. From this the target 100% slope line for these data are:

147 g/km Target specific emissions of $CO_2 = 0.080\ PL + 72.4$ Eqn 9
where PL = the vehicle payload in kg.

Shape of the limit function

Some general comments regarding the importance of this consideration, and some options considered, are given in section 4.1.3.

The payload utility parameter CO_2 emissions graph comprises two distinct regions:

- up to around 1,900 kg, where each mass band has a number of models with different CO_2 emissions, and
- above 1,900 kg, where there are only a few models.

From the cleaned dataset it was found around 200 rows or data, out of around 12,600, had a payload plus vehicle mass greater than 3,500 kg. Hence these vehicles, principally made by Daimler and Fiat (Iveco) are interpreted as vans whose mass in running order is less than 2,610 kg, but whose GVW is above 3.5 tonnes.

The linear limit function provided is a reasonable approximation up to 1,900 kg, but provides CO_2 emissions value that are disproportionately high above this weight.
Alternatively, a linear function with a horizontal cut-off at the high end, e.g. around 1,500 kg payload, may be a better description of what is observed.

As was noted in section 4.1.3, some details of Figure 28 are most probably partially a consequence of the testing procedure. In particular:

- a step function increasing the CO_2 emissions when testing LCV whose mass in running order is greater than 1,675 kg probably accounts for some of the step increase seen around a payload of 750 kg, and
- the use of the same dynamometer inertia setting for vehicles weighing above 2,210 and the same dynamometer resistance factor settings for vehicles weighing above 2,610 kg. accounts for some of the levelling off of the emissions seen for vehicles whose payload is above 1,300 kg.

Given the above deviations of the CO_2 emissions for different payloads from the sales weighted least squares fit, it is useful to consider the sales distribution over the payload range. This is shown in Figure 29. This shows that very few sales, <1%, are for LCV whose payload is greater than 1,950 kg.

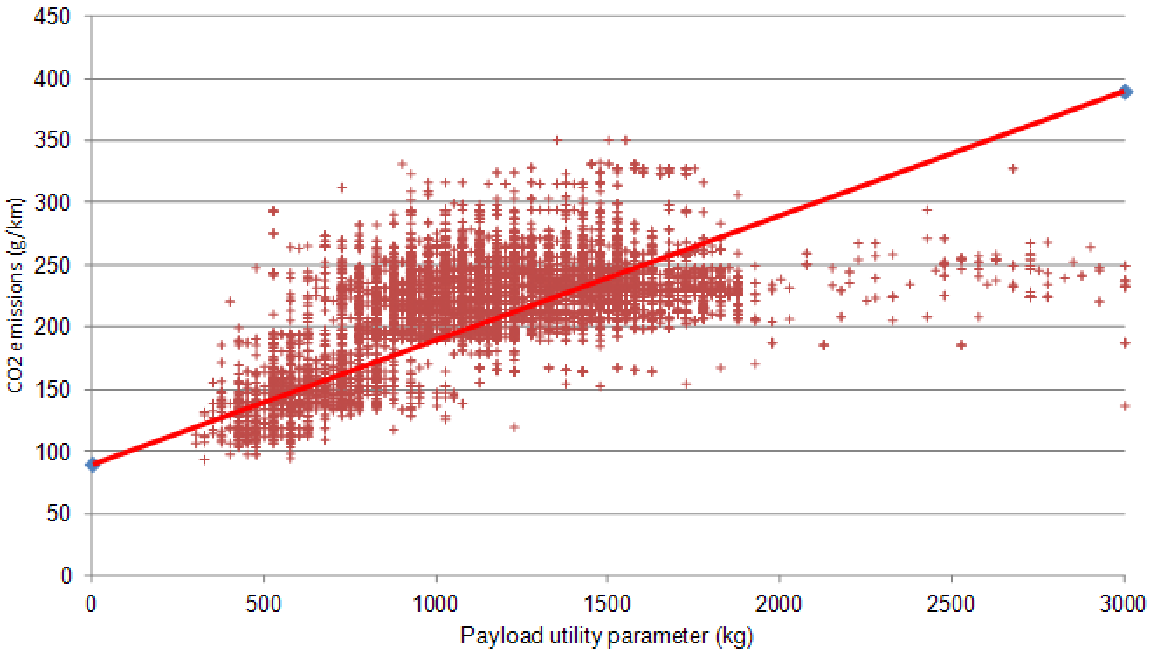

Figure 28 CO_2 and payload values of LCV sales in 2010, and the sales weighted least squares fit through the data

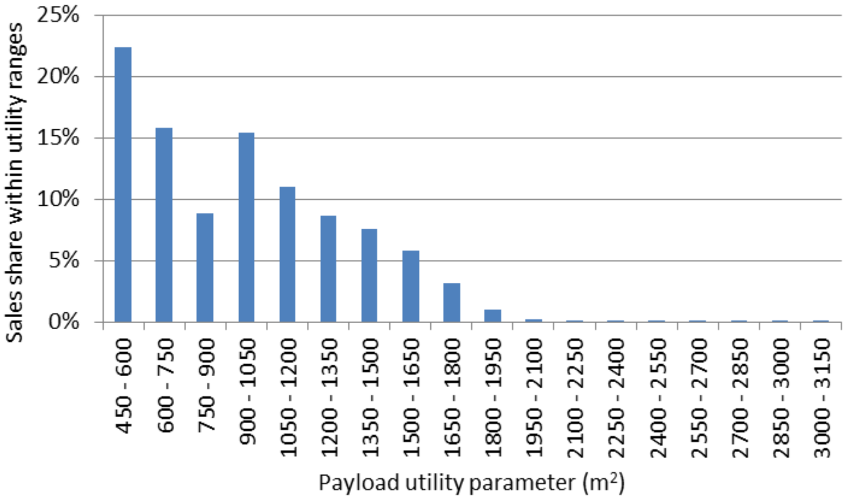

Figure 29 The sales distribution as a function of payload utility parameter from the JATO 2010 LCV database

As for the other potential utility parameters, the sales weighted relationship between payload and CO_2 emissions was investigated for the six different LCV segments. Figure 30 is a revised version of Figure 28 where different marker options are used for the six different segments.

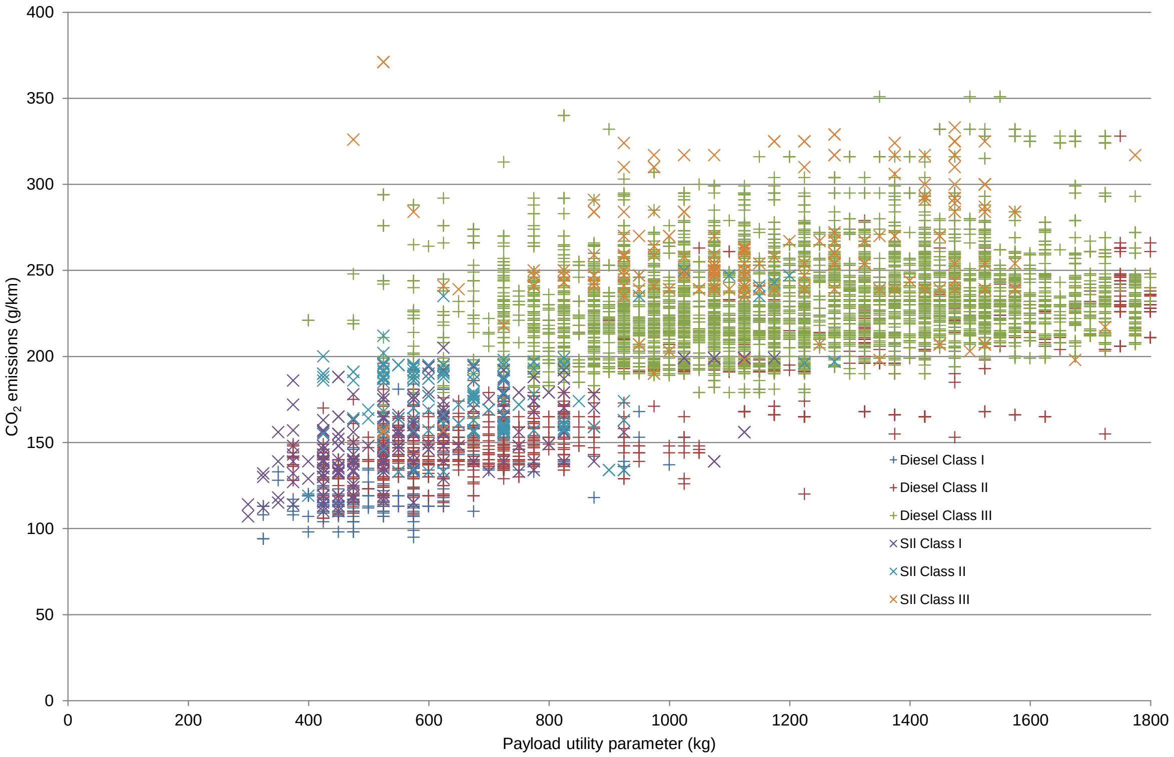

Figure 30 CO_2 and payload values of LCV sales in 2010, for the six different LCV segments

The gradient and intercepts from sales weighted least squares fit to each segment were less consistent than the vehicle segment analysis based on mass in running order. Therefore, as for footprint, it is concluded that disaggregating the sales to generate sales weighted least squares fits at the vehicle segment level is not useful, and the individual results are not tabulated.

4.3.4 Analysis of sales weighted average CO_2 emissions as a function of payload for individual manufacturers.

The 1,029,620 LCV sales for which both CO_2 emissions and payload data were known were then reanalysed using the “Vehicle Make” field to define categories. The methodology described in section 4.1.4 was then applied to generate manufacturer average data for 16 vehicle manufacturers. These are summarised in Table 20.

The sales weighted averages for each manufacturer are graphically illustrated as a bubble graph in Figure 31. Table 21 contains the summary data from Table 20 together with the difference above or below the current sales trend calculated using the sales weighted payload and Equation 7. This provides a quantification of each manufacturers current LCV characteristics relative to the average. No similar analysis was undertaken using the 2007 LCV database, and so no comparative data are available.

Table 20 Average CO_2 emissions and payload for the different LCV manufacturers, and their sales for different LCV segments

Manufacturer	CO_2 g/km	Average Payload kg	Sales of ICE vehicles	Sales of Electric vehicles	TOTAL
Daimler	226.5	1,236	88,455	50	88,505
Fiat	160.1	845	118,130	73	118,203
Ford	203.1	1,054	117,997	7	118,004
GM	173.1	851	53,276	0	53,276
Hyundai	221.3	1,049	1,862	0	1,862
Isuzu	223.8	1,115	6,322	1	6,323
Iveco	229.0	1,374	34,312	0	34,312
Land Rover	279.8	909	6,055	0	6,055
Mazda	249.4	1,167	661	0	661
Mitsubishi	226.7	1,020	11,449	0	11,449
Nissan	214.8	1,100	25,887	1	25,888
PSA	158.8	757	253,478	162	253,640
Piaggio	135.5	771	3,436	324	3,760
Renault	169.7	1,526	195,696	16	195,712
Ssangyong	222.9	724	1,050	0	1,050
Toyota	222.3	1,009	12,659	22	12,681
Volkswagen	194.5	1,821	97,820	2	97,822
Other small LCV volume manufacturers			1,075	1	1,076
TOTAL			1,029,620	659	1,030,279

Comments on the data in Figure 31 and Table 20:

- The pattern is quite like the distribution for manufacturers when considering mass in running order as the utility parameter. Like mass in running order, and unlike footprint, the manufacturers average payloads span a wide range of values
- The average emissions for Land Rover are high – as for other potential utility parameters.
- Generally the large volume LCV manufacturers are quite close to the best fit line.
- Those furthest from the average payload would be most affected by changes in the line’s gradient, e.g. Daimler and PSA, who are at the opposite ends of the range.

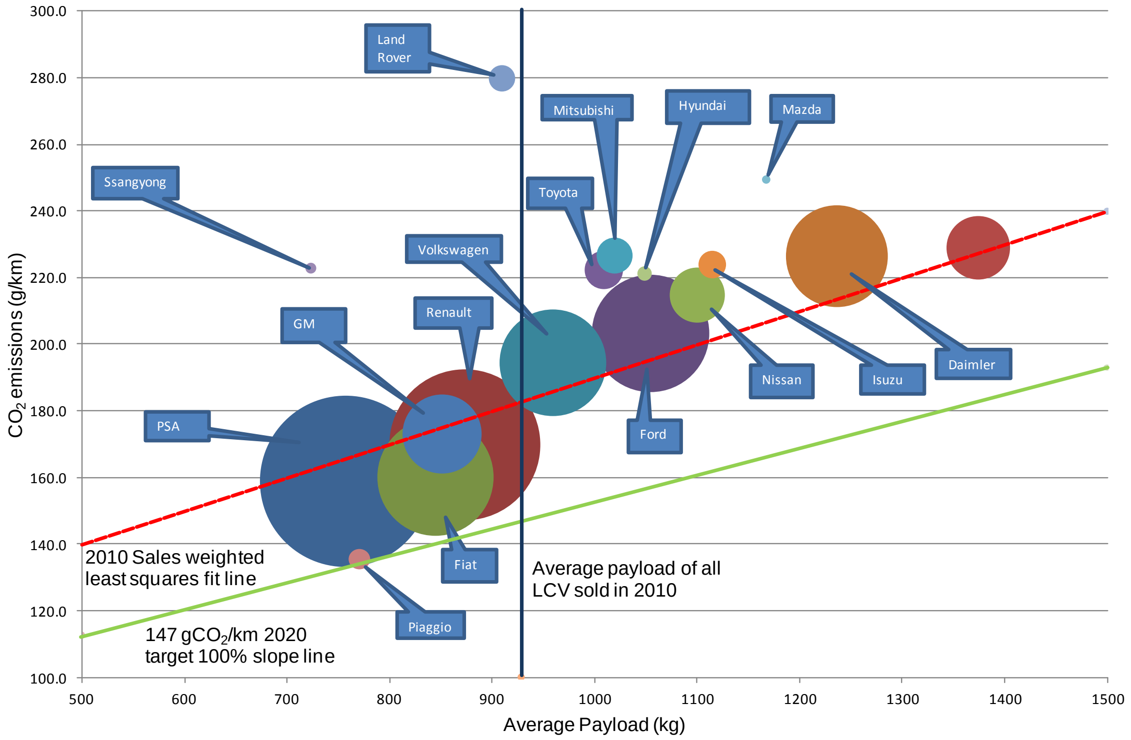

Figure 31 Average CO_2 emissions as a function of payload for various manufacturers selling LCV in Europe. The size of the bubbles indicates the sales volume.

Table 21 Average CO_2 emissions and payload for the different LCV manufacturers, and the deviations of these from the 147 g CO_2/km 2020 target 100% slope line.

	Analysis of 2010 LDV database				
Manufacturer	CO_2 g/km	Average Payload kg	TOTAL LCV sales	CO_2 from least squares fit	Difference
Daimler	226.5	1,236	88,505	171.8	-54.7
Fiat	160.1	845	118,203	140.3	-19.8
Ford	203.1	1,054	118,004	157.1	-46.0
GM	173.1	851	53,276	140.8	-32.3
Hyundai	221.3	1,049	1,862	156.7	-64.6
Isuzu	223.8	1,115	6,323	162.0	-61.8
Iveco	229.0	1,374	34,312	182.9	-46.2
Land Rover	279.8	909	6,055	145.5	-134.3
Mazda	249.4	1,167	661	166.2	-83.2
Mitsubishi	226.7	1,020	11,449	154.4	-72.3
Nissan	214.8	1,100	25,888	160.8	-54.0
PSA	158.8	757	253,640	133.3	-25.5
Piaggio	135.5	771	3,760	134.3	-1.2
Renault	169.7	873	195,712	142.6	-27.1
Ssangyong	222.9	724	1,050	130.5	-92.4
Toyota	222.3	1,009	12,681	153.5	-68.8
Volkswagen	194.5	960	97,822	149.5	-44.9

4.3.5 *Potential changes in strategic behaviour of manufacturers in response to changing utility parameter to payload.*

It is important that when reading this section, it is remembered that payload (or maximum permissible load) is a declared value that can not be independently verified. This is a major disadvantage of payload. It can be manipulated by manufacturers.

Effects of upward limit of GVW
The likely effect of the legal upwards limit of GVW <3500kg for LCV vehicles is that the LCV market will potentially experience some gaming activities from manufacturers, with the market offering moving towards heavy commercial vehicles (HCV). In this scenario the likelihood of LCV market polarisation is even higher, with a large portion moving towards the +3500kg GVW category while the urban-delivery sector will likely be converted to smaller CDV vehicles and/or quadra-cycle like vans which are arguably better suited to manoeuvrability in crowded city centres. Although this fleet changeover will likely be governed by the legal driver's licence requirements for larger commercial vehicles (licences obtained after 1st January 1997 are restricted to nothing heavier than 3.5-ton in selected EU countries).

Strategic behaviour of manufacturer
If payload were to become the LCV utility parameter, then a 100% slope line, from the analysis of current LCV sold, would lead to LCV with larger payloads having higher CO_2 emissions targets. Generally, in the absence of manipulation of this declared value, the CO_2 impact of the vehicle modifications required to increase payload could be relatively small, and would most probably provide for an increased target at relatively low cost. This would offer scope for manufacturers to make vans with larger payloads than, those currently sold, to take advantage of this factor.

Another option available for the manufacturers could be to reconsider the current light commercial vehicle (LCV) offering and start engineering and design activities on LCV vehicles which could likely be based upon smaller passenger car vehicles which are already subjected to strict CO_2 regulation. These CDV would be smaller sized commercial vehicle solutions that are likely to attract less severe regulation due to lower payload capability. Under this scenario the conventional LCV vehicle would be deemed unattractive to the manufacturers, and for the commercial purposes that require higher utility factors then offered by the CDV, the manufacturers would certainly offer a slightly larger commercial vehicle offering, which –depending on the size and weight- could be excluded from the car category and consequently not be affected by the change of utility parameter.

A further alternative at the manufacturers' disposal is the creation of LCV vehicles with flexible load-areas, which are convertible to smaller or larger payloads. Given that the manufacturer is able to declare the payload capability, this could be based upon a mixture of smallest/biggest payload capability and so overall the utility parameter impact could be reduced.

Strategic behaviour of fleet owners
Any fleet-owner behavioural changes are thought to be rather limited due to the fact that the CO_2 compliance liability lies squarely with the manufacturers, hence any behavioural change will mostly be a function of the strategy changes pursued by the manufacturers. However some behavioural change could be anticipated due to corporate social responsibility (CRS) policies adopted by selected fleet-owners.

Those fleets that are likely to react in response to the payload parameter change are most likely to pursue alternative powertrain choices, in the understanding that these will be exempted from the regulation and provide them with additional 'green marketing' capabilities. A change in LCV vehicle-type will be out of the question for many fleets due to potential payload loss. However some portion of fleets could potentially switch over to either smaller or larger commercial vehicles depending on the mission profile required. These partial fleet changeovers will likely be governed by the legal driver's licence requirements for larger commercial vehicles (licences obtained after 1st January 1997 are restricted to nothing heavier than 3.5-ton in selected EU countries).

Implications in terms of emissions and safety
The overall implications of any of these strategic changes concerning payload parameter remain unclear, but stakeholder discussions do hint that unless alternative powertrain choices are pursued the emissions outcome could potentially work out neutrally due to a polarisation of the LCV market with demand heading towards either car-derived vans (CDV) or towards the heavy-van end with less

demand for the currently popular middle-of-the-road LCV vehicles. So while the CDV vehicles will likely reduce the emissions impact, these reductions could be off-set by the increase in heavy-vans which are differently regulated. While the possible introduction of small quadra-cycle based vans will reduce the overall emissions impact theoretically, but in reality these new vehicles will also feature emissions that will however be regulated differently.

As for the safety implications of the proposed payload change the expected impact is rather negative due to the likely polarisation of the LCV market. The implication being that the market will experience an increase in both smaller and larger vehicles, which from a crash-impact point of view are deemed less compatible with each other. While the possible introduction of small quadra-cycle based vans, vehicles which are exempt from car-like safety systems adoption, is expected to further negatively impact the overall market safety situation.

4.4 Evaluation of utility parameters mass in running order, footprint and payload

The preceding three chapters considered mass in running order, footprint and payload, respectively, as three potential utility parameters. Table 15 contains a summary of some key features, pluses and minuses, of these options.

Analyses of data were presented, sales weighted best fits through these were provided. Also, the data was analysed on a manufacturer by manufacturer basis. For each utility parameter the sales weighted least squares fit was lowered to meet the 2020 average 147 gCO_2/km target for an LCV with the average utility parameter. This was done using a methodology that makes the relative reduction equal over the utility range. This defines the 2020 target 100% slope line. For manufacturers selling more than 500 LCV in 2010 the distance between their current performance and the 2020 target (as given by the 2020 target 100% slope line) was calculated and tabulated. These differences can be expressed as the percentage reduction required from the current CO_2 performance for each potential utility parameter. These data are summarised in Table 16 and Figure 32.

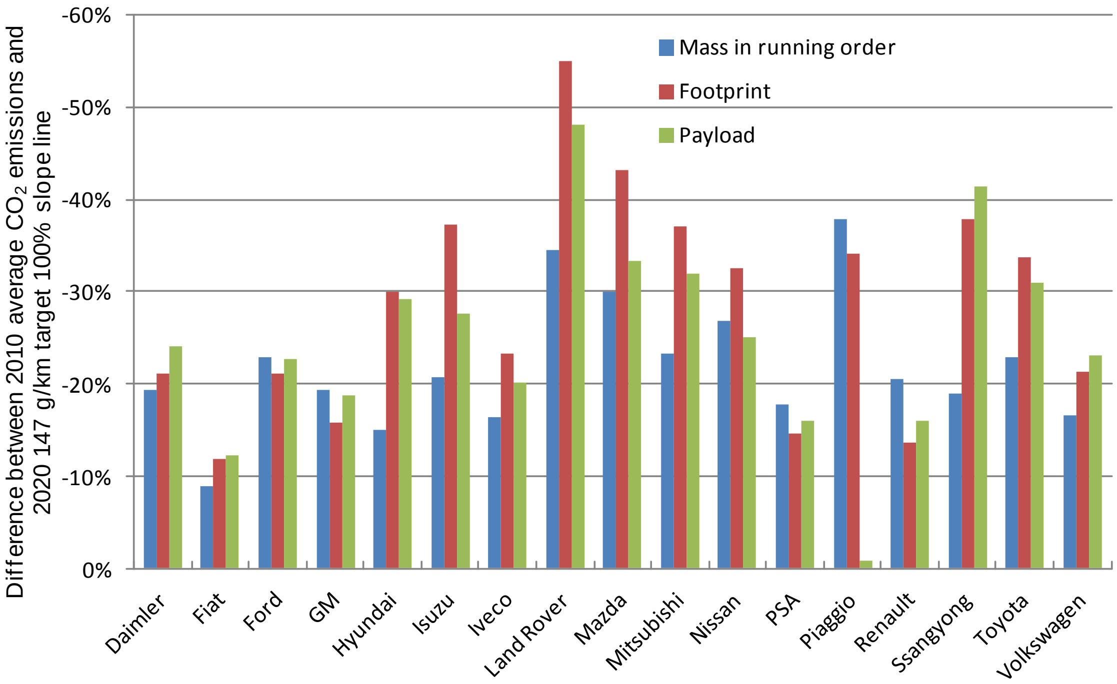

Figure 32 Summary of the differences between the current average CO2 emissions of different LCV manufacturers and their specific 2020 target based on an overall 147 g/km target and a 100% slope line for the three utility parameters considered

This table contains three blocks of data relating to mass in running order, footprint and payload. In each block the average CO_2 emissions (g/km) for each manufacturer is given, together with the average value of the utility parameter being considered. The 2020 target values for the 147 gCO_2/km 100% slope of linear functions are given for each manufacturers average utility parameter (calculated from the functions given in Equations 3, 6 and 9), together with the difference between actual current average, and this “target” value.

The data are colour coded, with shades of green being used if the reduction to meet the 2020 100% slope line is less than 20%, and bright red denoting the reduction required is greater than 45%. These data are also shown in Figure 32.

The table and figure both show how the improvement to be made can be relatively independent of the selection of utility parameter. For example Ford, GM and PSA all require a reduction in the range 10 to 20% for all three utility parameters. Other manufacturers have a relatively narrow range of reductions required, but do cross the thresholds leading to different coloured cells. Examples are Daimler, Fiat, Iveco, Renault and Volkswagen.

However, what is also evident from both the table and the figure is that there are a few manufacturers for which the choice of utility parameter markedly affects the CO_2 reduction required. Examples include Isuzu, Piaggio and Ssangyong where mass, payload and mass, respectively, would be the advantageous utility parameter for their LCVs.

Some general conclusions are:

1. Mass correlates best with CO_2, but is not a good proxy for utility and provides a disincentive for mass reduction. Since lower vehicle mass can increase payload, manufacturers do have an incentive for mass reduction. Therefore mass is a better option for a utility parameter for vans than for cars.
2. Footprint is not a preferable utility parameter for vans, because a more complex (than linear) is needed to evenly distribute effort over the footprint range. This will be analysed in section 5.5.
3. Payload correlates reasonably well with CO_2 up to about 1900 kg (99% of sales). In principle, it is a good proxy for van utility. However, anomaly exists where larger vans have a larger load capacity, but are heavier when empty and have a lower payload capacity than its short wheel base relatives. Moreover payload (or maximum permissible load) is a declared value that cannot be independently verified. This is a major disadvantage of payload. It can be manipulated by manufacturers. Also the CO_2 impact of vehicle modifications to increase payload could be relatively small. This would offer room for gaming. For these reasons, payload is discarded from further analysis.

Together this leads to the overall conclusion that mass seems to be a better utility parameter for vans than footprint or payload. First of all it correlates better with CO_2. Secondly footprint and payload offer room for gaming unless the utility based target slope is chosen very flat, cancelling the objective of the utility based function. Moreover, the payload advantage (see above) of mass reduction (partly) compensates the disincentive generated by assigning more CO_2 credits for heavier vehicles.

5 Modalities for 147 g/km in 2020

5.1 Introduction

In this section the possible modalities for a legislative approach to reduce CO_2 emissions from LCVs to an average level of 147 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.

A similar methodology as the one used in this study, was applied in previous studies by TNO, e.g. in [TNO 2011] for a target of 95 gCO_2/km for passenger cars in 2020. Therefore, the applied methodology is only described concisely. A more detailed explanation can be found in [Smokers, 2006]. Differences in methodology compared to [Smokers 2006] and [TNO 2011] are mentioned explicitly.

The additional manufacturer costs and distributional impacts are only calculated for diesel LCVs divided over Class I, Class II and Class III for the reasons explained in section 3.2.1.

5.2 Setting out the policy options

5.2.1 Generating the 'long list' of regulatory options

In close consultation with the Commission services, the following main candidates for defining the 147 g/km target for 2020 have been selected. This report assesses 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 LCV CO_2 emissions, and to be responsible for ensuring that this takes place. For the same reasons as identified in previous studies, e.g. [Smokers 2006], and in line with the legislation in place for the 175 g/km target in 2017 (Regulation (EU) No 510/2011), 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 established in Regulation (EU) No 510/2011– a Community average of 147 g/km by 2020. For the implementation of this target at the level of individual manufacturer groups various types of utility-based limit functions are possible, e.g. linear, linear with horizontal cut-offs, etc. For the purpose of consistency between the current limit function and that of previous LCV studies and with the limit function for passenger cars [TNO 2011], a linear slope is preferred. However for some utility parameters, a linear limit curve might not do justice to the way CO_2 emissions of vehicles are scattered over the utility range (section 4.2.3). In these cases one or more non-linear limit function types are analysed.

  Targets varying according to some measure of a vehicle's 'utility' (discussed below), 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.

- ***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;
  - understandability;
  - minimising perverse effects;
  - not excluding technical options

Based on these criteria three main options were selected for detailed analysis of cost impacts:

- vehicle weight (or mass in running order),
- footprint (vehicle track width x wheel base) and
- payload (gross vehicle weight rating minus curb weight).

Mass and footprint were also assessed in [TNO 2011] for application in the CO2 legislation for passenger cars. Pros and cons for both options are fairly balanced. Nevertheless [TNO 2011] expresses a preference for footprint as utility parameter for passenger cars because:

- mass reduction will be an important measure for future CO2 reduction beyond 95 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.
- footprint is a better measure for utility from a consumer perspective. Consumers tend to buy certain vehicles because of their size and not because they are heavy.

The conclusions drawn in section 4.4 regarding the suitability of the assessed utility parameters for LCVs, differ from the ones drawn for passenger cars. Firstly, mass seems to be a more suitable utility parameter for LCVs than for passenger cars. LCV manufacturers have an extra commercial incentive to reduce vehicle mass, because it can lead to higher payload. This partly compensates the disincentive for mass reduction that originates from a mass-based limit function.

Footprint was deemed unfavourable in section 4.4 because of the rather poor linear correlation between footprint and CO_2 for LCVs. This is largely the result of the CO_2 emissions levelling off above approximately 7 m^2. However, since in principle footprint is a good proxy for utility for LCVs, the suitability of this parameter is further analysed here using a non-linear limit function.

Payload was only assessed concisely in [TNO 2011]. It was deemed unfavourable for passenger cars primarily because of the very weak correlation with CO_2 emissions. For LCVs, this correlation is significantly better. However, a remaining issue, valid for both LCVs and passenger cars, is that payload (or maximum permissible load) is a declared value that cannot be independently verified. This is a major disadvantage of payload. It can be manipulated by manufacturers. Also the CO_2 impact of vehicle modifications to increase payload could be relatively small. This would offer room for gaming. Therefore payload is not taken into account in the remainder of this section.

- ***Instruments and sanctions:*** The main sanction type considered is an excess emissions premium of a 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.

Apart from the advantages and disadvantages of various potential utility parameters described above, the additional manufacturer costs and distributional impact are also important criteria for the selection of the favourable utility parameter. The additional manufacturer costs and distributional impacts are therefore determined for mass and footprint as utility parameters in sections 5.4 and 5.5.

5.3 Assessed cost impact modalities

Using an updated version of the model developed for [TNO 2006] and [TNO 2011], a range of regulatory options for implementing the 147 g/km legislation for LCVs have been quantitatively assessed with respect to average additional costs per vehicle for meeting the target. Especially the distribution of required CO_2 reduction efforts and associated costs per vehicle over the various manufacturers / manufacturer groups selling LCVs in Europe and over the three market segments discerned in the model (small, medium and large vehicles running on diesel) have been analysed.

5.3.1 Additional manufacturer costs optimisation model

The optimisation model mentioned above, determines per manufacturer the cost optimal distribution of CO_2 reduction efforts over the three segments by which the manufacturer can meet its specific target, given its sales distribution over the three diesel segments. This optimisation is based on minimising the total additional manufacturer costs per manufacturer (group). Costs for CO_2 reduction per segment are determined by the cost curves presented in section 3.3.7. In the optimum the marginal costs are equal over all segments.

As discussed in section 3.2.1, the year 2010 was selected as the baseline year for the current study, while in previous studies for passenger cars and vans, e.g. [Smokers 2006], [TNO 2011] and [Smokers et al. 2009], the year 2002 was defined as the baseline year. The 2010 data were decided to be preferable over previously acquired LCVs data because it is believed to be much more complete and reliable.

Reduction potential and costs are therefore based on 2010 baseline vehicles (the best selling vehicle types in each of the three diesel LCV segments). These are assumed to be representative for the 2010 LCV sales; homogeneity in applied technologies is assumed. Therefore every CO2 reducing technology (based on 2010 baseline vehicles) listed in [TNO 2012] is assumed to be applicable to every LCV model available in the assessed 2010 LCV database.

5.3.2 Assessed options

The following option of basic regulatory options has 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.

Having selected linear limit functions, different utility parameters and multiple slope variations are possible. Since this slope value can have an effect on the additional manufacturer costs and a significant effect on distributional impacts, it is taken into account in the detailed assessment. The considerations for a final slope value are therefore discussed in section 5.7.

Application of a certain measure to the sales weighted average CO_2 emissions per manufacturer group implies that manufacturer groups (see Annex A) are allowed to perform internal averaging, i.e. the excess emission of one vehicle that emits more than the target value indicated by the limit function can be compensated by other vehicles that emit less than their specific targets. 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 internal averaging is included implicitly as all vehicles in the segment undergo CO_2 reduction up to the same level of marginal costs.

5.3.3 Reference scenarios

In this report the costs for meeting the 2020 target are expressed relative to two different references:

- **A 2010 reference situation**: Costs in this case are the costs of additional technology applied between 2010 and 2020 for moving from the 2010 average to the 147 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 175 g/km is maintained between 2017 and 2020. Additional costs for meeting 147 g/km are defined relative to the costs assessed for meeting 175 g/km in 2020 (on the basis of the utility-based limit function defined in Regulation (EU) No 510/2011) 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 175 g/km target in 2017, since new cost curves for 2020 were developed[9] (section 3.3.7).

In the remainder of this report, the second reference is handled before the first reference, since these outcomes represent the additional impacts resulting from moving from the existing ‘business as usual’ scenario, i.e. including the target of 175 g/km for 2017, to the new target that was laid down for 2020, i.e. 147 g/km.

5.3.4 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 2010 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 2010 and 2020. This is consistent with [TNO 2011] analysing the impact of a 95 gCO_2/km target for passenger cars, and the method used to generate the 2017 limit function for a 175 gCO_2/km target for LCVs.

5.3.5 Baseline data for 2010

In an additional task within [TNO 2011] a passenger car sales database with only a limited number of EU countries was compared to an EU27 database. From the comparison it was deduced that using a database with information on only a limited number of countries leads 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. Exceptions to these findings were some manufacturers originating from a European country outside the countries available in the limited database, e.g. Saab from Sweden.

For this study on vans also only a database with a limited number of countries is available, i.e. a database purchased from JATO containing information for the five biggest European economies (France, Germany, Italy, Spain and the UK).

Similar to the situation for passenger cars, also for LCVs the majority of new registrations (over 76%) within the EU27 are registered in the 5 EU countries in the database. Because all large European manufacturers originate from one of the five countries for which data is available in the database, this database is expected to be representative for the new registrations within the EU27.

Manufacturer groups, used for the assessment, have been based on the situation per November 1st, 2011. For each manufacturer group the 2010 sales of all brands belonging to that group are included in the sales averaged values of utility and CO_2 per segment.

5.3.6 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:

$$147 \text{ g/km} = a \langle U \rangle_{2020} + b,$$

with $\langle U \rangle_{2020}$ 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. The way this “100% slope line” is generated is explained in the text box below.

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[9] For these new cost curves, new cost estimations and reduction potentials are determined for the identified CO_2 reducing technologies. Moreover the baseline year in this study is 2010, while for previous studies this was 2002. Finally the distances to the manufacturers’ CO_2 targets are based on a newly acquired sales database.

100% slope of a linear limit function

The “100% slope” limit functions is constructed by firstly introducing a sales-weighted least squares fit through the CO_2 emission values of all 2010 vehicle models (including non-diesels) plotted as function of their respective utility values. Hereafter this line is lowered to meet the average of 147 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 2010 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%.

For the non-linear utility-based limit functions a rather simple type was selected from an infinite number of possible non-linear functions, i.e. two interconnected linearly increasing limit functions. Also for the non-linear limit function, variants with different slopes are defined relative to a “100% slope” base limit function. The way this non-linear equivalent of the “100% slope line” is generated is explained in the text box below.

100% slope of a non-linear limit function

The equivalent of the non-linear “100% slope” limit functions is constructed by firstly estimating the utility value at which a deviation from the trend is observed. Then sales weighted linear least squares fits are constructed for the vehicle sales with utility values lower than the estimated deviation point and for the vehicle sales with utility values higher than the estimated deviation point (including non-diesel vehicles).

Hereafter this line is lowered to meet the average of 147 g/km in such a way that the relative reduction is equal for all utility values. This way the non-linear equivalent of the “100% slope” base limit function is defined as the limit function for which the burden of CO_2 reduction between 2010 and 2020 is evenly distributed over the range of utility values. The point where the two linear parts of the limit function meet is the ‘bending point’. 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%.

In order to compare the effects of using either mass or footprint as the utility parameter, the same set of data ought to be used for determining the distributional impacts. This leads to using all lines of sales data in the database that record CO_2 emissions, vehicle mass data and footprint data. This criteria lead to 96% of all new diesel LCV registrations being included.

5.3.7 Presentation of results

Additional manufacturer costs resulting from the implementation of CO_2 reducing technologies on LCVs to meet a target of 147 gCO_2/km for new registrations in 2020 are calculated per manufacturer as well as per segment. As explained above, this is done for various utility parameters and different slope values between 60% and 140%.

Besides absolute manufacturer costs related to achieving the 2020 target, some 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 mark-up factor of 1.11, according to [Smokers 2009], and dividing that by the average retail price calculated from the 2010 database.

Independent manufacturers which sell fewer than 22000 vehicles per year can also apply to the Commission for an individual target instead of their equivalent of the 175 gCO_2/km target. As Tata (incl. Land Rover), selling 90% Land Rovers, is likely to request such an individual target, they are not taken into account in the figures in this section. Nonetheless, to show the impact of the 2020 target for Tata (incl. Land Rover), the results for this manufacturer group are shown in Annex B.

5.3.8 *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 distribution and average CO_2 emissions per vehicle per segment) similar to that manufacturer group.

5.4 Results for mass as utility parameter

5.4.1 *Analysed slope values*

In order to determine the most appropriate slope value for mass in running order as a utility parameter, additional manufacturer costs and distributional impacts are determined for different slopes between 60% and 140% (Table 22).

Table 22 Utility based limit functions for mass as utility parameter.

mass-based limit function (aU + b)	*a*	*b*
limit function for 2017 target	0.093	16.3
least squares fit 2011	0.118	-14
slope 60%	0.057	52.4
slope 70%	0.067	36.6
slope 80%	0.077	20.8
slope 90%	0.086	5.1
slope 100%	0.096	-10.7
slope 110%	0.105	-26.5
slope 120%	0.115	-42.3
slope 130%	0.124	-58.0
slope 140%	0.134	-73.8

As depicted in Table 22, the 100% slope based on 2010 data is slightly steeper than the limit function for 2017 legislation, which was also based on a 100% slope and assumed no autonomous mass increase between the database year and the target year. Furthermore, it can be concluded from Figure 33 that the average mass has reduced between 2007 and 2010. This effect, partly resulting from a sales shift from Class III to Class I and II vehicles, is shown in Figure 13.

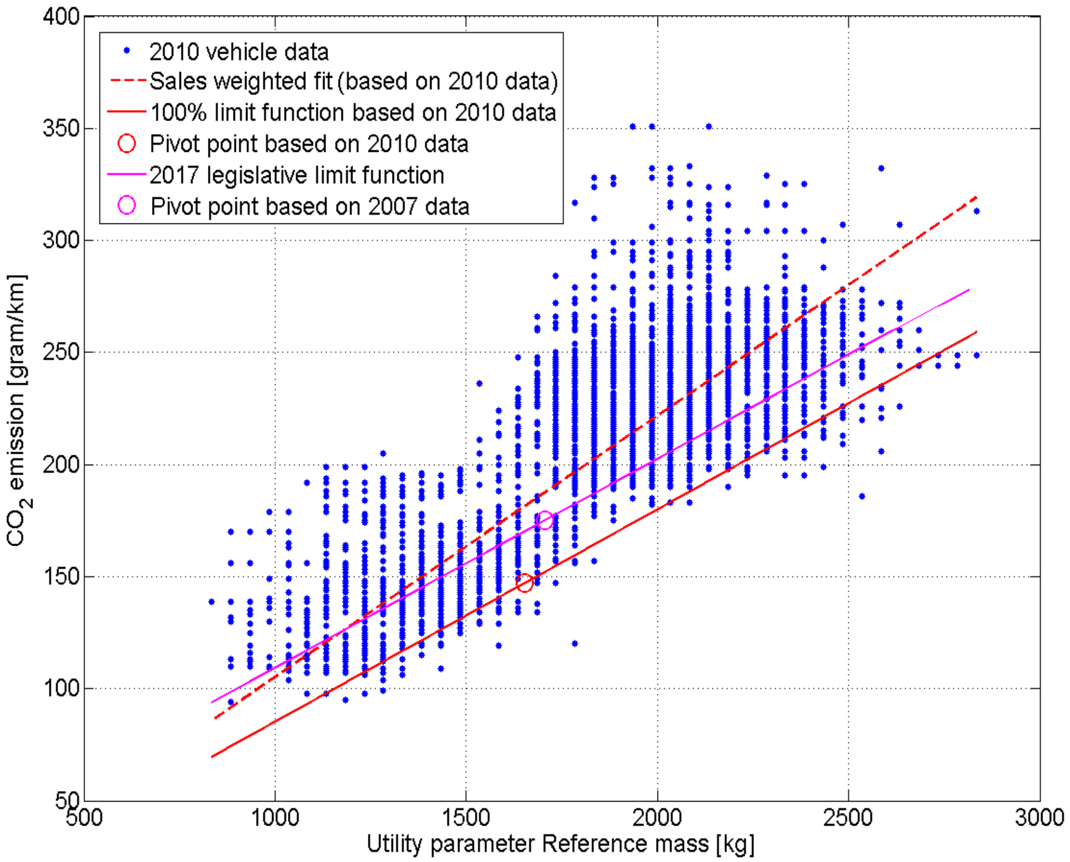

Figure 33 The 100% slope mass-based limit function for the 2020 target (based on 2010 data) compared to the limit function for the 2017 target.

5.4.2 Results expressed as cost impacts relative to a baseline in which 175 g/km is maintained between 2017 and 2020

Figure 35 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 175 g/km legislation is maintained between 2017 and 2020. The distribution of absolute manufacturer cost increases over market segments is presented in Figure 36. The relative retail price increases per manufacturer group and the distribution over the segments are respectively shown in Figure 37 and Figure 38.

In the assessment of the costs of technological measures applied to reduce CO_2 emissions the translation from additional costs to the manufacturer to retail price increase involves a mark-up, which includes possible margins for the manufacturer, importers and dealers and various taxes (vehicle purchase tax and VAT). To be consistent with [IEEP 2007] and the practices used by the Commission Services for Impact Assessments the translation from additional manufacturer costs for CO_2 reduction measures to sales price increase in this report only includes taxes, i.e. no manufacturer and dealer margins are assumed for these measures. For the case of N vehicles (vans) this gives a translation factor of 1.11 to convert additional manufacturer costs into retail price increase exclusive of VAT. This is in line with [Smokers 2009].

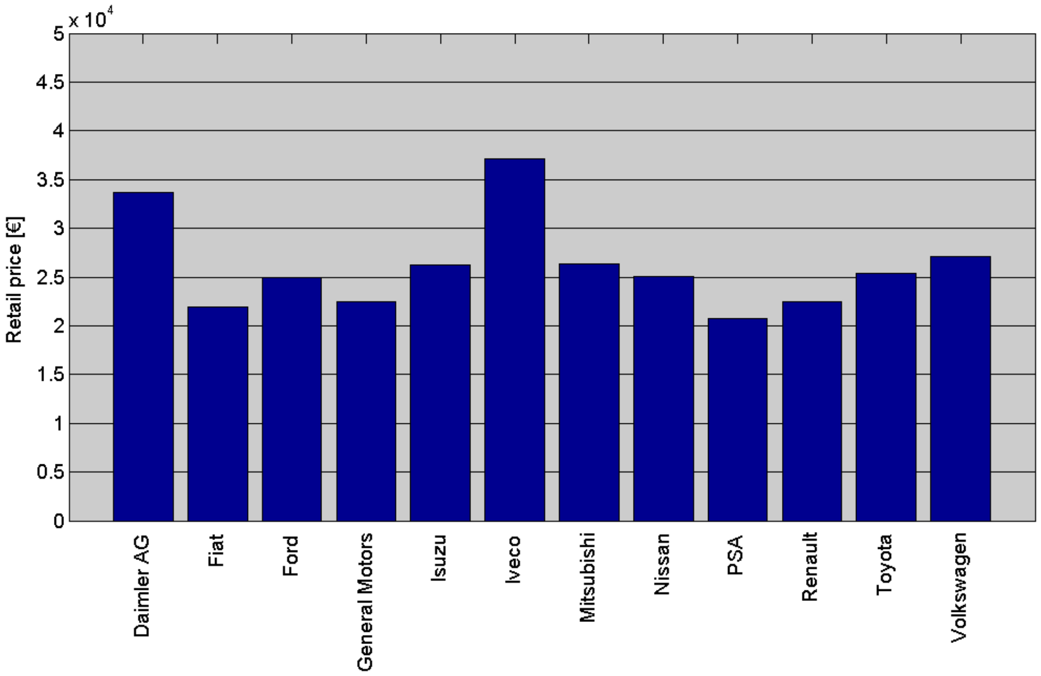

Figure 34 2010 average retail price per manufacturer.

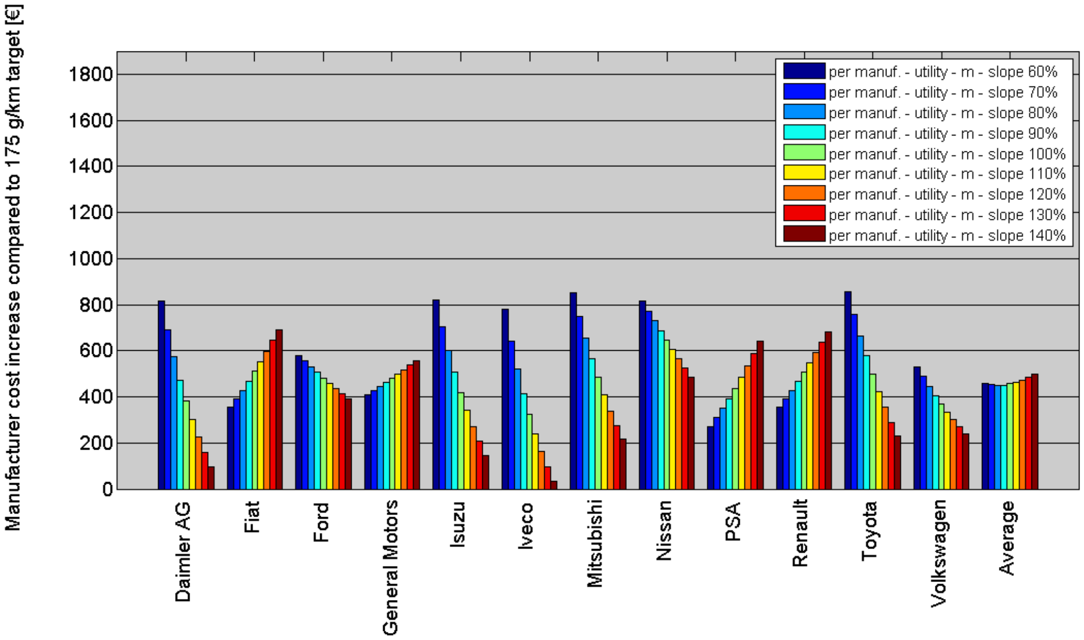

Figure 35 Absolute manufacturer cost increase per manufacturer for mass-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

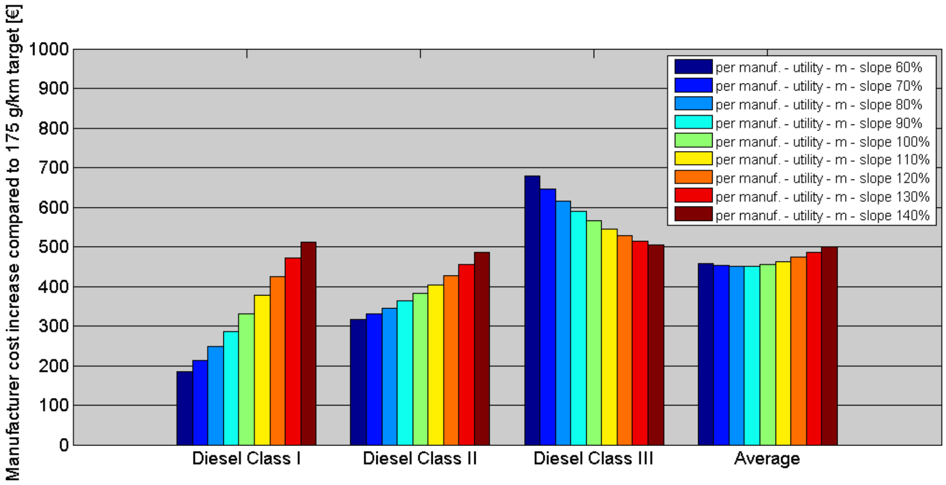

Figure 36 Absolute manufacturer cost increase segment for mass-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

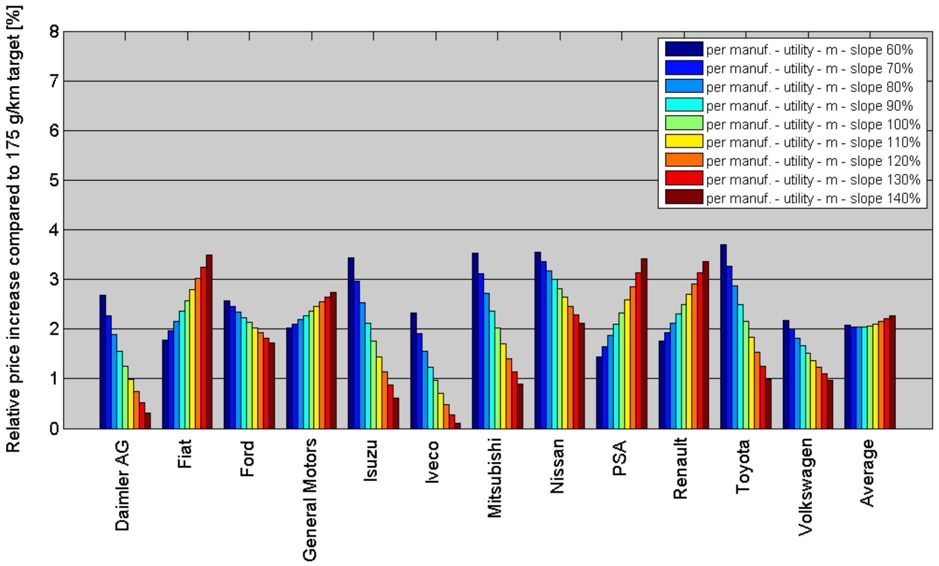

Figure 37 Relative price increase per manufacturer for mass-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

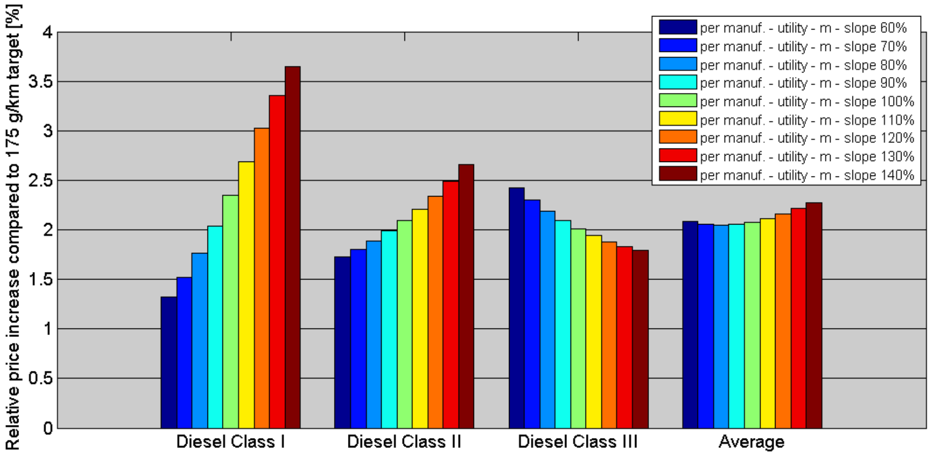

Figure 38 Relative price increase relative per segment for mass-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

5.4.3 Results expressed as cost impacts relative to 2010

The absolute manufacturer cost increase per manufacturer relative to 2010 resulting from applying a mass-based CO_2 limit function with different slope values at the level of manufacturer groups is depicted in Figure 39. The distribution of absolute manufacturer cost increases over market segments is presented in Figure 40. The relative retail price increase per manufacturer relative to 2010 is depicted in Figure 41. The distribution of relative retail price increases over market segments relative to 2010 is presented in Figure 42. An alternative representation of the relative price increase is presented in Figure 43. The relative retail price increase is based on the average retail price per manufacturer in 2010 as depicted in Figure 34. As explained in section 5.3.7, a translation factor of 1.11 is used to convert additional manufacturer costs into retail price increase exclusive of VAT.

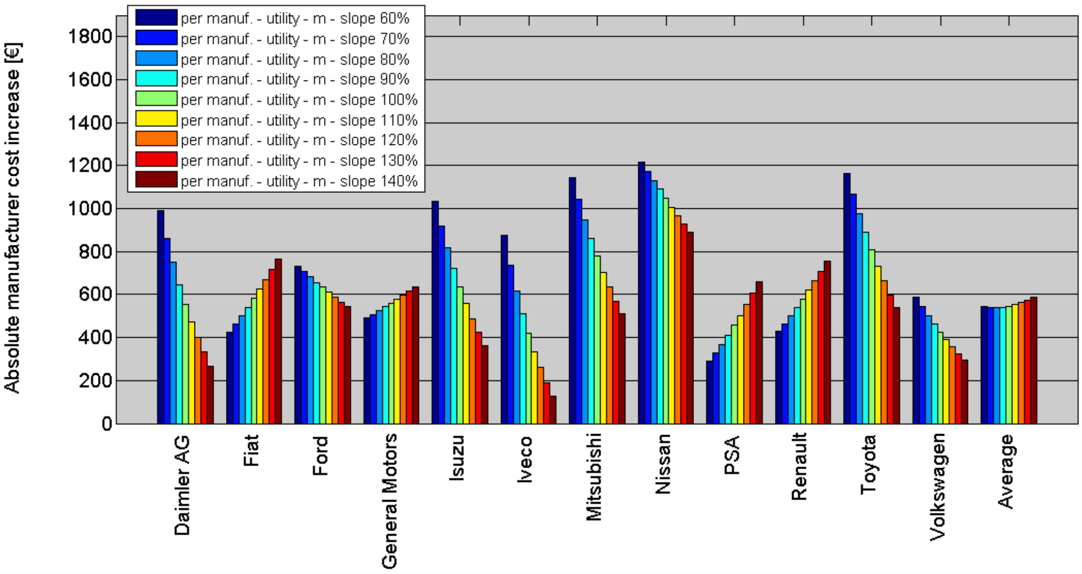

Figure 39 Absolute manufacturer cost increase relative to 2010 per manufacturer for mass-based limits applied per manufacturer.

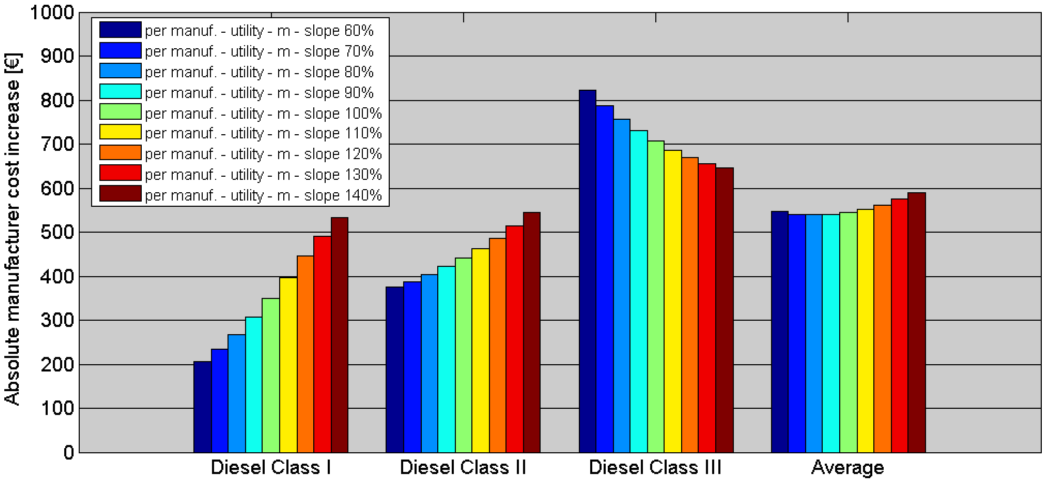

Figure 40 Absolute manufacturer cost increase relative to 2010 per segment for mass-based limits applied per manufacturer.

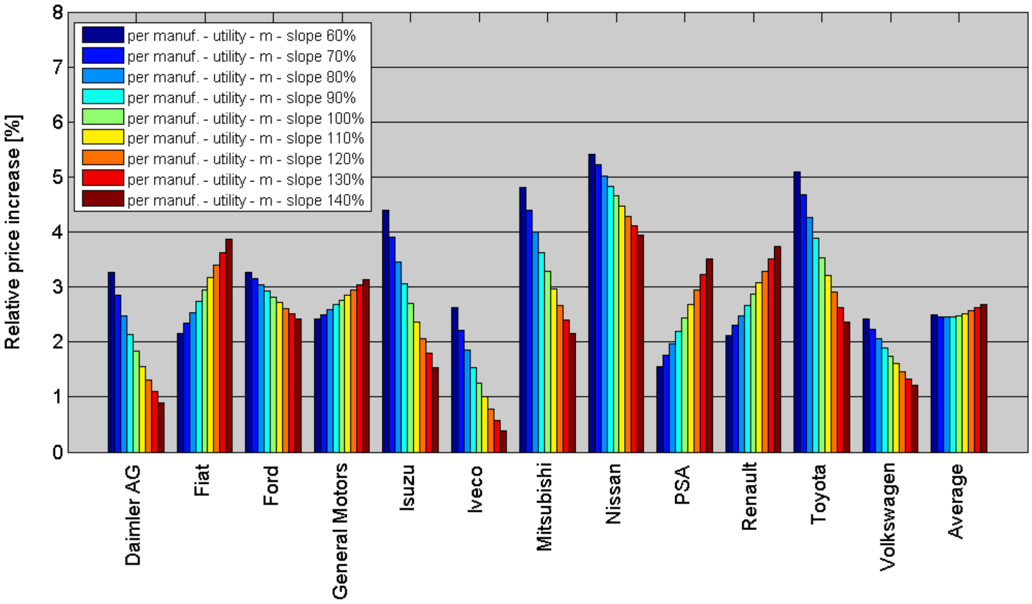

Figure 41 Relative retail price increase compared to 2010 per manufacturer for mass-based limits applied per manufacturer.

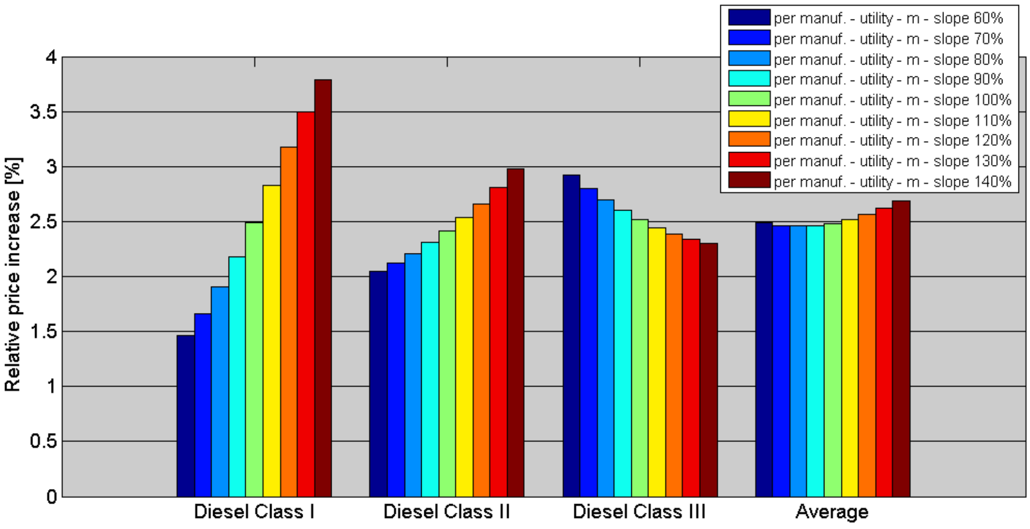

Figure 42 Relative retail price increase compared to 2010 per segment for mass-based limits applied per manufacturer.

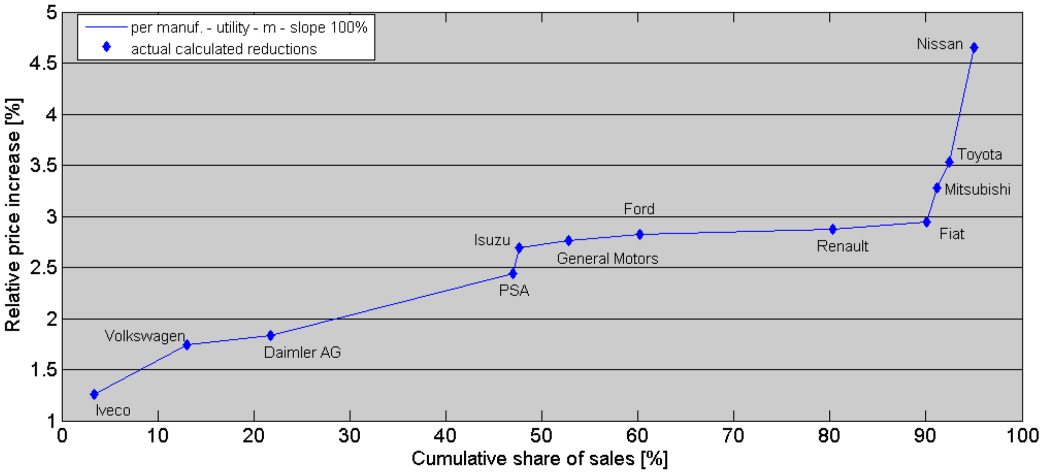

Figure 43 Relative retail price increase compared to 2010 per manufacturer for mass-based limit applied per manufacturer, and a limit function with slope = 100%.

5.4.4 *Conclusions regarding the case: mass-based limit function applied per manufacturer*

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 an increase in slope, while for manufacturers with above-average mass the costs decrease with an increase in 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 also sensitive to the slope of the utility based limit function but here the sensitivity is limited.

The way the additional manufacturer costs and relative price increase are distributed over the segments (Figure 36, Figure 38, Figure 40 and Figure 42) is heavily influenced by the shape of the cost curves. Though the additional manufacturer cost as function of the relative CO_2 reduction are quite similar for the three segments, the absolute and marginal costs for a given absolute CO_2 reduction are lower for larger vehicles than for smaller vehicles. In the model it is assumed that manufacturers strive to minimise the additional manufacturer costs for meeting their average CO_2 emission target. The optimum distribution is characterised by equal marginal costs over the three size segments. Therefore the model predicts that manufacturers are likely to apply larger reductions to the larger vehicles in their sales portfolio than to the smaller vehicles. It should be noted that from this uneven distribution of costs and price increase over segments it can therefore not be concluded that the costs are higher for manufacturers selling relatively many Class III vehicles.

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.

- **Daimler**, **Isuzu**, **Iveco**, and to a lower extent **Mitsubishi** and **Toyota** are relatively sensitive to slope changes. The average mass for new registrations for these manufacturer groups is well above average.
- Since the average retail price of **Daimler** and **Iveco** is relatively high (Figure 34), the relative retail price increase is low compared to the additional manufacturer cost increase.
- Since manufacturer groups such as **Fiat**, **General Motors** and **PSA** have relatively low average retail prices, the additional manufacturer costs are high compared to the retail price. As a result, the relative price increase of these groups is high compared to the additional manufacturer costs.
- The additional manufacturer costs and relative price increase are relatively high for **Mitsubishi**, **Nissan** and **Toyota**. This is a result of a rather long distance to target. This is especially the case for the costs and price relative to 2010, since a large part of this distance to the 2020 target will already have to be covered to reach the Nissan equivalent of the 175 gCO_2/km target for 2017. It should be noted however, that a large part of the sales of these manufacturers are pick-up trucks and all-terrain vehicles
- As shown in Annex B, the average vehicle mass of the 2010 new **Tata (incl. Land Rover)** registrations is relatively high. As a result, additional manufacturer costs (relative to 2010) are high and the group is relatively sensitive to changes in the slope value. Relative to the 175 gCO_2/km target, additional manufacturer costs are relatively low for low slope values. This is the result of a significant part of the cost to meet their equivalent of the 147 g/km target, have already been made to meet the 175 g/km target. As a result of these costs, the overall average additional manufacturer cost are higher when Tata (incl Land Rover) is included in the analysis. The impact is limited because of the low sales volume.

5.5 Results for footprint as utility parameter

5.5.1 Analysed slope values

As explained in section 5.2.1, a linear limit function was deemed inadequate for a footprint-based limit function, because CO_2 emissions of LCVs level off for high footprint values. The selected non-linear limit function consists of two linear parts. This non-linear limit function is constructed using the following method:

- When analysing the way CO_2 emissions are scattered over the footprint range, two different trend lines can be observed. The first one for LCVs with a footprint below 7 m^2 and a second one for vehicles with a footprint above 7 m^2. For constructing the non-linear equivalent of the 100% footprint-based limit function, two separate linear least squares fits have been determined for the sales below and above this $7m^2$. These fits intercept at 7.6 m^2.
- A non-linear trend line is constructed by combining the fit for small vehicles (up to a footprint value of 7.6 m^2) with the trend line based on large vehicles for footprint values (above 7.6 m^2).
- This combined trend line is then lowered to meet the average of 147 g/km in such a way that the relative reduction is equal for all utility values, i.e. the non-linear equivalent of the “100% slope”.
- Variants of the function are constructed by changing the slope of the left and the right parts of the non-linear 100% limit function. For the 60% slope, the slope values of the left and right part (the a in $y = ax+b$) are multiplied by a factor 0.6 and for the 140% limit function by a factor 1.4, while the bending point remains 7.6 m^2. Finally, the non-linear function is moved in the vertical direction to meet the constraint of 147 gCO_2/km.

Figure 44 shows the non-linear equivalent of the 100% footprint-based limit function and a number of non-linear alternatives with different slopes. For comparison also the 100% linear limit function is shown. As explained above, for defining variants of the non-linear function with different slopes the choice was made to keep the footprint value of the bending point of the variants constant for the slope variants of the non-linear limit function. Alternatively, the two linear parts of every slope variant could be shifted in vertical direction relative to one another (in an infinite number of ways) to meet the constraint of 147 gCO_2/km. This would lead to different positions of the bending point. As a result of multiple possible ways in which slope variants can be constructed, the final shapes of these displayed slope variants are partly the result of choices made to construct them, rather than just the consequence of the internal logic of changing the slope value. As a result also some of the distributional impacts of changing the slope may be the result of this choice made in how to construct the different limit functions rather than of the changed slope itself.

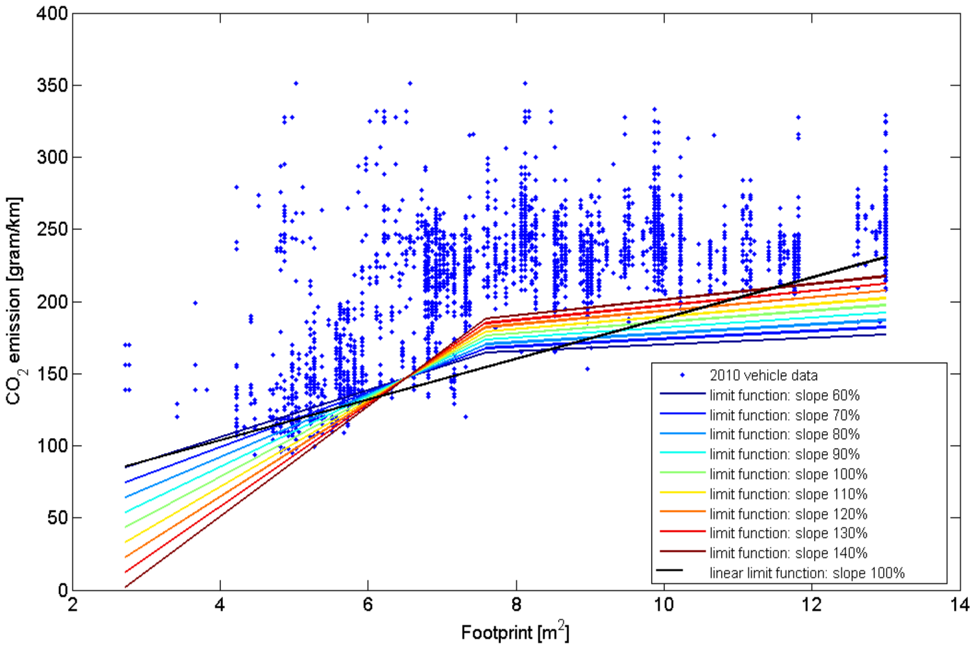

Figure 44 The non-linear equivalent of the 100% footprint-based limit function and a number of alternatives between 60% and 140% slopes. The bending point is 7.6m^2 and the pivot point is 6.5m^2.

Table 23 Utility based limit functions footprint utility parameter

	aU + **b** (left from the bending point)		**a**U + **b** (right from the bending point)	
non-linear footprint-based limit function	*a*	*b*	*a*	*b*
least squares fit 2010	33.4	-38.8	4.7	179.1
slope 60%	16.4	40.3	2.3	147.0
slope 70%	19.1	22.5	2.7	146.9
slope 80%	21.8	4.8	3.1	146.9
slope 90%	24.6	-13.0	3.5	146.9
slope 100%	27.3	-30.8	3.9	146.9
slope 110%	30.0	-48.6	4.3	146.9
slope 120%	32.7	-66.4	4.6	146.9
slope 130%	35.5	-84.2	5.0	146.9
slope 140%	38.2	-101.9	5.4	146.9

5.5.2 Results expressed as cost impacts relative to a baseline in which 175 g/km is maintained between 2017 and 2020

Figure 45 shows the absolute manufacturer cost increases at the level of manufacturer groups, resulting from applying a non-linear footprint-based CO_2 limit function with different slope values. These costs are relative to the situation in which the current 175 g/km legislation is maintained between 2017 and 2020. The distribution of absolute manufacturer cost increases over market segments is presented in Figure 46. The relative retail price increases per manufacturer group and the distribution over the segments are respectively shown in Figure 47 and Figure 48. As explained in section 5.3.7, a translation factor of 1.11 is used to convert additional manufacturer costs into retail price increase exclusive of VAT.

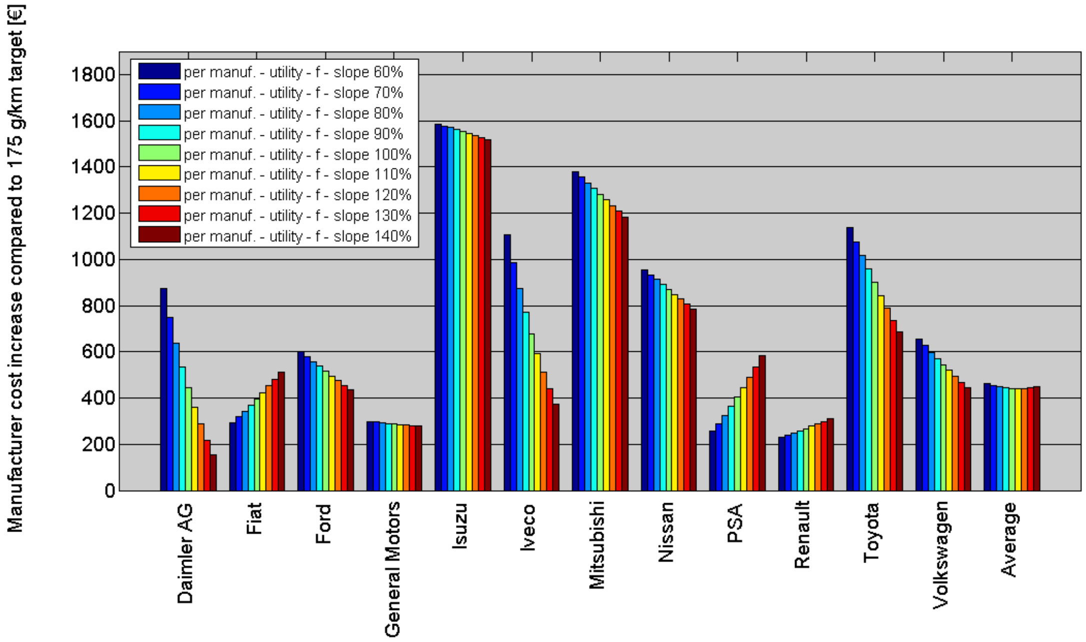

Figure 45 Absolute manufacturer cost increase per manufacturer for footprint-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

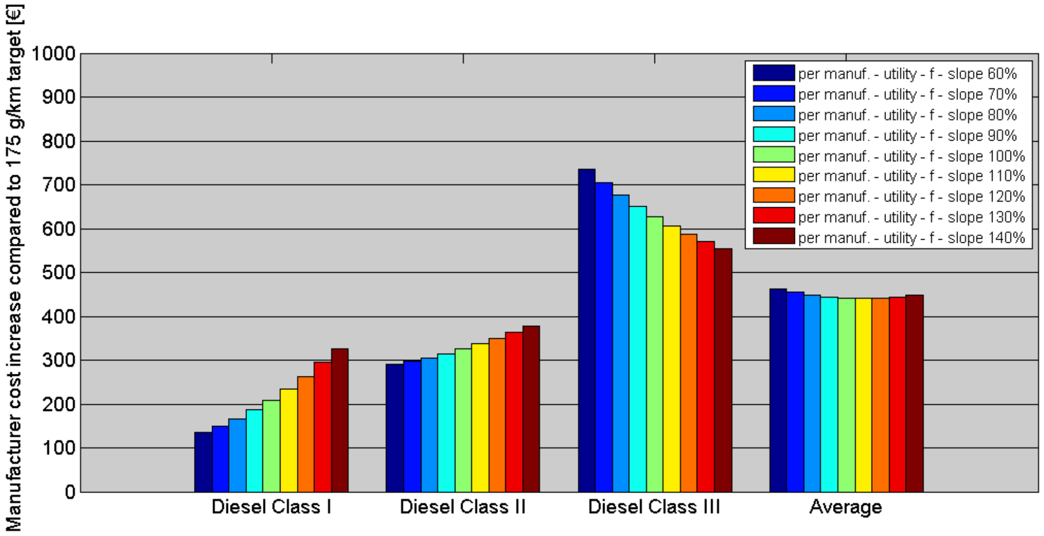

Figure 46 Absolute manufacturer cost increase segment for footprint-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

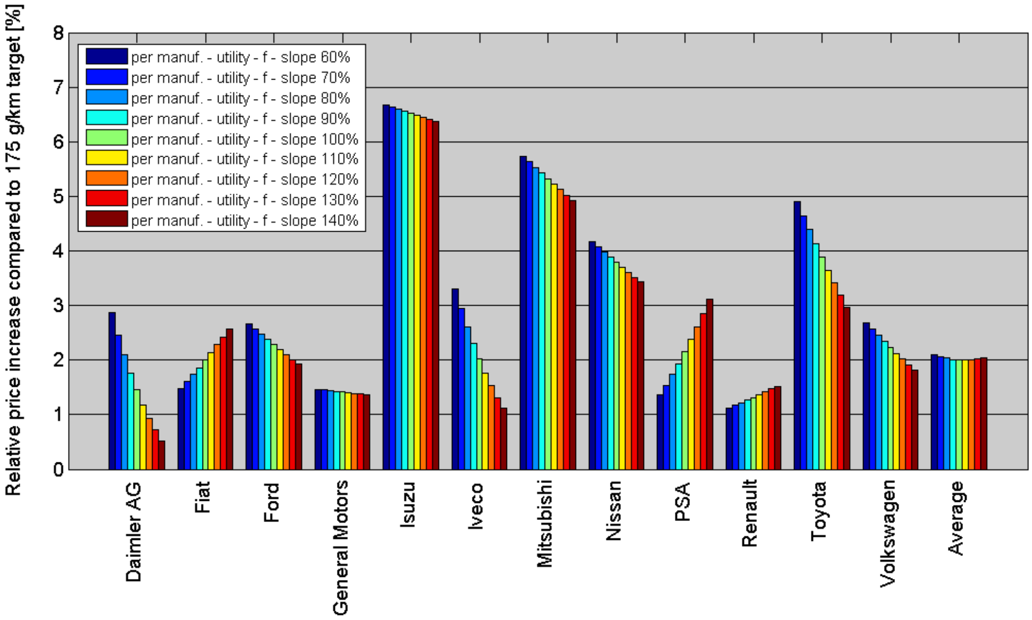

Figure 47 Relative price increase per manufacturer for footprint-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

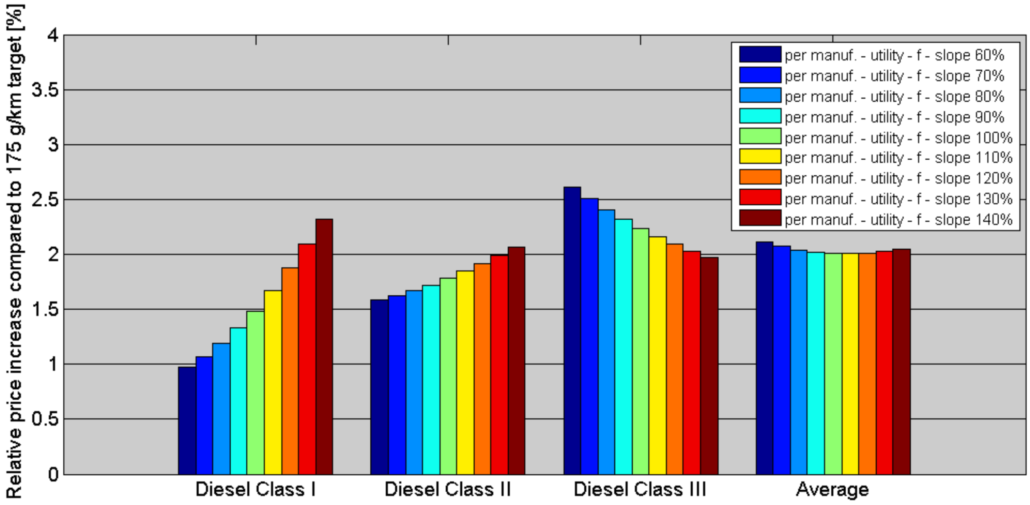

Figure 48 Relative price increase relative per segment for footprint-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

5.5.3 Results expressed as cost impacts relative to 2010

The absolute manufacturer cost increase per manufacturer relative to 2010 resulting from applying a non-linear footprint-based CO_2 limit function with different slope values at the level of manufacturer groups is depicted in Figure 49. The distribution of absolute manufacturer cost increases over market segments is presented in Figure 50. The relative retail price increase per manufacturer relative to 2010 is depicted in Figure 51. The distribution of relative retail price increases over market segments relative to 2010 is presented in Figure 52. An alternative representation of the relative price increase is presented in Figure 53. As explained in section 5.3.7, a translation factor of 1.11 is used to convert additional manufacturer costs into retail price increase exclusive of VAT.

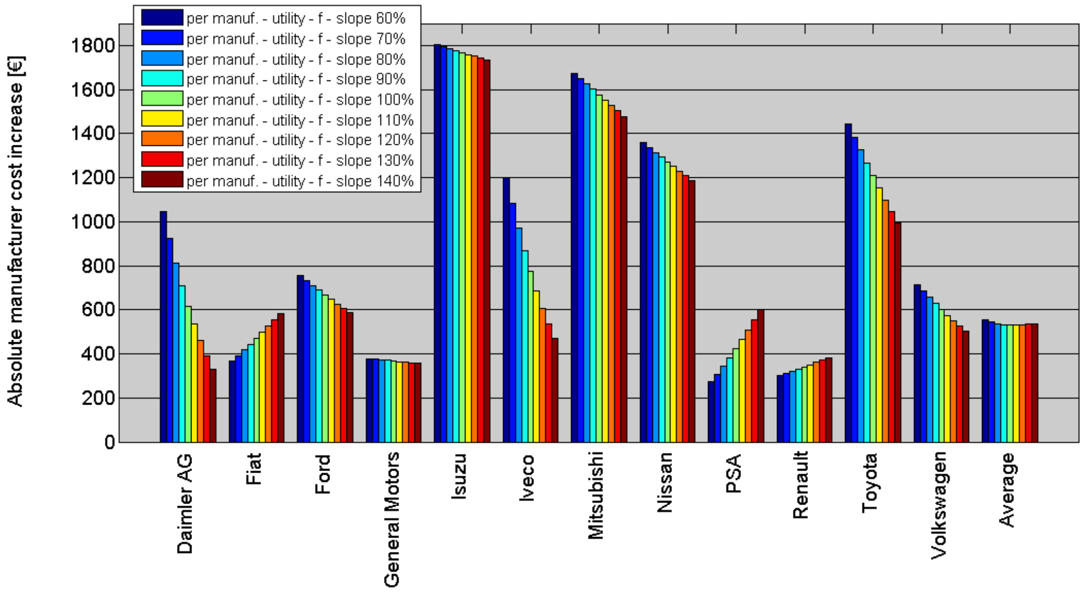

Figure 49 Absolute manufacturer cost increase relative to 2010 per manufacturer for footprint -based limits applied per manufacturer.

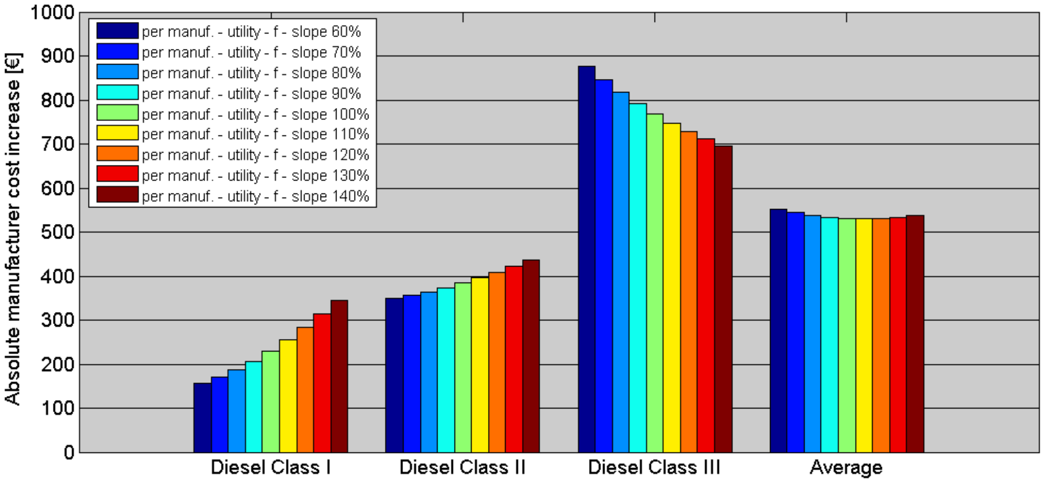

Figure 50 Absolute manufacturer cost increase relative to 2010 per segment for footprint -based limits applied per manufacturer.

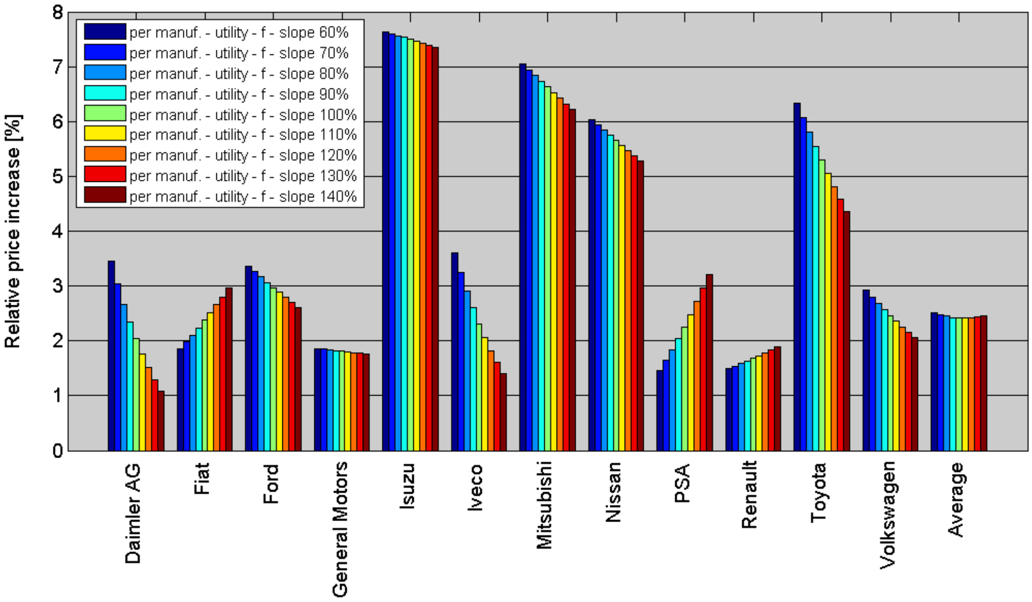

Figure 51 Relative retail price increase compared to 2010 per manufacturer for footprint -based limits applied per manufacturer.

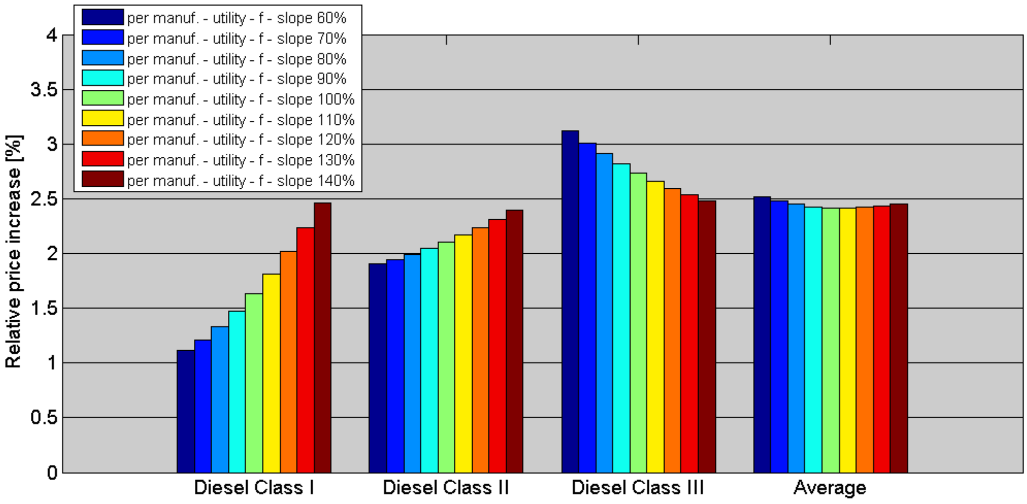

Figure 52 Relative retail price increase compared to 2010 per segment for footprint -based limits applied per manufacturer.

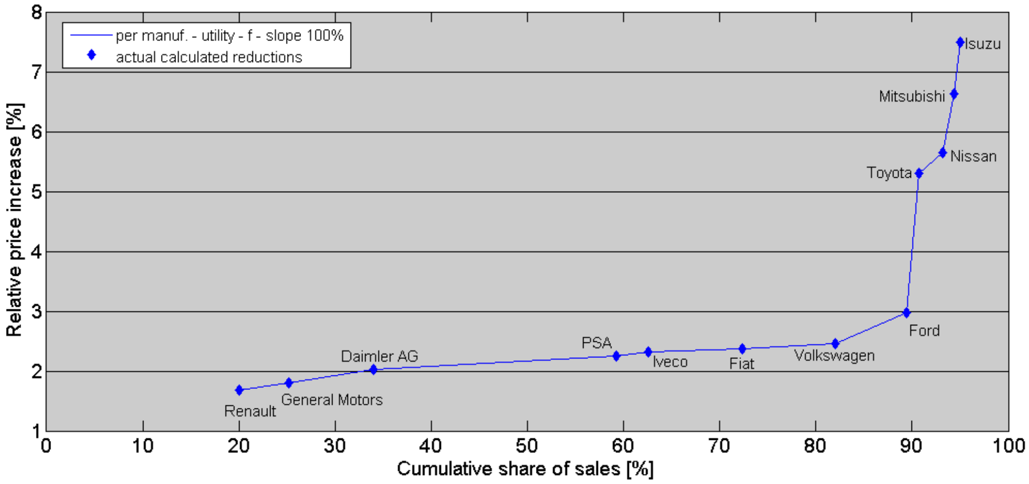

Figure 53 Relative retail price increase compared to 2010 per manufacturer for footprint-based limit applied per manufacturer, and a limit function with slope = 100%.

5.5.4 *Conclusions regarding the case: footprint-based limit function applied per manufacturer*

Average costs per vehicle for each manufacturer group scale almost linearly with the slope of the limit function. For manufacturers with a sales-averaged footprint below the pivot point (6.5 m^2, not the overall average footprint), the costs increase with an increase in slope, while for manufacturers with a sales-averaged footprint above the bending point the costs decrease with an increase in slope. Sensitivity to changing slope is very different for the different manufacturer groups depending on the difference between the average footprint of the manufacturer group and the pivot point footprint value. Overall average costs are also sensitive to the slope of the utility based limit function but here the sensitivity is limited.

As also explained for mass as utility parameter the cost optimal way for manufacturers to meet their specific target, under the assumption that additional manufacturer costs are minimised, implies that manufacturers apply larger absolute reductions to the larger vehicles in their portfolio. As a consequence the absolute cost increase for large vehicles will tend to be larger than for small vehicles. Also for the case of footprint it should thus be noted that from an uneven distribution of costs and price increase over segments as shown in Figure 50 and Figure 52 it cannot be concluded that the costs are higher for manufacturers selling relatively many Class III vehicles. However, for Iveco, a manufacturer of mostly Class III vehicles, the footprint-based target results in a lower CO_2 target and therefore higher costs. This causes the additional manufacturer costs and relative price increase of Class III vehicles to be relatively high.

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.

- **Mitsubishi**, **Isuzu**, **Nissan** and **Toyota** have relatively high additional manufacturer costs to meet their equivalents of the 147gCO_2/km targets. It should be noted however, that a large part of the sales of these manufacturers are pick-up trucks and all-terrain vehicles
- **Daimler** and **Iveco** are relatively sensitive to slope changes. The average footprint for new registrations for these manufacturer groups is well above average. Since the average retail price of Daimler and Iveco is relatively high, the additional manufacturer costs are low compared to the retail price.
- Since the average footprint of **PSA** is quite a bit lower than the pivot point, this manufacturer group is also relatively sensitive to slope changes. This effect is amplified by the fact that the average footprint is also lower than the bending point; the effect of slope change is larger to the left from the bending point.
- Since manufacturer groups such as **Fiat**, **General Motors** and **PSA** have relatively low average retail prices, the additional manufacturer costs are relatively high compared to the retail price. As a result the relative price increase of these groups is high compared to the additional manufacturer costs.

- When footprint is used as the utility parameter, **Tata (incl. Land Rover)** is not able to meet its target (Annex B). This is the result of the average CO_2 emissions being high compared to their footprint. These emissions are high mostly because of the relatively high mass of these vehicles. Since the sales share of this manufacturer group is less then 1% of all LCV sales, the effect of Tata not being able to meet its target is small. As a result of these costs, the overall average additional manufacturer cost are higher when Tata (incl Land Rover) is included in the analysis. The impact is limited because of the low sales volume, but higher than with a mass-based utility parameter.

5.6 Comparison of the utility parameters

As shown in Table 25, the average additional manufacturer costs for meeting the 147 gCO_2/km target are very similar for the non-linear footprint-based limit function and the linear mass-based limit function. Only at the relatively steep slopes, the costs are slightly higher when the mass-based limit function is applied (Table 25). This is due to manufacturers such as Renault and General Motors (including Opel) being further away from the pivot point for the mass-based limit function than from the pivot point for the footprint-based limit function. Therefore, costs increase relatively much when the mass-based limit function is applied.

Table 24 Average CO_2 emissions per segment for 100% limit function slopes

Average CO_2 emissions per segment	**Class I**	**Class II**	**Class III**
100% mass-based limit function [g/km]	104	133	176
100% footprint-based limit function [g/km]	108	135	174

Some smaller manufacturers have a relatively high average mass relative to their average footprint. This high mass results in relatively high energy consumption and therefore high CO_2 emissions. Clear examples of manufacturers whose distance to target is longer when footprint is used as the utility parameter are Isuzu, Nissan, Toyota and Mitsubishi as can be seen in Table 26 and Tata (incl. Land Rover) as shown in Annex B. It should be noted however, that a large part of the sales of these manufacturers are pick-up trucks and all-terrain vehicles. For the manufacturers selling actual vans, the cost difference between the two utility parameters is much lower and for some manufacturers costs are even lower with the footprint-based limit function, e.g. Fiat, General Motors, PSA and Renault (Table 27).

Table 25 Average additional manufacturer costs relative to 175 gCO_2/km legislation for various slope values

Average additional manufacturer costs relative to 175 gCO_2/km legislation [€]	**60%**	**70%**	**80%**	**90%**	**100%**	**110%**	**120%**	**130%**	**140%**
Linear mass-based limit function	457	452	450	451	456	463	473	485	500
Non-linear footprint-based limit function	463	455	448	444	441	440	442	445	449

Table 26 Distance to target (2010 - 2020) for all LCV manufacturers for the 100% slope limit function for both mass in running order and footprint as utility parameters

Distance to target [g/km]	**Daimler AG**	**Fiat**	**Ford**	**General Motors**	**Isuzu**	**Iveco**	**Mitsubishi**	**Nissan**	**PSA**	**Renault**	**Toyota**	**Volkswagen**
Mass in running order	41.6	32.2	39.3	32.9	44.4	35.3	49.4	55.6	26.8	32.4	50.3	31.2
Footprint	44.2	28.5	40.4	25.9	74.6	50.5	70.1	61.5	25.6	24.0	61.5	37.9
Difference	2.6	-3.6	1.1	-7.0	30.2	15.2	20.7	5.8	-1.1	-8.3	11.3	6.7

Table 27 Additional manufacturer costs (2010 - 2020) for all LCV manufacturers for the 100% slope limit function for both mass in running order and footprint as utility parameters

Additional manufacturer cost relative to 2010 [€]	**Daimler AG**	**Fiat**	**Ford**	**General Motors**	**Isuzu**	**Iveco**	**Mitsubishi**	**Nissan**	**PSA**	**Renault**	**Toyota**	**Volkswagen**
Mass in running order	555	583	633	561	636	419	779	1048	456	580	807	426
Footprint	616	469	668	367	1768	773	1576	1272	422	340	1209	601
Difference	62	-113	34	-193	1132	354	797	225	-34	-240	402	175

Overall, the distribution of the additional manufacturer costs and relative price increase over manufacturers is more even for mass than for footprint as utility parameter. This is emphasised by manufacturer groups selling relatively high shares of pick-up trucks and all-terrain vehicle (e.g. Isuzu, Nissan, Mitsubishi and Toyota) having a longer distance to target when footprint instead of mass as the utility parameter. Additionally, of the manufacturer groups selling mostly vans, Iveco sells relatively heavy LCVs compared to their footprint resulting in higher costs when footprint is the utility parameter.

Independent manufacturers which sell fewer than 22000 vehicles per year can also apply to the Commission for an individual target instead of their equivalent of the 175 gCO_2/km target. The assessment above shows that manufacturer groups with relatively low N1 sales (with a significant part sold as pick-ups or all-terrain vehicles) are the ones with relatively high cost, especially when a footprint-based utility parameter is applied.

Finally it should also be noted that the time between the short term target of 175 g/km based on mass (year 2017) and the longer term 147 g/km target (2020) is only three years. In case footprint is deemed favourable for the 2020 target, manufacturers with deviant mass-footprint ratios might have to severely adapt their CO_2 reduction strategies in a relatively short period.

5.7 Favourable slope value for the limit function

5.7.1 Mass

Since with an increasing steepness of the limit function the incentives for gaming increase, it is recommendable to implement a slope that is not steeper than the absolute value used in the mass-based limit function in the legislation currently in place to reduce average CO_2 emissions to a level of 175 g/km by 2017 (a = 0.094). Since the 100% limit function derived from the 2010 sales database is only slightly steeper (a = 0.096), a slope value of 100% or lower is recommendable.

The relative price increase (and additional manufacturer costs) is distributed most evenly over the manufacturers in the range between around 100% slope. Since also the average costs for meeting the 147 g/km target are lowest in this range, a slope value in this range is preferable.

In [Smokers 2006] it is stated that the weight increase ΔM is translated into a CO_2-emission increase ΔCO_2 for constant vehicle performance using the following formula:

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

In case mass is added to a vehicle without any other changes, the performance decreases. In that case the coefficient in the formula will be lower than 0.65.

Starting from the average mass (1654 kg) this leads to a CO_2 increase of 0.071 g/km per kg weight increase in 2010 (when CO_2 = 181 g/km). A decreasing CO_2 average of new registrations over the years, results in a coefficient of 0.058 g/km per kg weight increase in the target year (when CO_2 = 147 g/km).

Since slopes higher than this coefficient described above, leave room for gaming it is desirable to select a slope as close to this value as possible. Within the 80% to 100% slope range the 80% slope (a = 0.077) comes closest and is therefore considered as favourable from the perspective of avoiding incentives for gaming with mass.

5.7.2 Footprint

Although differences are very small, the lowest overall average additional manufacturer costs for footprint occur at the 110% slope, as can be seen in Table 25. Around this slope also the additional manufacturer costs are distributed most evenly over the manufacturers. This distribution, however, is influenced by a limited number of manufacturers (with relatively high sales) selling mostly large LCVs, e.g. Daimler and Iveco that benefit from a higher slope as it results in a higher, easier CO_2 target for them.

By stretching a vehicle (and increasing the wheelbase) the footprint can be increased without large negative implications on the CO_2 emissions (nor on the performance). As such changes in vehicle design are much easier to implement in many vans than in passenger cars, gaming with footprint is considered relatively easy for vans. The incentive for gaming is especially strong for vehicles with a relatively low footprint, as the non-linear limit function is relatively steep at this part of the footprint range. As long as adding footprint to an LCVs leads to more loading area and this extra space is used effectively, stretching an LCV need not be discouraged. However, stretching for the purpose of increasing the CO_2 target could lead to unnecessarily and undesirably large vehicles.

For the reason of avoiding gaming a lower slope would be desirable for the vans regulation. But as can be seen from Figure 49, a lower slope increases differences in cost impacts especially for the manufacturer groups that sell typical vans rather than pick-ups or all-terrain vehicles and that represent the majority of the market. This trade-off needs to be considered in the choice of slope value for the limit function.

5.8 Penalty or excess premium

If the average CO_2 emissions of a manufacturer's fleet (sales of new LCVs) exceed its limit value, the manufacturer has to pay an excess emissions premium for each car registered. According to Regulation (EU) No 510/2011, this premium amounts to €95 for every g/km of exceedance from 2019 onwards. This is equal to the excess premium level for passenger cars.

In Figure 54 and Figure 55, the marginal costs for realising the final 1 g/km CO_2 emission reduction needed to meet the manufacturer's equivalent of the 147 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 for the hypothetical reduction effort after which it could become cheaper to pay the premium) is different for every manufacturer, because the 2010 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 significantly higher than the average marginal costs for meeting the 2020 target for every manufacturer (which on average is just below € 30 g/km for all slopes analysed). Therefore, the current level of excess premium should provide more than enough incentive for all manufacturers to reduce the CO_2 levels of their vehicle fleet rather than paying the penalty for exceeding its limit value.

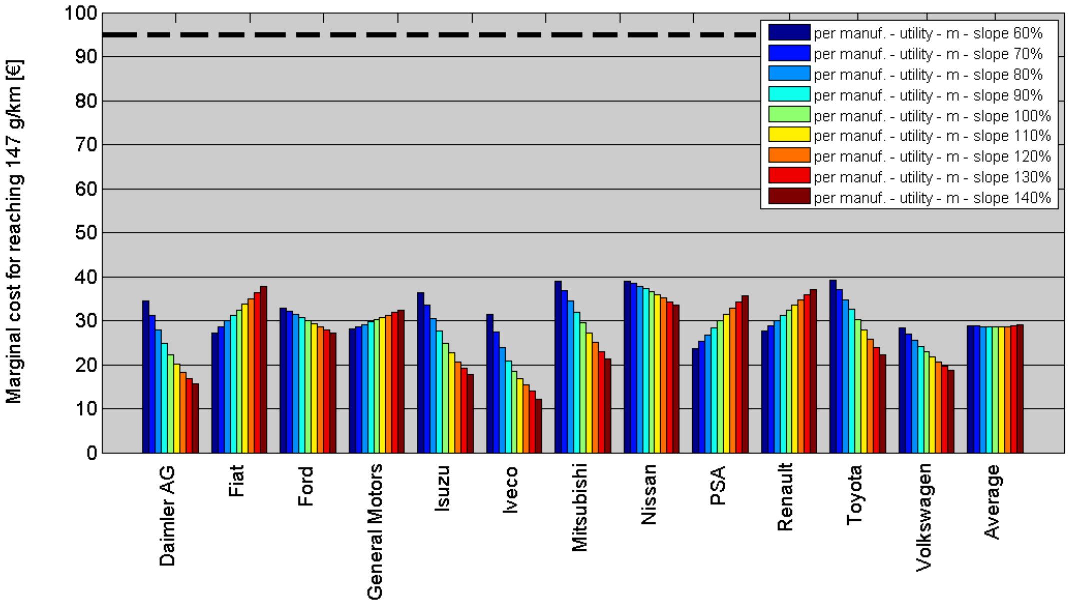

Figure 54 Marginal cost for every analysed manufacturer group for mass in running order as utility parameters for reaching the average 147 g/km in 2020.

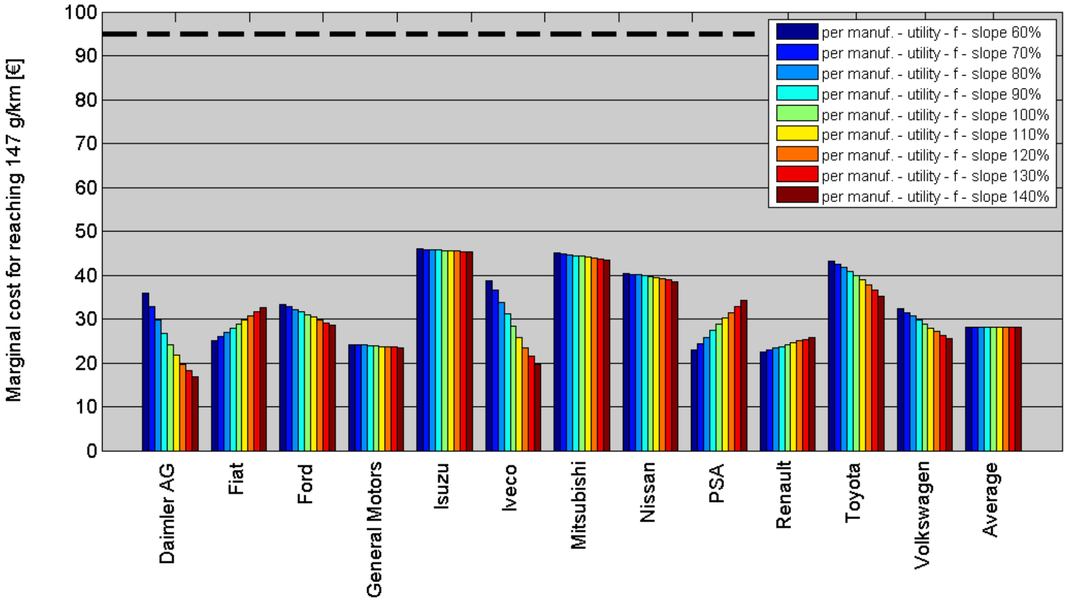

Figure 55 Marginal cost for every analysed manufacturer group for footprint as utility parameters for reaching the average 147 g/km in 2020.

5.9 Conclusions

For consistency reasons a number of modalities is proposed to remain unchanged compared to what is used in the legislation currently in place to support the 175 gCO_2/km target for new registrations within the EU27 by 2017. Therefore it is proposed that manufacturer groups remain defined as obligated entities and that the average CO_2 emissions of the total EU sales of manufacturer groups is used as target focus. The main sanction type considered remains an excess premium of penalty per vehicle for every g/km by which manufacturer’s average exceeds the manufacturer-specific target.

For simplicity sake a linear utility-based limit function is desirable, provided that the statistics for the selected utility parameter do not indicate a significant non-linear trend in the CO_2 versus utility value data for vehicles sold in the baseline year.

The main choices to be made with respect to the 2020 target for LCVs, therefore, are the utility parameter, the slope of the limit function and the excess premium level.

From the three potential utility parameters studied in section 4, mass in running order was concluded to be a seemingly suitable utility parameter that correlates linearly to the CO_2 emissions rather well. It was therefore analysed in more detail in this section using a linear limit function. On the other hand, payload was deemed unfavourable, because it is a declared value that can not be independently verified. The payload value can be manipulated by manufacturers. Also the CO_2 impact of vehicle modifications to increase payload could be relatively small, offering room for gaming. Because of these disadvantages payload was not further analysed as a potential utility parameter. Finally, for footprint it was found that the CO_2 emissions level off with towards the upper end of the footprint range, making a linear limit function inadequate. However, since footprint is a rather suitable for passenger cars, and since it is in principle a good proxy for LCV utility, it was analysed in more detail in this section. This was done using a non-linear limit function.

The CO_2 emissions of LCVs level off for high footprint values, because of two reasons. One of them is the fact that vans with large footprint are generally extended versions of shorter base models whereby the increase in CO_2 emissions due to increasing vehicle length and wheelbase is limited. The second cause for CO_2 emissions of LCVs to level off lies in the definition of test procedures, where test mass is not increased for vehicles with reference mass above 2610 kg and resistance settings of the chassis dynamometer are kept constant from 2210 kg upwards. This clause in the test procedure was motivated by the limited capabilities of mechanical chassis dynamometers at the test procedure was developed. With modern electromechanical chassis dynamometers these limitations no longer exist. In order to improve the basis of CO_2 legislation for LCVs it would therefore be advisable to update type approval test procedures in such a way that especially for larger vans measured CO_2 values become more realistic. Such amendments to the test procedure would reduce a large part of the non-linearity currently observed in the footprint versus CO_2 statistics for LCVs and might thus reduce the need to apply a non-linear limit function. Also when mass is chosen as utility parameter for the 2020 target of 147 g/km, updating the test procedure for CO_2 emission measurement would greatly improve the effectiveness of the regulation and may be expected to have implications for what is the most appropriate limit function. In both cases therefore amendments to the test procedure before 2020 would need to be accompanied a review and possible revision of the limit function that is now to be selected for defining the modalities for implementation of the 2020 target.

Compared to footprint, using mass as the utility parameter leads to slightly higher additional manufacturer costs for steeper limit functions. These slightly higher costs are mainly caused by a small number of manufacturers (with a relatively large sales shares) that are more sensitive to the slope of the mass-based limit function than to the slope of the footprint-based limit function.
The additional manufacturer costs are distributed more evenly for mass than for the footprint based limit function. This is mostly due to a limited number of manufacturers selling partly or mostly pick-up trucks with high mass relative to their footprint. Apart from Iveco (relatively high costs for footprint-based limit function), the additional manufacturer costs for footprint and mass are rather similar for manufacturers selling mostly typical vans intended for goods transport.

It should also be noted that the time between the short term target of 175 g/km based on mass (2017) and the longer term 147 g/km target (2020) is only three years. In case footprint is deemed favourable for the 2020 target manufacturers with deviant mass-footprint ratios, might have to severely adapt their CO_2 reduction strategies in a relatively short period

Slope values of the limit function affect the distance to target for the various manufacturers. A steep slope leads to a relatively short distance to target (and relatively low costs) for manufacturers producing rather large vehicles and to a relatively large distance to target (and relatively high costs) for manufacturers producing rather small vehicles. On the other hand, a flatter slope leads to a relatively large distance to target (and relatively high costs) for manufacturers producing rather large vehicles and to a relatively short distance to target (and relatively low costs) for manufacturers producing rather small vehicles. Since it is desirable to have LCVs of different sizes, the burden of the

147 gCO_2/km target should in principle be distributed evenly over the utility range. For both mass and footprint as utility parameters, the costs are distributed most evenly over the manufacturer (groups) around the 100% slopes. The distribution of cost impacts over different size segments is found to be uneven if when the relative distance to target is more or less constant over the utility range. This is a consequence of shape of the cost curves for different segments and the optimisation of additional manufacturer costs that manufacturers are assumed to strive for. The cost optimum is generally characterised by higher reductions, and therefore higher costs, for larger vehicles.

The footprint of an LCV can be increased without large negative implications on the CO_2 emissions (nor on the performance). As such changes in vehicle design are much easier to implement in many vans than in passenger cars, gaming with footprint is considered relatively easy for vans. The incentive for gaming is especially strong for vehicles with a relatively low footprint, as the non-linear limit function is relatively steep at this part of the footprint range. As a result vans might be stretched for solely the purpose of increasing the CO_2 target, leading to unnecessarily and undesirably large vehicles. On the other hand, lowering the slope, increases differences in cost impacts especially for the manufacturer groups that sell typical vans rather than pick-ups or all-terrain vehicles and that represent the majority of the market. This trade-off needs to be considered in the choice of slope value for the limit function for footprint.

For mass in running order as utility parameter, the slope of the 100% linear limit function is almost equal to the slope of the CO_2 legislation currently in place for LCVs. In order not to increase the room for gaming, a slope value of 100% or lower is recommendable. Around this 100% slope, the relative price increase (and additional manufacturer costs) is distributed most evenly over the manufacturers in the range.
In [Smokers 2006] a formula was derived to translate the weight increase ΔM into a CO_2-emission increase ΔCO_2 for constant vehicle performance. According to this formula, a 80% slope value should be enough of a disincentive for gaming. Taking all these arguments into account, a 80% to 100% slope range is recommendable.

Finally, it can be concluded that the estimated costs for meeting the 147 gCO_2/km target are significantly lower than expected in [Smokers 2009]. Reasons are the following:

- The overall average CO_2 emissions based on the 2010 LCV database are significantly lower than those estimated in [Smokers 2009]. This is partly caused by the levelling-off of the CO_2 emissions at the upper range of the utility values that are identified in this study. In [Smokers 2009], this phenomenon was far less severe as a result of estimating lacking CO_2 data to fill gaps in the 2007 database. It now seems that these estimated CO_2 emissions were overestimated. Since a significant part of the CO_2 data was lacking at the upper end of the utility range, the overestimated CO_2 values affected the overall average significantly.
- According to Figure 13 the sales share of Class III LCVs (with high CO_2 emissions) has decreased, while the shares of Class II and Class I (with relatively low CO_2 emissions) have increased. This phenomenon has led to a lower overall average CO_2 emission factor. As a result the average distance to target and therefore the costs have decreased.
- Finally, the cost efficiency of the technologies as determined for this study is in general higher than that of the same technologies mentioned in [Smokers 2009]. This is the result of new studies delivering new insights.

The relatively low additional manufacturer costs that are found in this study, lead to the conclusion that the 147 gCO_2/km target for LCVs is less challenging for the manufacturers than the 95 gCO_2/km target for passenger cars.

6 Passenger cars versus vans

6.1 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. In [TNO 2011] three approaches for such a combined target for passenger cars and vans were already studied in more detail.

The main conclusion from [TNO 2011] was such a combined target could be feasible. However, overall the evaluation of existing evidence with respect to the different approaches did 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, it was concluded that the subject would still benefit from closer scrutiny. Since the current study on LCVs provides more information on suitable limit functions for LCVs, a combined target for passenger cars and LCVs will be shortly described in this section.

Moreover comparing potential limit functions for LCVs and passenger cars will provide valuable insights in possible incentives for having vehicles type approved and registered as LCV rather than as a passenger car or the other way around.

6.2 Comparing potential limit functions of cars and vans

6.2.1 Mass

As can be seen in Figure 56, the mass-based 100% limit function for LCVs is steeper than that of passenger cars, although the CO_2 emissions of passenger cars and LCVs over the mass range appear to be similar. This slope difference is largely due to the fact that the 100% limit function is derived from a sales weighted best fit. For LCVs a large share of the vehicles are sold in Class III, whereas for the passenger cars, the share of heavy (mass>1700 kg) is limited. As a result the right part of the LCV sales cloud affects the best fit (and therefore the 100% limit function) more than the right part of the passenger cars sales cloud.

Moreover the depicted LCV limit function is higher than that of the passenger cars over (almost) the total mass range. This is mainly the result of a higher target for LCVs than for passenger cars.

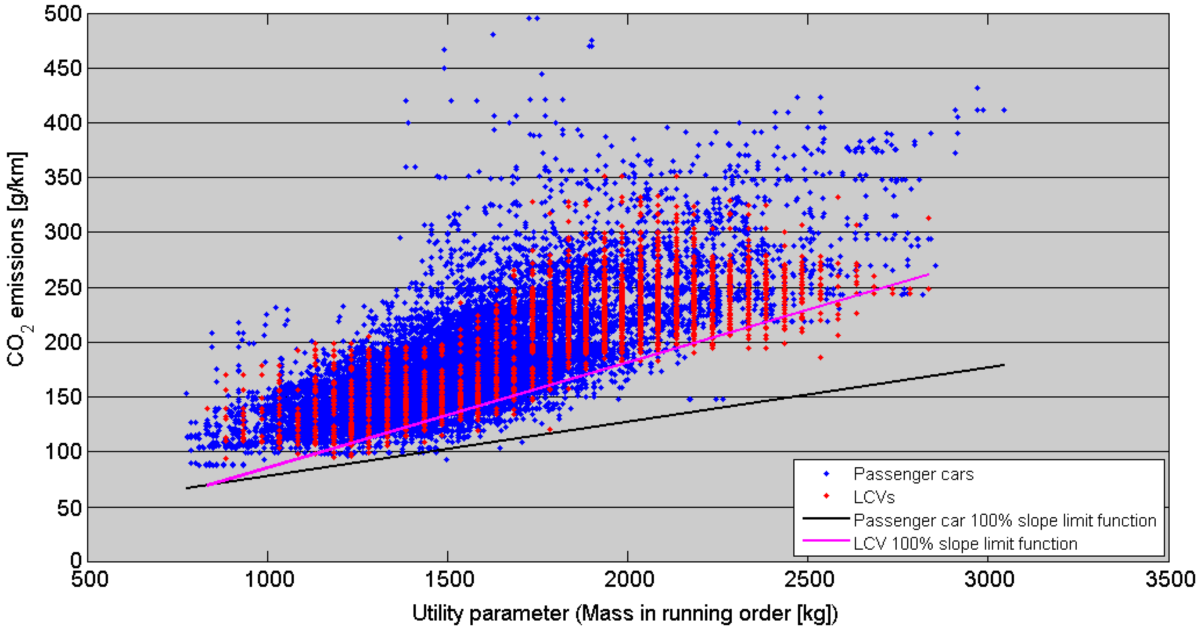

Figure 56 Comparison of 2010 LCV data and 2009 passenger car data, including the mass based 100% slope functions for both vehicle types.

6.2.1 Footprint

As described in section 5.5.1, the footprint-based 100% limit function for LCVs in non-linear. In contrary to the mass-based situation, the 100% limit function for LCVs is now below (or right from) the 100% limit function for passenger cars (Figure 57). This results from a generally higher footprint (relative to their mass) for LCVs than for passenger cars. For passenger cars, mass increases significantly with an increasing footprint, while for LCVs mass increases only limitedly with increasing footprint. Moreover the average footprint for LCVs is significantly greater than the average footprint for passenger cars, shifting the limit function to the right.

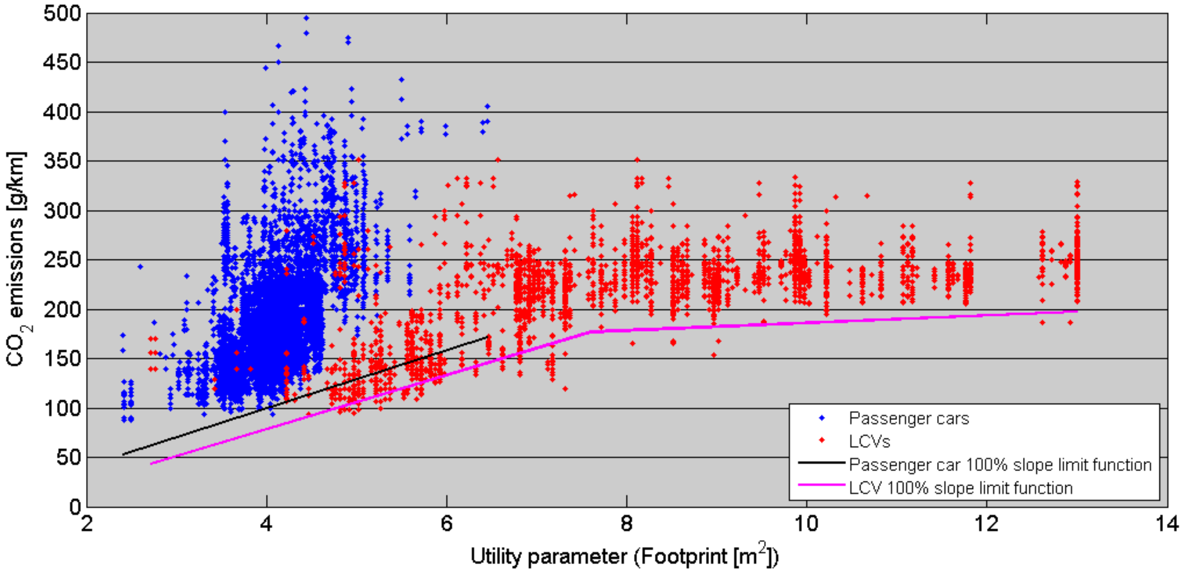

Figure 57 Comparison of 2010 LCV data and 2009 passenger car data, including the footprint based 100% slope functions for both vehicle types.

6.3 Marginal costs for meeting the passenger cars and LCV CO_2 targets

As mentioned in 6.1, a combined CO_2 target for LCVs and passenger cars was already studied in [TNO 2011]. However, potential limit functions and distributional impacts for LCVs were not available at that time. As concluded in chapter 5, the average additional manufacturer costs (and therefore the effort that manufacturers have to do to reduce CO_2 emissions) for meeting the 147gCO_2/km are lower than indicatively determined in previous studies.

Since the CO_2 reducing technologies that can be applied to LCVs are largely similar to the technologies for passenger cars, relatively limited technologies have to be applied to LCVs to meet the 2020 target. In case the target for passenger cars and LCVs would be combined, manufacturers selling both LCVs and passenger cars may decide to divide their effort over both vehicle types, which may delay the introduction of certain more advanced (but less cost effective) technologies. On the other hand, manufacturers of passenger cars that do not make LCVs would not have this advantage. Because of this competition advantage for manufacturers selling both passenger cars and LCVs makes it undesirable to combine the current targets that are planned for 2020.

6.3.1 Average LCV CO_2 emissions when marginal costs for meeting the 2020 LCV target are equal to those of the 2020 passenger cars target of 95gCO_2/km

In order to eliminate this potential competition advantage, the marginal costs for the LCV and passenger car target should be equal. In [TNO 2011] it was determined that the average marginal costs for meeting the 95 gCO_2/km passenger car target are € 91/g/km (Figure 58). For LCVs this average marginal cost level is reached at an overall average CO_2 emission of 113.3 gCO_2/km, which is significantly lower than the proposed target, which is 147 g/km.

This higher reduction also results in higher costs. The average additional manufacturer costs are € 2130, compared to estimated average additional manufacturer cost € 520 to € 545 to meet the 147 g/km target.

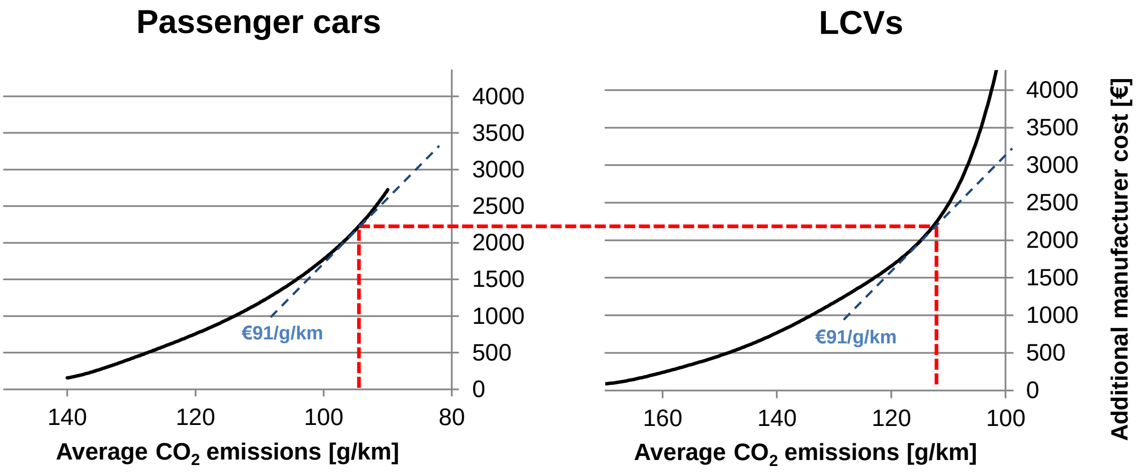

Figure 58 Average CO_2 emissions and additional manufacturer costs for the CO_2 reduction achieved at the marginal cost level of the 95g/km target for passenger cars.

6.3.2 Dissimilarities in the comparison of marginal costs for passenger cars and LCVs

This calculation is merely performed to indicate the reduction level that would be needed to reach an average CO_2 emission level that requires an equivalent amount of effort as the 95 g/km for passenger cars. As already indicated in 6.3.1 the calculation performed for LCVs is simplified as individual manufacturer's targets are not taken into account.

Another difference is that cost curves for LCVs and passenger cars were not generated simultaneously, leading to slightly other insights for defining CO_2 reduction potentials and costs of technologies. The differences between LCV cost curves in previous studies and this study (section 3.4) also partly occur between the [TNO 2011] cost curves for passenger cars and this study on LCVs, i.e.

- a different baseline year (2010 instead of 2002) and
- lower estimated costs for CO_2 reducing technologies.

As a result of these difference bases, the cost curves from [TNO 2011] and this study are not completely equivalent. Therefore, the average CO_2 emission level that requires an equivalent amount of effort as the 95 g/km for passenger cars (i.e. 113.3 g/km) is indicative.

6.4 Incentives for type approving and registering vehicles as LCV or passenger car

Recently COM Regulation No 678/2011 amending Directive 2007/46 (Annex I) came into place, which includes some criteria (e.g. loading space) to more clearly define the vehicle characteristics of the M1 and N1 categories. This will limit the overlap between M1 and N1 and will therefore limit potential CO_2 leakage from vehicles being accounted for in the incorrect CO_2 regulation scheme.

Even if this directive would, CO_2 leakage may still occur in the overlap between vans and cars. In case national authorities allow users to unrestrictedly use M1 vehicles for goods carriage or N1 vehicles for private use, certain financial incentives may be decisive in the type (M1 or N1) of vehicle to be acquired rather than the intended purpose of the vehicle.

Vehicles with certain characteristics (combination of CO_2 emissions and utility parameter value) can have a positive influence on the manufacturer's average CO_2 emissions in one category (M1 or N1) and a negative effect on the average CO_2 emissions of the other category. For instance, selling a N1 vehicle "between" the two mass-based limit functions (e.g. 2500kg and 200 gCO_2/km), will have a positive effect on the manufacturer's distance to target for LCVs, while an M1 vehicle with these characteristics will have a negative effect on the distance to the passenger cars target. Therefore a manufacturer may (financially) encourage users to (is available) acquire the N1 variant of a certain vehicle. In case this vehicle is used as a passenger, it is accounted for in the incorrect CO_2 regulation. If this occurs, manufacturers selling both passenger cars and LCVs will have to reduce less CO_2, resulting in CO_2 leakage.

Type approval authorities and national registration authorities play an important role in preventing such CO_2 leakage. It is therefore desirable to define unambiguous European wide guidelines for national registration authorities.

7 Impact of electric vehicle penetration

7.1 Introduction

This section addresses the potential market penetration of electric vehicles (EVs) in the light commercial vehicle fleet in the coming years, and it's impact on meeting the target of 147 g/km in 2020. The development of electric vehicles has only just started, and an increasing number of models are being offered by various vehicle manufacturers. Main focus of these developments is currently on the passenger car market, mainly because of the limitations of the batteries. However, a number of electric light commercial vehicles have recently come on the market (e.g. the Renault Kangoo Z.E., the Peugeot Partner Origin, the Mercedes-Benz Vito E-Cell), and there is a growing interest both in cities and with hauliers and couriers, as electric vehicles can have a positive impact on air quality and overall ecological footprint.

There are various options to design EVs, ranging from full battery electric vehicles (BEV) to vehicles that have both internal combustion engines (ICEs) and electric drives, in various configurations. Note that in this report, EVs are defined as vehicles with an electric drive powered by batteries that can be charged from the electricity grid. 'Conventional' hybrid electric vehicles may also have battery powered electric drive trains on board, but the batteries are only charged with the combustion engine.

In the current CO_2 regulations for cars and vans, only emissions of the vehicle itself are considered. Electric driving is thus considered to be zero emission, and any emissions of electricity production are ignored[10]. An increasing market share of these vehicles could thus have quite a significant impact on the efforts that vehicle manufacturers would have to put into reducing CO_2 emissions of ICEVs. For example, if the target is 147 g/km, manufacturers can bring one vehicle of 294 g/km on the market, or 147 vehicles of 148 g/km for each zero-emission vehicle that is being sold. The use of supercredits further enhances this effect.

These potential market uptake and impacts of electric LCVs on the CO_2 emission target of ICEVs will be investigated in the following paragraphs.

7.2 Electric LCVs: developments and costs

7.2.1 Vehicle categories

The Light Commercial Vehicle fleet is divided into three different segments:

- N1 Class I,
- N1 Class II and
- N1 Class III.

Class I are the lightest and smallest vehicles of this category, Class II are the larger and heavier LCVs. The characteristics of these categories are described in section 2.5.

Looking at electric vehicles, we can also distinguish 3 different types:

- Battery electric vehicles (BEV)
    - BEVs have an electric drive only which is driven by electricity stored in batteries. The batteries are charged from the electricity grid.
- Extended range electric vehicles (EREV)
    - EREVs have an electric drive train which is also powered by electricity in batteries. These batteries may be charged from the grid, but they can also be charged via an on-board combustion engine which runs on conventional petrol or diesel.
- Plug-in hybrid vehicles (PHEV)
    - PHEVs have both and electric drive train and a conventional drive train on board. The first can be charged both from the grid and with the combustion engine.

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[10] These emissions are included in the EU Emission Trading System, though.

BEVs can only drive on electricity from the grid, and will have zero vehicle emissions during type approval and in real world driving. Their main drawbacks are cost and driving range, both mainly due to high battery cost. Typical driving ranges are expected to be 75-100 miles (see section 3.3.4), depending on vehicle type, weight and driving pattern, and, of course, on-board battery capacity. It is expected that R&D regarding battery capacity and cost will continue, and will increase battery capacities and thus driving range over time, or, alternatively, reduce vehicle cost whilst keeping the driving range constant.
This technology is therefore, at least in the short to medium term, most suited for relatively light vehicles (N1 Class I or II), and/or to vehicles with limited mileages. City courier services and local (urban) goods distribution are markets where these vehicles could be expected to gain first market shares in the period until 2020. Market uptake In the heavier vehicle classes would probably be limited to relatively limited niche markets of vehicles in urban areas with relatively limited daily mileages.

EREVs and PHEVs have resolved the issues of the limited range by adding an internal combustion engine. EREVs are expected to typically achieve about 40-50 miles electric driving range (with fully charged batteries), PHEVs would probably have comparable or less electric range (20-30 miles), again depending on vehicle weight, driving pattern and battery capacity developments. Compared to BEVs, these EV types have the advantage of providing the driving ranges that customers are used to with ICEVs, probably even at (much) lower vehicle cost. They do not achieve zero emissions, though, as they will not always drive in full electric mode, and their cost per kilometre is higher when they drive on conventional fuels.
These technologies could be suited for all types of LCVs.

7.2.2 Expectations regarding electric vehicle uptake in the LCV fleet

Electric LCVs are still very much in their infancy, and it is difficult to predict at this time what their market uptake will be in the coming years. Current efforts of vehicle manufacturers seem to be aimed at passenger cars mainly, but the light commercial vehicle market can be expected to benefit from any technological progress made in that sector – albeit with some delay.

There are a number of key conditions and developments that can contribute to EV uptake in the LCV market:

- **Costs to consumers** (total cost of ownership) need to be competitive with conventional vehicles
- **Technological developments** of batteries and (fast) charging are needed, to increase battery capacities, reduce their cost and remove (or reduce) the current disadvantage of limited range and long charging times
- Availability of a **charging infrastructure**
- **Customer interest**

Demand is only likely to grow when costs are becoming competitive with that of conventional cars, or when potential buyers perceive other benefits. Relatively high cost of the batteries are currently the main barrier to both market supply and demand. This is the main reason that purchase cost of EVs is higher than that of conventional cars, and total cost of ownership (TCO) as well.

Cost reductions can be realised either due to technological developments (incremental improvements of existing technology or new, breakthrough changes) or due to government incentives and policies. The latter can be a direct financial incentive, for example a tax reduction or subsidy for EVs, free parking spaces, access to environmental zones or reduced tariffs in congestion charging, these may compensate part of the additional cost. Alternatively, the incentives may be more indirect, for example by subsidising battery R&D. The super credits in the CO_2 and cars and CO_2 and vans regulation of the EU are also examples of this kind of incentives, as they generate value for manufacturers that sell EVs.

Charging infrastructure is also seen as an important prerequisite for getting consumers interested in these vehicles. The LCV market might be able to benefit from the charging infrastructure that is being developed further in the coming years for the passenger car market. The speed of these developments is uncertain, though. Various countries and companies have set themselves targets regarding charging point availability, but these are not always met. There is still quite some uncertainty and debate regarding the number of charging points necessary in the future, and the potential role of fast charging and battery swap stations. The way forward will depend on cost developments and business model feasibility for the parties involved.

Customer interest in electric LCVs has been limited so far, mainly because of the high cost of these vehicles and the (resulting) lack of vehicles on the market. There has been some interest, though, with certain companies and (local) governments. Electric vehicles can be a means to meet internal (company) environmental targets, they can also be used as a marketing tool to attract attention and promote a ‘green image’, and demonstrate to customers and the public that the company is concerned about its environmental impact. Governments may opt for EVs in the context of green public procurement.

In view of all these uncertainties, quantifying market expectations for electric LCVs is currently a difficult task. There are certainly developments in this field, but sales number are still very low. It seems reasonable to expect, though, that EV development in the coming years will continue to focus on passenger cars, after which the technologies will also be applied in LCVs. This would then probably be in the lighter, Class I, segments at first, as these are (technologically) are similar to passenger cars, followed by the larger segments.

In order to develop a rough estimate of potential EV market uptake in the LCV fleet in the period until 2020, it was thus decided to start from scenarios for passenger cars, as developed for DG Clima in [Kampman 2011]. In this study, expectations regarding cost developments, government policies and consumer interest was taken into account. Three distinct scenarios were developed::

- Scenario 1: The ‘most realistic’ scenario, based on the data gathered from market research and expert opinion
- Scenario 2: ICE breakthrough, assuming that conventional vehicle technology would develop faster than expected in scenario 1, and cost and performance of electric vehicles would lag behind
- Scenario 3: EV breakthrough, where EVs (i.e. their batteries) were assumed to strongly reduce in cost from 2015 onwards.

The calculated market share of EVs in annual passenger car sales are shown in Table 28. Focussing at 2020, EVs are expected to gain about 3-10% market share in new sales, depending on the scenario. In all scenarios, PHEVs are expected to have the largest market share, with only small differences between BEV and EREV sales shares. This is due to the high battery cost: the additional cost of plug-in hybrids is assumed to be significantly lower than that of BEVs or EREVs. This cost difference can also be found in the cost estimates for these technologies in LCVs, see Table 9. These results also illustrate that the EV market shares are not expected to be very significant until 2015. Between 2015 after 2020, however, growth rates could increase strongly, especially in scenario 3.

The time lag between EV uptake in passenger cars and that in LCVs will probably depend quite strongly on the policy incentives for electric light commercial vehicles: if the incentives are in place, either at the supply or the demand side, vehicle manufacturers can be expected to put more effort into bringing these vehicles on the market than would be the case without these incentives.

Assuming that the sales shares of electric vehicles in the Class I segment lag about 2 years behind that of large diesel passenger cars, Class II lags another 2 years behind and Class III another year, we can now derive three rough scenarios for electric LCV market uptake in 2020. Results are shown in Table 29.

Table 28 EU-27 annual car sales, expressed in % of each vehicle type in the total sales (Source: [Kampman 2011])

Scenario 1	**2010**	**2015**	**2020**	**2025**	**2030**
Conventional	100%	99%	95%	74%	48%
PHEV	0%	1%	3%	16%	30%
EREV	0%	0%	1%	5%	11%
BEV	0%	0%	1%	5%	11%
Scenario 2	**2010**	**2015**	**2020**	**2025**	**2030**
Conventional	100%	99%	97%	90%	80%
PHEV	0%	0%	2%	7%	13%
EREV	0%	0%	1%	2%	3%
BEV	0%	0%	0%	2%	3%
Scenario 3	**2010**	**2015**	**2020**	**2025**	**2030**
Conventional	100%	99%	90%	46%	16%
PHEV	0%	1%	6%	31%	44%
EREV	0%	0%	2%	13%	22%
BEV	0%	0%	2%	10%	18%

Clearly, these are very rough estimates, based on many assumptions. However, since the three scenarios cover a large range of development options (from pessimistic to optimistic), it seems reasonable to expect that these scenarios cover the playing field of future LCV development – sufficiently accurate to provide a basis for the assessments in the next section.

Table 29 EU-27 market share of the various electric vehicle types in Light Commercial Vehicle sales, for three scenarios, in 2020

	Class I			**Class II**			**Class III**		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
PHEV	3.2%	1.8%	5.3%	1.6%	1.0%	2.3%	0.8%	0.7%	0.9%
EREV	1.1%	0.5%	1.9%	0.6%	0.3%	0.8%	0.3%	0.2%	0.3%
EV	1.0%	0.4%	1.5%	0.5%	0.2%	0.7%	0.2%	0.1%	0.3%
Total	**5.2%**	**2.7%**	**8.7%**	**2.6%**	**1.6%**	**3.9%**	**1.3%**	**1.0%**	**1.5%**

7.2.3 Potential impacts on average emissions of the new fleet

In the current CO_2 and vans regulations, the EVs count as zero-emission vehicles if they emit less than 50 gCO_2/km. This means that if the sales share of these vehicles increases, the conventional, ICE light commercial vehicles are allowed to emit more – as long as the average target is met. As shown in the introduction of this chapter, this means that if the target is 147 g/km, manufacturers can bring one vehicle of 294 g/km on the market, or 147 vehicles of 148 g/km, for each zero-emission vehicle that is being sold.

In the period between 2014 and 2017, the regulation uses so-called super credits, to provide specific incentives to these very low-emission vehicles. In 2014 and 2015, each zero-counting vehicle sold may be counted as 3.5 towards the target. This factor reduces to 2.5 in 2016 and 1.5 in 2017. This incentive is intended to be temporary, so no further super credits are specified after 2017. The use of super credits further increases the CO_2 emissions allowed in the ICE fleet.

The impact of an EV market share on the average CO_2 emissions of the ICEs sold can now be calculated, for the range of EV shares predicted in the three scenarios. Results are shown in Figure 59 below for the situation in 2020, for a number of super credits. Clearly, the impact can be quite significant when EV shares increase, especially with super credits in force.

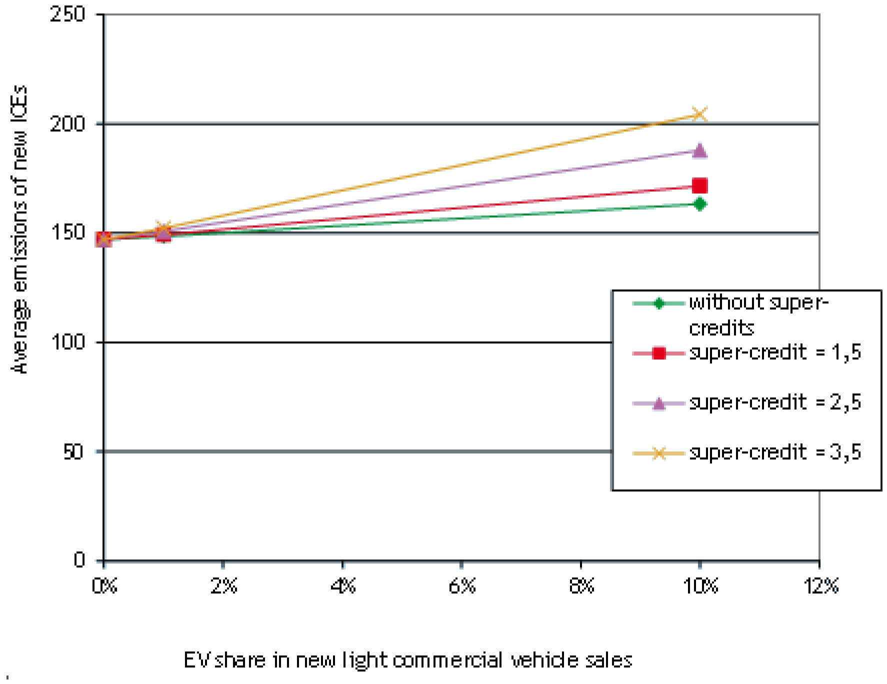

Figure 59 Impact of increasing EV shares on the average emission of new conventional LCVs, in 2020

A more generic graph of the impact of zero emission vehicle sales and super credits is given below (Figure 60). These data indicate the potential increase of average ICE emissions, in percentage increase above the target. Without super credits, a 10% EV sales share would mean that ICE emissions are allowed to be somewhat more than 10% above the overall target. If a super credit is in force whilst EV sales shares are so high, the ICE emissions could be almost 40% above the average target[11].

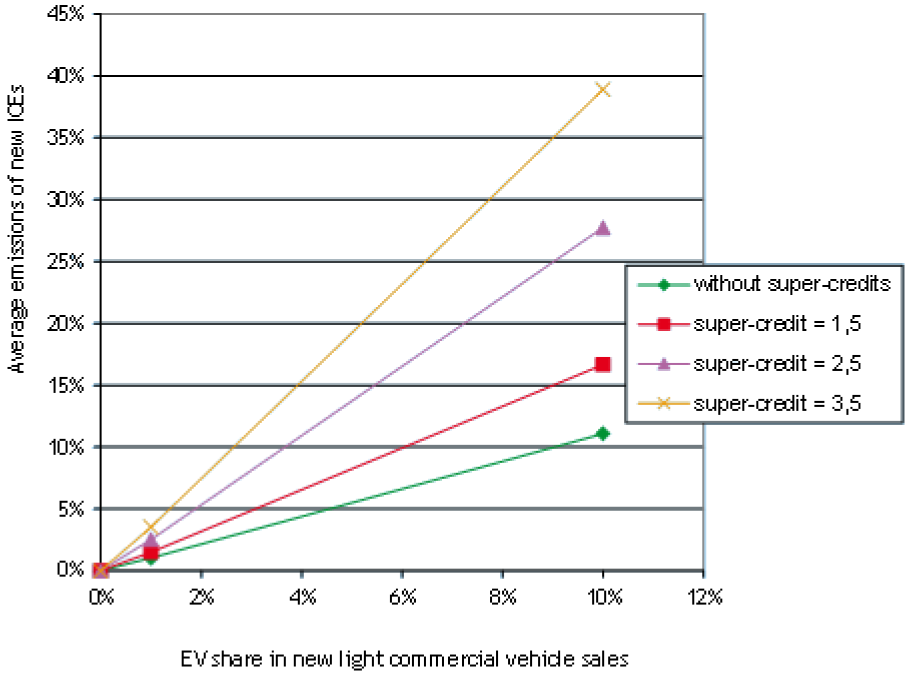

Figure 60 Impact of increasing EV shares on the average emission of new conventional LCVs, in 2020

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[11] Note that under the current regulation, this combination of high EV share and high super credit is extremely unlikely, as EV sales are not expected to pick up before 2015, not even in the most optimistic case.

Apart from the potential impact as a result of super-credits, it is very important to assess if manufacturers are likely to actively market EVs as a strategy to meet their CO_2 targets in view of the cost effectiveness of selling EVs relative to reducing CO_2 of ICEVs.

Applying the reductions as listed in Table 9 to the average emissions per segment results in average CO_2 emissions of EVs as depicted in Table 30. By introducing such low CO_2 emission vehicles in the fleet, the average emissions of ICEVs may be lowered less to still achieve an average of 95 g/km.

Table 30 Scenario's indicating the share of EVs (FEV, EREV and PHEV) per LCV segment in 2020

Segment average CO_2 emissions of various EV types	**Class I**	**Class II**	**Class III**
Average 2010 CO_2 emissions	120.2	162.4	223.3
PHEV (25% CO_2 reduction)	90.1	121.8	167.5
EREV (40% CO_2 reduction)	72.1	97.5	134.0
FEV (100% CO_2 reduction)	0.0	0.0	0.0

When these emissions are combined with the market shares (Table 29) the average CO_2 emissions of ICEVs become 153.1 g/km, 150.0 g/km and 157.5 g/km respectively for scenario 1, 2 and 3 (Table 31). As a result the average additional manufacturer costs for ICEV are lowered to € 384, € 462 and € 286, while this was € 545 for meeting the 147 g/km target without EVs. However as the cost for manufacturing EVs are high (between € 8000 and € 10000 per EV, depending on the shares of different EV types), the additional manufacturer costs for meeting 147 g/km are higher if EV are included in the sales than if they are not. Even with a super-credit level of 3.5, selling EVs does not seem to be a cost effective measure to reduce the average CO_2 emissions (Table 32).

It cannot be concluded that manufacturers are not likely to manufacturer N1 EVs. For some end users, the investment of purchasing an EV at a (probably) relatively high price could be returned by the relatively low user costs, as electricity is a relatively low cost energy carrier. Moreover such EVs can be fiscally attractive, depending on national policy.

Table 31 Result of the penetration of low emission vehicles on the average ICEV CO_2 emissions to meet 147 g/km and the average additional manufacturer costs (super credit = 1)

Utility parameter = mass Slope = 100% Super credits = 1	**Baseline scenario**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Scenario characteristics				
Sales share PHEVs	0.0%	5.6%	3.5%	8.5%
Sales share EREVs	0.0%	2.0%	1.0%	3.0%
Sales share FEVs	0.0%	1.7%	0.7%	2.5%
Total sales share EVs	0.0%	9.3%	5.2%	14.0%
Average CO_2 emissions per EV [g/km]	-	87	93	83
Scenario impact on ICEVs				
Sales share of ICEVs	100%	90.7%	94.8%	86.0%
Average ICEV emissions to reach 147 g/km [g/km]	147	153.1	150.0	157.5
Results				
Average additional manufacturer cost per EV [€]	-	9794	8094	9540
Average ICEV costs to meet target ICEV [€]	545	384	462	286
Average overall costs to meet 147 g/km target [€]	**545**	**1259**	**859**	**1582**

Table 32 Result of the penetration of low emission vehicles on the average ICEV CO_2 emissions to meet 147 g/km and the average additional manufacturer costs (super credit = 3.5)

Utility parameter = mass Slope = 100% Super credits = 3.5	**Baseline scenario**	**Scenario 1**	**Scenario 2**	**Scenario 4 (TNO)**
Scenario characteristics				
Sales share FEVs	0.0%	5.4%	3.5%	8.1%
Sales share PHEVs	0.0%	1.9%	1.0%	2.9%
Sales share EREVs	0.0%	4.9%	2.1%	7.1%
Total sales share EVs	0.0%	12.3%	6.5%	18.1%
Average CO_2 emissions per EV [g/km]	-	87.5	93.1	82.6
Scenario impact on ICEVs				
Sales share of ICEVs	100%	87.7%	93.5%	81.9%
Maximum ICEV emissions to reach 95 g/km [g/km]	147	155.3	150.8	161.2
Results				
Average additional manufacturer cost per EV [€]	-	9794	8094	9540
Average ICEV costs to meet target ICEV [€]	545	320	438	198
Average overall costs to meet 95 g/km target [€]	**545**	**1483**	**937**	**1888**

7.3 Conclusions

In the coming years and decades, electric vehicles are likely to enter the Light Commercial Vehicle fleet. The may be either battery electric vehicles, i.e. vehicles solely powered by batteries and an electric motor, or hybrid types, which typically have a full electric driving range of several tens of kilometres, but can also be powered with an internal combustion engines.

The number of electric LCVs on offer and in the EU fleet is still very limited, and large scale market uptake still seems to be quite far away. However, the electric light commercial vehicle market can be expected to benefit from efforts currently put into the development of electric passenger cars, and from the incentives provided in the CO_2 and vans regulation. Key conditions for EV uptake in the LCV market are cost, technological developments, availability of charging infrastructure and consumer interest. It is likely that these conditions will be met first in a number of niche markets, and in the lighter LCV categories (Class I).

Various electric LCV market uptake scenarios were developed, using recent forecast scenarios for electric passenger cars as a starting point. These take into account expectations and uncertainties regarding vehicle and driving cost, driving range, consumer interest, etc. Key assumptions were that the uptake of electric LCVs follows that of electric passenger cars with a time lag, and that the Class I LCV will be easier to 'electrify' than the heavier LCV classes. The resulting scenarios predict the electric vehicle share of new LCV sales in 2020 to be between 2.7 to 8.7% in Class I, 1.6-3.9% in Class II and 1.0 – 1.5% in Class III LCVs. More than half of these cars are expected to be plug in hybrid electric vehicles.

As the sales of EVs count as zero-emission in the current CO_2 and vans regulation if they emit less than 50 gCO_2/km, these sales will impact the emissions of the internal combustion engine vehicles in the LCV fleet. A 10% share of zero-emission vehicles in the sales would allow conventional vehicles to emit somewhat more than 10% more than the target on average, whilst still meeting the target. This impact is enhanced during the years that super-credits are in force.

Currently the costs for manufacturing N1 LCVs are so high that it is not likely that manufacturers will actively market EVs as a strategy to meet their CO_2 targets. However, as for some end users, the investment of purchasing an EV at a (probably) relatively high price could be returned by the relatively low user costs, as electricity is a relatively low cost energy carrier. Moreover such EVs can be fiscally attractive, depending on national policy.

8 Possible knock-on consequences resulting from price LCV increase

8.1 Introduction

Previous sections have produced estimates of expected changes in emission factors and purchase costs as a result of limiting CO_2 emissions of N1 vehicles to a new sales fleet average of 147g/km by 2020 (down from the currently established limit of 175g/km by 2017). Apart from the already established changes to individual vehicles, the composition of the fleet could also be expected to change because of changes in relative costs of procurement and usage. User preferences for certain types of vehicles and the utility they generate can cause shifts in purchase behaviour.

This section will estimate the expected shift between light duty vehicles and either passenger cars or heavy duty vehicles as a result of the increased purchase price and reduced fuel consumption caused by setting an emission target of 147g/km by 2020.

8.2 Modelling with TREMOVE

8.2.1 Model input

In this section, these changes are evaluated using the TREMOVE model (a slightly modified version 3.5b). This version of the model contains the assumptions of the 2011 White Paper for Transport, including a 2025 emission target for passenger cars of 95g/km. The original 3.4 and 3.5 versions also had a 2025 target for LDV/van of 135g/km in the baseline, but this was removed for the sake of the simulation to be done in the present report.

An overview of the main relevant assumptions:

- Limit values for N1 type vehicles are 175g/km for 2017 and 147g/km for 2020, matching the terms used in the rest of this 3rd service request.
- In the current study, cost functions were only created for diesel N1 vehicles, further split in 3 classes. In TREMOVE, gasoline powered N1 vehicles are an important part of new sales (up to 1/3), but there is only one size class. The distinction made in TREMOVE is on the use of the vehicle, in this case either passengers (vans) of freight (light duty vehicles of LDV).
- The applied cost functions for the TREMOVE run use mass as the utility parameter, with a 100% slope. Cost functions for the intermediate target of 175g were not changed.
- To aggregate overall size classes, the average mass was used to determine the required emission savings and extra cost to so. The relative cost increase to reach 147g was calculated to be 2.08% in comparison to the cost for 2017 (a 175g/km vehicle).
- Relative cost increase for gasoline powered N1 vehicles was estimated using the equivalent ratio to reach 175g in 2017. This ratio was 1.82, so the relative cost increase for gasoline powered N1 vehicles is set at 3.78%.
- Vans and LDVs have the same costs and emission savings per fuel class – this implies the average mass of an N1 used for transport of passengers and for freight is equal.
- Costs remain the same after 2020, ergo no AMI is assumed.

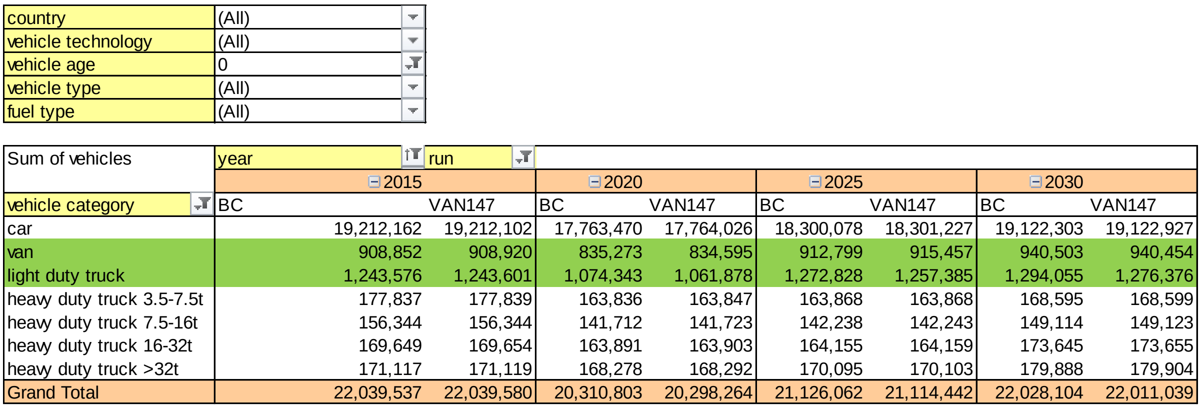
The model was run for the EU27, with scenario modifications to model parameters RFACTORACEA and RPCS_INCREASE_2012.

8.2.2 Model output

Evolutions within the N1 class

Initially, in the transition period of the new regulation (2017-2020), there is a slight drop of 0.7% (for 2020) in the sales of N1 vehicles, both for passenger and freight transport. Table 33 shows the overall projections.

Table 33 New sales of road transport vehicles as a result of 147g/km regulation

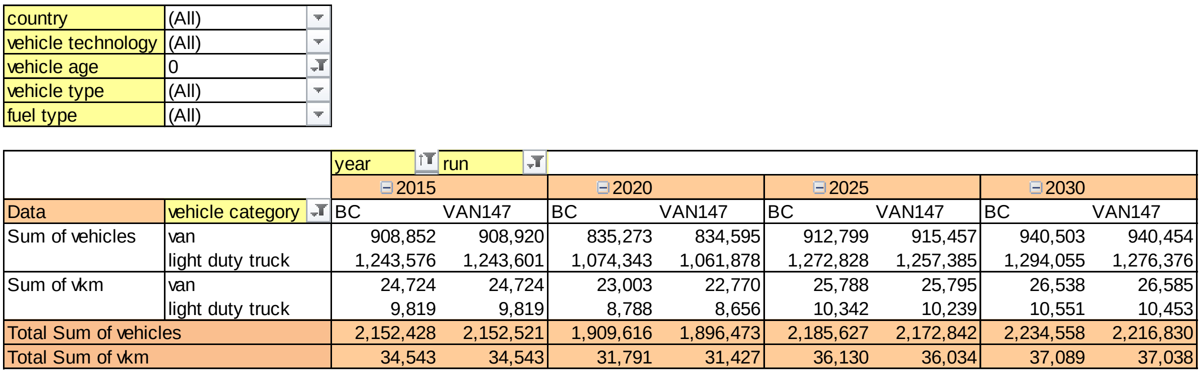


country	(All)
vehicle technology	(All)
vehicle age	0
vehicle type	(All)
fuel type	(All)

Sum of vehicles	year	run						
	⊟2015		⊟2020		⊟2025		⊟2030	
vehicle category	BC	VAN147	BC	VAN147	BC	VAN147	BC	VAN147
car	19,212,162	19,212,102	17,763,470	17,764,026	18,300,078	18,301,227	19,122,303	19,122,927
van	908,852	908,920	835,273	834,595	912,799	915,457	940,503	940,454
light duty truck	1,243,576	1,243,601	1,074,343	1,061,878	1,272,828	1,257,385	1,294,055	1,276,376
heavy duty truck 3.5-7.5t	177,837	177,839	163,836	163,847	163,868	163,868	168,595	168,599
heavy duty truck 7.5-16t	156,344	156,344	141,712	141,723	142,238	142,243	149,114	149,123
heavy duty truck 16-32t	169,649	169,654	163,891	163,903	164,155	164,159	173,645	173,655
heavy duty truck >32t	171,117	171,119	168,278	168,292	170,095	170,103	179,888	179,904
Grand Total	22,039,537	22,039,580	20,310,803	20,298,264	21,126,062	21,114,442	22,028,104	22,011,039

In later years, it can be noticed that sales of N1 for passenger transport are much less affected by the changes in purchase and usage cost than those intended for freight. The reason lies in the annual mileage values calculated by TREMOVE. For vans, this value for new vehicles is around 28000km. For Light commercial vehicles, TREMOVE gives average annual mileage for new vehicles of only 8000km. This results in a much higher weight for the increase in purchase costs for the low-usage LDVs, which profit a lot less from the lower fuel consumption the 147g/km regulation entails, in comparison to high-mileage vans. It should be noted that this difference in annual mileage between vans and LDVs is large, probably too large to be realistic. This is due to unlikely values for fleet composition, introduced in TREMOVE v3.3 with the inclusion of the FLEETS[12] project.
As a result, the internal evolution of van vs. LDV can best be disregarded. The result of the N1 group as a whole is still valid though.

Table 34 New vehicles and their mileage



country	(All)
vehicle technology	(All)
vehicle age	0
vehicle type	(All)
fuel type	(All)

		year	run						
		⊟2015		⊟2020		⊟2025		⊟2030	
Data	vehicle category	BC	VAN147	BC	VAN147	BC	VAN147	BC	VAN147
Sum of vehicles	van	908,852	908,920	835,273	834,595	912,799	915,457	940,503	940,454
	light duty truck	1,243,576	1,243,601	1,074,343	1,061,878	1,272,828	1,257,385	1,294,055	1,276,376
Sum of vkm	van	24,724	24,724	23,003	22,770	25,788	25,795	26,538	26,585
	light duty truck	9,819	9,819	8,788	8,656	10,342	10,239	10,551	10,453
Total Sum of vehicles		2,152,428	2,152,521	1,909,616	1,896,473	2,185,627	2,172,842	2,234,558	2,216,830
Total Sum of vkm		34,543	34,543	31,791	31,427	36,130	36,034	37,089	37,038

Evolutions to and from the N1 class

There is no real shift from light duty vehicles to either cars or heavy duty vehicles. The 13,143 fewer N1 sales in 2020 (mainly in LDV) would not shift as such to heavy duty vehicles or passenger cars. What does happen is a very slight overall increase of transport demand (vkm) as a result of the lower overall cost (the cost decrease due to lower fuel consumption outweighs the purchase price increase in N1, thus transport as a whole becomes cheaper).

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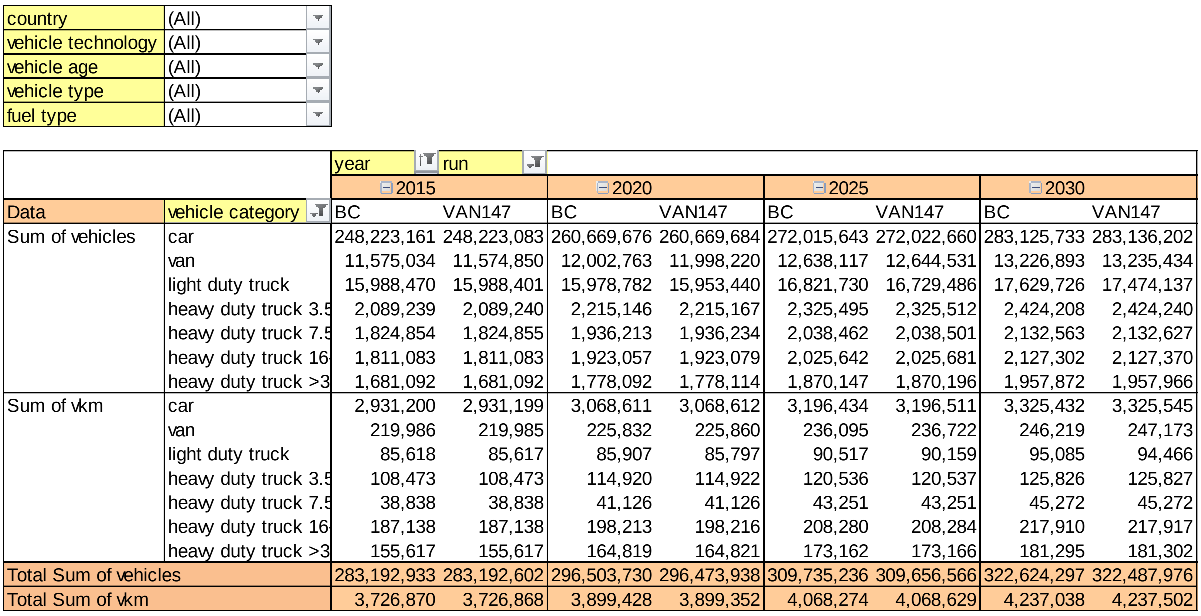
[12] FLEETS: http://www.e3mlab.ntua.gr/reports/Fleets_Final_Report.pdf



country	(All)
vehicle technology	(All)
vehicle age	(All)
vehicle type	(All)
fuel type	(All)

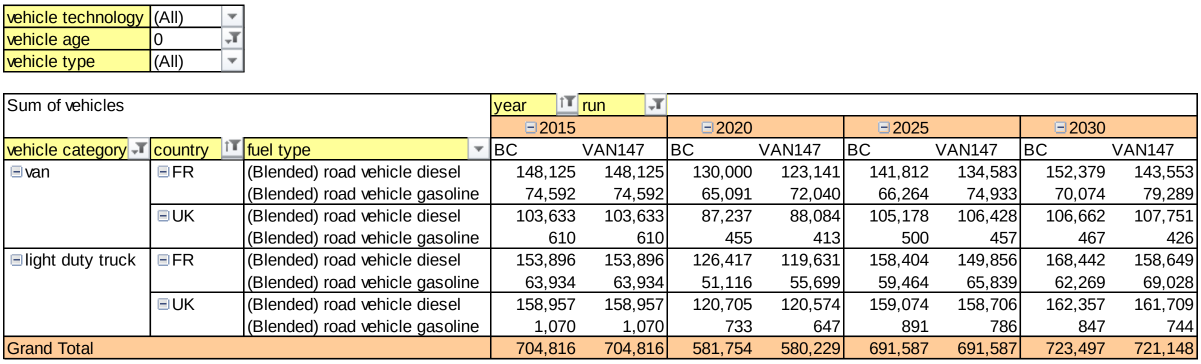
		year / run							
		2015		2020		2025		2030	
Data	vehicle category	BC	VAN147	BC	VAN147	BC	VAN147	BC	VAN147
Sum of vehicles	car	248,223,161	248,223,083	260,669,676	260,669,684	272,015,643	272,022,660	283,125,733	283,136,202
	van	11,575,034	11,574,850	12,002,763	11,998,220	12,638,117	12,644,531	13,226,893	13,235,434
	light duty truck	15,988,470	15,988,401	15,978,782	15,953,440	16,821,730	16,729,486	17,629,726	17,474,137
	heavy duty truck 3.5	2,089,239	2,089,240	2,215,146	2,215,167	2,325,495	2,325,512	2,424,208	2,424,240
	heavy duty truck 7.5	1,824,854	1,824,855	1,936,213	1,936,234	2,038,462	2,038,501	2,132,563	2,132,627
	heavy duty truck 16	1,811,083	1,811,083	1,923,057	1,923,079	2,025,642	2,025,681	2,127,302	2,127,370
	heavy duty truck >3	1,681,092	1,681,092	1,778,092	1,778,114	1,870,147	1,870,196	1,957,872	1,957,966
Sum of vkm	car	2,931,200	2,931,199	3,068,611	3,068,612	3,196,434	3,196,511	3,325,432	3,325,545
	van	219,986	219,985	225,832	225,860	236,095	236,722	246,219	247,173
	light duty truck	85,618	85,617	85,907	85,797	90,517	90,159	95,085	94,466
	heavy duty truck 3.5	108,473	108,473	114,920	114,922	120,536	120,537	125,826	125,827
	heavy duty truck 7.5	38,838	38,838	41,126	41,126	43,251	43,251	45,272	45,272
	heavy duty truck 16	187,138	187,138	198,213	198,216	208,280	208,284	217,910	217,917
	heavy duty truck >3	155,617	155,617	164,819	164,821	173,162	173,166	181,295	181,302
Total Sum of vehicles		283,192,933	283,192,602	296,503,730	296,473,938	309,735,236	309,656,566	322,624,297	322,487,976
Total Sum of vkm		3,726,870	3,726,868	3,899,428	3,899,352	4,068,274	4,068,629	4,237,038	4,237,502

Diesel-gasoline interactions

This drop also incorporates a move from diesel to gasoline powered vehicles. This is the net effect of a transition to the more expensive fuel type (fuel cost per km decreases, so the importance of this cost in the total goes down), which differs per country. Countries where diesel is relatively cheaper, like France, or Belgium, see a transition to gasoline, whereas the opposite holds for countries like the UK and Denmark, which have higher diesel prices.

The share of fuel cost in TCO decreases as fuel efficiency increases. Ergo, a lower fuel price, as is the case for diesel, would contribute less to the attractiveness of diesel vehicles when consumption is low than when consumption is higher. Ceteris paribus, this would mean that the relative attractiveness of a gasoline vehicle increases, and their share in total vehicle sales would increase. This is demonstrated in Table 35.

Table 35 Diesel-gasoline interaction in France and the UK, new sales



vehicle technology	(All)
vehicle age	0
vehicle type	(All)

Sum of vehicles			year / run							
			2015		2020		2025		2030	
vehicle category	country	fuel type	BC	VAN147	BC	VAN147	BC	VAN147	BC	VAN147
van	FR	(Blended) road vehicle diesel	148,125	148,125	130,000	123,141	141,812	134,583	152,379	143,553
		(Blended) road vehicle gasoline	74,592	74,592	65,091	72,040	66,264	74,933	70,074	79,289
	UK	(Blended) road vehicle diesel	103,633	103,633	87,237	88,084	105,178	106,428	106,662	107,751
		(Blended) road vehicle gasoline	610	610	455	413	500	457	467	426
light duty truck	FR	(Blended) road vehicle diesel	153,896	153,896	126,417	119,631	158,404	149,856	168,442	158,649
		(Blended) road vehicle gasoline	63,934	63,934	51,116	55,699	59,464	65,839	62,269	69,028
	UK	(Blended) road vehicle diesel	158,957	158,957	120,705	120,574	159,074	158,706	162,357	161,709
		(Blended) road vehicle gasoline	1,070	1,070	733	647	891	786	847	744
Grand Total			704,816	704,816	581,754	580,229	691,587	691,587	723,497	721,148

Given the current evolution of fuel prices (a relatively higher increase in diesel prices), the evolution in countries like the UK may be more representative for the future.

8.3 Conclusions

The main conclusion to be drawn from this modelling exercise is that no significant shifts are expected from N1 vehicles to other classes as a result of the expected retail price increase. Still, the increased purchase price is likely to have an impact on the total amount of N1 vehicles sold. N1 vehicle sales are expected to drop by around 0.7% in 2020 and 0.8% in 2030. In a business-oriented segment as N1 is, very minor changes in costs do not cause major changes in purchase behaviour.

Furthermore a very slight overall increase of transport demand (vkm) is observed as a result of the lower overall cost (the cost decrease due to lower fuel consumption outweighs the purchase price increase in N1, thus transport as a whole becomes cheaper).

This drop also incorporates a move from diesel to gasoline powered vehicles. This is the net effect of a transition to the more expensive fuel type (fuel cost per km decreases, so the importance of this cost in the total goes down), which differs per country. Countries where diesel is relatively cheaper, like France, or Belgium, see a transition to gasoline, whereas the opposite holds for countries like the UK and Denmark, which have higher diesel prices. The share of fuel cost in TCO decreases as fuel efficiency increases. Ergo, a lower fuel price, as is the case for diesel, would contribute less to the attractiveness of diesel vehicles when consumption is low than when consumption is higher. Ceteris paribus, this would mean that the relative attractiveness of a gasoline vehicle increases, and their share in total vehicle sales would increase.

9 Fuel cost savings in relation to additional costs resulting from the 2020 target

9.1 Introduction

Reducing the CO_2 emissions from vehicle is the result of a reduced fuel consumption. From a societal perspective, part of the price increase resulting from the additional manufacturer cost made to lower CO_2 emissions, can therefore be compensated during the lifetime of a vehicle. For the end user this means that even if the retail price of LCVs increases because of the CO_2 target set, the total cost of ownership (TCO) may end up lower than without applying the CO_2 reducing technologies to meet the CO_2 target of 95 g/km.

9.2 Methodology

In order to assess the net effect of the regulation on the TCO, the fuel cost savings are determined per g/km CO_2 reduction relative to a vehicle within a certain class with the average CO_2 emissions of that class.

9.2.1 Vehicle lifetime and annual mileage

For the lifetime of the vehicle 13 years is assumed. Moreover the LCV is assumed to have an annual mileage of 23500 km/year.

9.2.2 Fuel price

Fuel prices (including and excluding taxes) are closely related to the oil price. The relations in this study are taken from the SULTAN tool that was developed for project: “EU Transport GHG: Routes to 2050” (Figure 61). Since the fuel price significantly affects the TCO by means of fuel cost savings, the TCO impact is determined for various fuel prices (and therefore for oil prices).

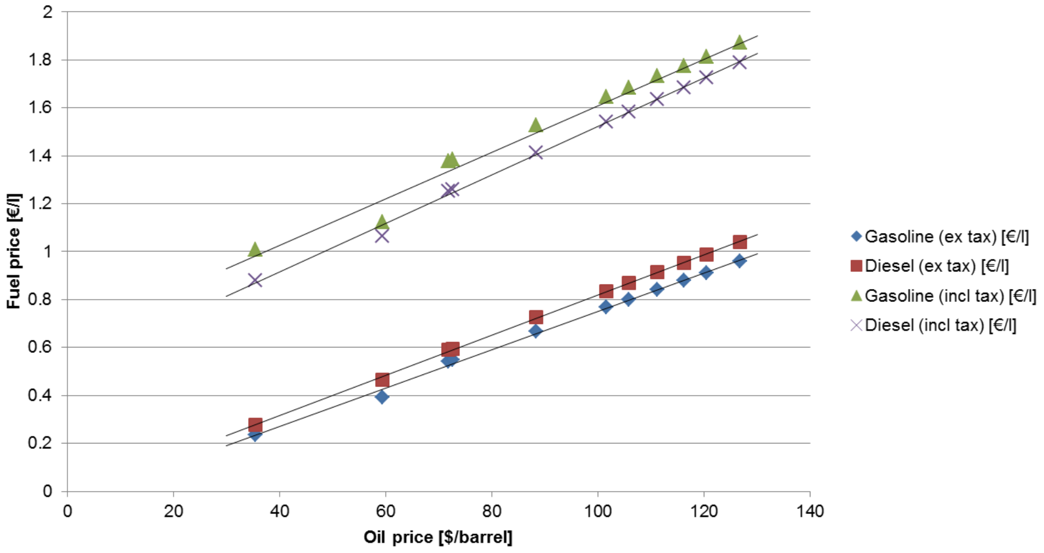


Figure 61 Relation between oil and fuel prices (source: SULTAN tool developed for project: “EU Transport GHG: Routes to 2050”)

9.2.3 Tax rate

An average European VAT rate of 21% is assumed. This value is consistent with the relations shown in Figure 61. For the average European excise tax for petrol and diesel respectively € 0.58/l and € 0.44/l is assumed. As a result the relations between the oil and fuel prices (including and excluding VAT and taxes) are:

*Gasonline price (ex tax) [€/l]= 0.0080 * Oil price [€/l] - 0.051*
*Diesel price (ex tax) [€/l]= 0.0084 * Oil price [€/l] - 0.020*
*Gasonline price (incl tax) [€/l]= (1 + VAT) * Gasonline price (ex tax) [€/l] + gasoline tax [€/l]*
*Diesel price (incl tax) [€/l]= (1 + VAT) * Diesel price (ex tax) [€/l] + diesel tax [€/l]*

with

VAT= 21%
gasoline tax= € 0.58/l
diesel tax= € 0.44/l.

9.2.4 Translation of type approval into real world emissions

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 was derived for use in assessments of net CO_2 emission reductions and fuel cost savings over the lifetime of a vehicle. This factor is also used in the calculation to translate the TA emissions (on which the 95 g/km target is based) into RW emissions. 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.

9.2.5 Translation of additional manufacturer cost into price increase

For assessing the effect of the 95 g/km target on the TCO for the end consumer, the price increase resulting from the target has to be determined. As explained in section 5.3.7, the relative retail price increase is calculated by multiplying the additional manufacturer costs by a mark-up factor of 1.11, according to [Smokers 2009], and dividing that by the average retail price calculated from the 2010 database.
In the calculation, the fuel price is divided by this factor 1.11 in order to obtain a level equivalent to the manufacturer costs.

9.2.6 Discount rate

Finally a discount rate of 4% is used to account for lost interest revenue on fuel costs. For consumers an interest rate of 8% is used.

9.2.7 List of assumptions

In Table 36, a list of assumptions is presented, used to determine the effect of the 147 g/km target on the TCO for the end user.

Table 36 List of assumptions used to determine the effect of the 147 g/km target on the TCO for the end user.

Assumptions	**Diesel**
Vehicle lifetime [years]	13
Average annual mileage [km/year]	23500
CO_2 content [gCO_2/l]	2609
2010 average CO_2 emissions [g/km]	181
2017 average CO_2 emissions [g/km]	175
2020 average CO_2 emissions [g/km]	147
Investment relative to 2010 [€]	545
Investment relative to 2017 [€]	456
Lifetime reduced CO_2 relative to 2010 [tonnes]	12.2
Lifetime reduced CO_2 relative to 2017 [tonnes]	10.2
RW/TA	1.195
Interest rate [-]	4%
End user interest rate [-]	8%
Mark-up factor*	1.11
Average 2010 sales price [€]	24356
Average 2020 sales price [€]	24960

*Retail price increase/manufacturer costs

9.3 Results

9.3.1 Consumer perspective

In Table 37, the end user TCO results of the 147 g/km target for 2020 are presented relative to the situation in 2010. As can be concluded from this table, the break even period for the end user is only 0.9 to 1.3 years, depending on the oil price, which is well within the vehicle lifetime.

Given that an average CO_2 emissions level of 175 g/km (which is lower than the 2010 average) is already set for 2017, the fuel cost savings relative to this 2017 target are lower than relative to the 2010 target (Table 38). However, as the additional manufacturer costs and the resulting price increase (end user's additional investment) is also lower (as shown in Table 36), the break even periods are very similar (Figure 62).

Table 37 End user TCO results of the 147 g/km target for 2020 relative to the situation in 2010

Oil price [$/barrel]	90	100	110	120	130	140
Diesel price (incl taxes) [€/l]	1.42	1.52	1.62	1.73	1.83	1.93
Annual fuel savings [€ per g/km]	15.3	16.4	17.5	18.6	19.7	20.8
NPV of lifetime fuel savings [€]	121	130	138	147	155	164
Lifetime fuel cost savings [€]	4040	4329	4617	4906	5194	5483
End user break even period [years]	1.3	1.2	1.1	1.1	1.0	0.9

Table 38 End user TCO results of the 147 g/km target for 2020 relative to the 175g/km situation in 2017

Oil price [$/barrel]	90	100	110	120	130	140
Diesel price (incl taxes) [€/l]	1.42	1.52	1.62	1.73	1.83	1.93
Annual fuel savings [€ per g/km]	15.3	16.4	17.5	18.6	19.7	20.8
NPV of lifetime fuel savings [€]	121	130	138	147	155	164
Lifetime fuel cost savings [€]	3363	3603	3843	4083	4324	4564
End user break even period [years]	1.3	1.2	1.1	1.1	1.0	0.9

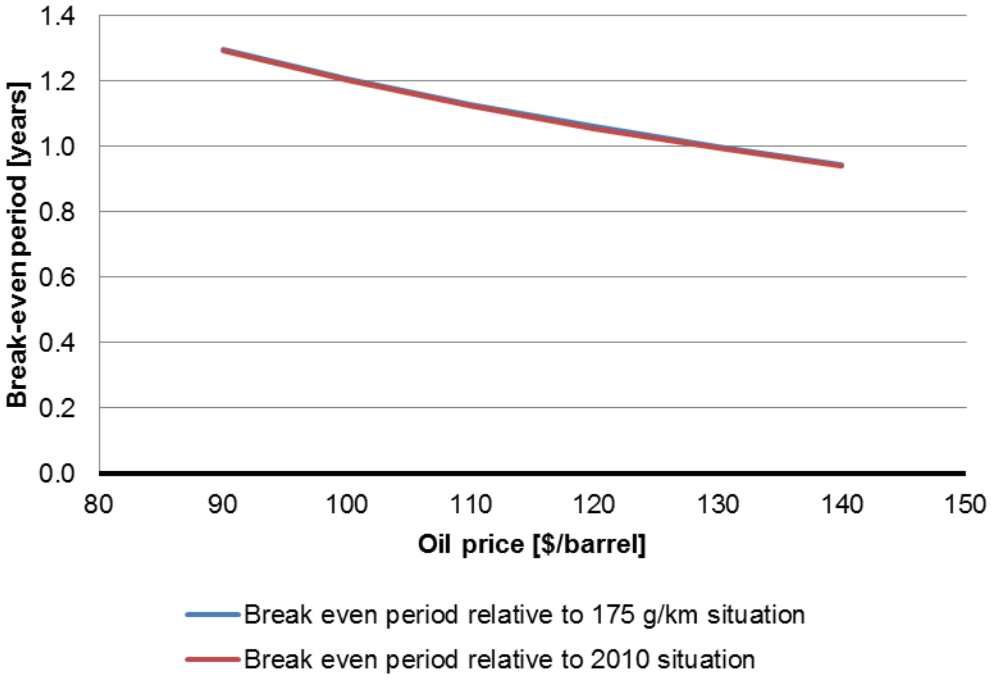


Figure 62 End consumer break even period of the 2020 CO_2 regulation in relation to the oil price.

9.3.1 Societal perspective

Also from a societal perspective, the lifetime fuel cost savings outweigh the additional investment resulting from the 2020 target. This is the case for the situation relative to the 2010 situation (Table 39) and also relative to the 175 g/km target set for 2017 (Table 40). This results in negative abatement costs for society between approximately -170 €/tonne CO_2 and -300 €/tonne CO_2, depending on the oil price (Figure 63). Also for the abatement costs, the higher extra investment relative to the 2010 situation compared to the 147 g/km situation, is compensated by the higher fuel cost savings.

Table 39 Societal effects of the 147 g/km target for 2020 relative to the situation in 2010

Oil price [$/barrel]	90	100	110	120	130	140
Diesel price (ex taxes) [€/l]	0.74	0.82	0.90	0.99	1.07	1.15
Annual fuel savings [€ per g/km]	8	9	10	11	12	12
NPV of lifetime fuel savings [€ per g/km]	79.0	88.0	97.1	106.1	115.1	124.1
Lifetime fuel cost savings [€]	2640	2941	3243	3544	3845	4146
Abatement costs [€/tonne CO_2]	-172	-196	-221	-246	-271	-295

Table 40 Societal effects of the 147 g/km target for 2020 relative to the 175g/km situation in 2017

Oil price [$/barrel]	90	100	110	120	130	140
Diesel price (ex taxes) [€/l]	0.74	0.82	0.90	0.99	1.07	1.15
Annual fuel savings [€ per g/km]	8	9	10	11	12	12
NPV of lifetime fuel savings [€ per g/km]	79.0	88.0	97.1	106.1	115.1	124.1
Lifetime fuel cost savings [€]	2198	2448	2699	2950	3201	3451
Abatement costs [€/tonne CO_2]	-172	-196	-221	-246	-270	-295

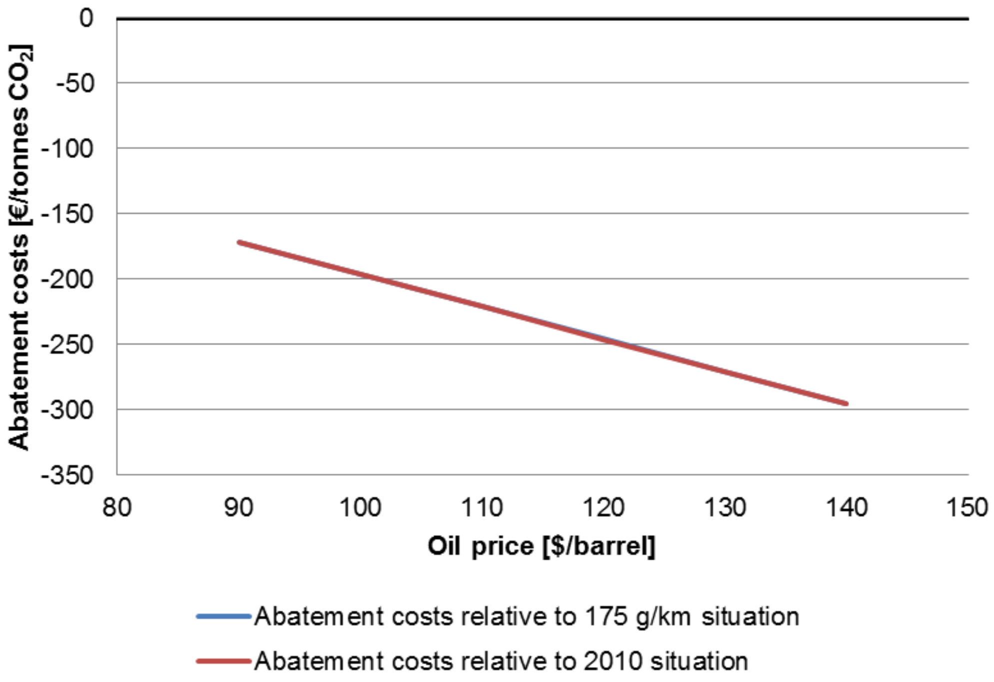


Figure 63 Abatement costs of the 2020 CO_2 regulation in relation to the oil price.

10 References

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Annex A: Manufacturer groups

Application of a certain measure to the sales weighted average CO_2 emissions per manufacturer group implies that manufacturer are allowed to perform internal averaging, i.e. the excess emission of one vehicle that emits more than the target value indicated by the limit function can be compensated by other vehicles that emit less than their specific targets.

The pooling used in this assessment is depicted in Table 41.

Table 41 LCV manufacturers pooled in manufacturer groups

Manufacturer group	**Brands**
Daimler	Mercedes-Benz Mitsubishi Fuso
Fiat	Fiat
Ford	Ford
General Motors	Opel Vauxhall GMC
Iveco	Iveco
Mitsubishi	Mitsubishi
Nissan	Nissan
PSA	Peugeot Citroen
Renault	Renault Renault-Trucks Dacia
Toyota	Toyota
Volkswagen	Volkswagen Skoda

Annex B: Impact analyses for all manufacturer groups including Tata (incl. Land Rover)

Independent manufacturers which sell fewer than 22000 vehicles per year can also apply to the Commission for an individual target instead of their equivalent of the 175 gCO_2/km target. As Tata (incl. Land Rover) is likely to request such an individual target, they are not taken into account in the figures in the main text of the report. Nonetheless, to depict the impact of the 2020 target for Tata (incl. Land Rover) the figures in this annex do include Tata (incl. Land Rover).

The grey bars indicate that the manufacturer group is not able to meet its equivalent of the 147 gCO_2/km target, even when the maximum possible CO_2 reduction (as determined in [TNO 2012]) is applied.

Utility parameter: Mass

Results expressed as cost impacts relative to a baseline in which 175 g/km is maintained between 2017 and 2020

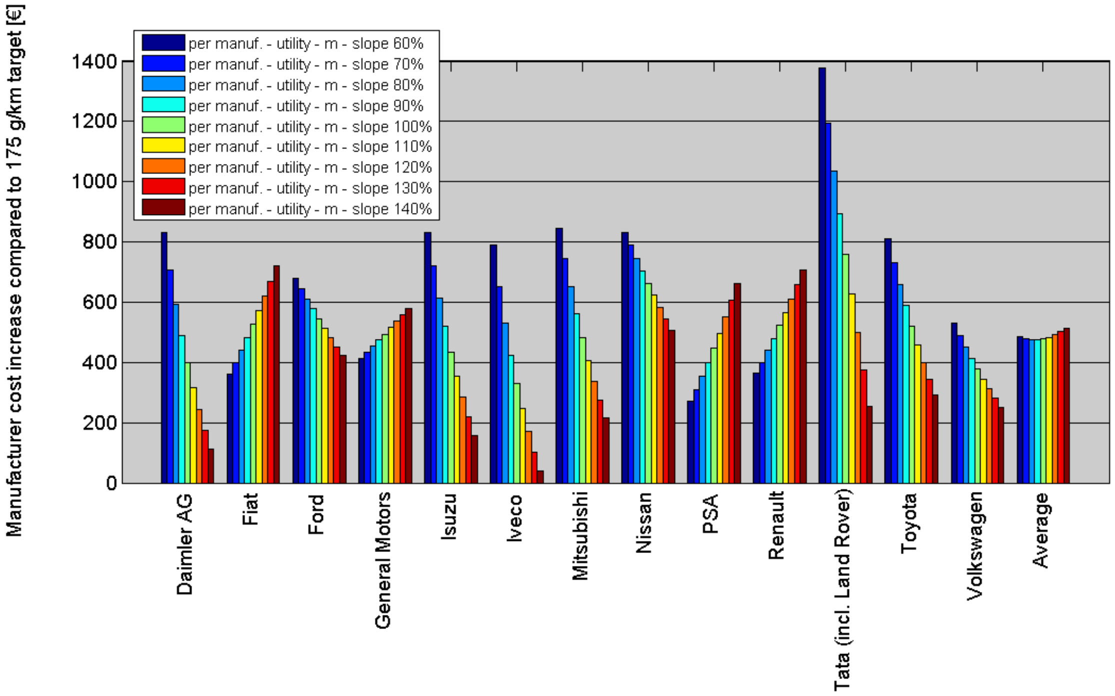

Figure 64 Absolute manufacturer cost increase per manufacturer for mass-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

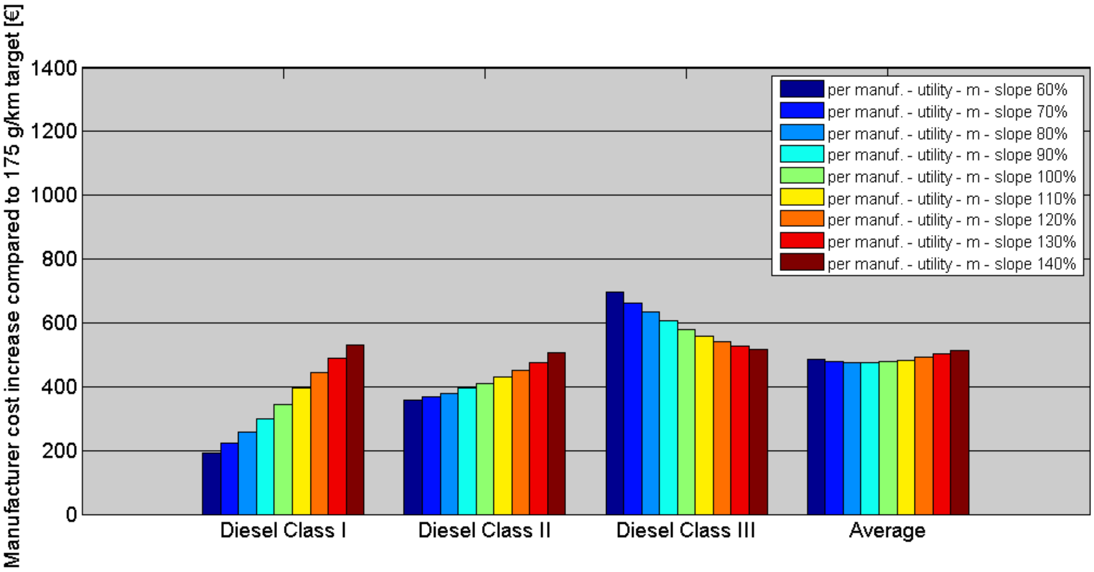

Figure 65 Absolute manufacturer cost increase segment for mass-based limits applied per manufacturer , compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

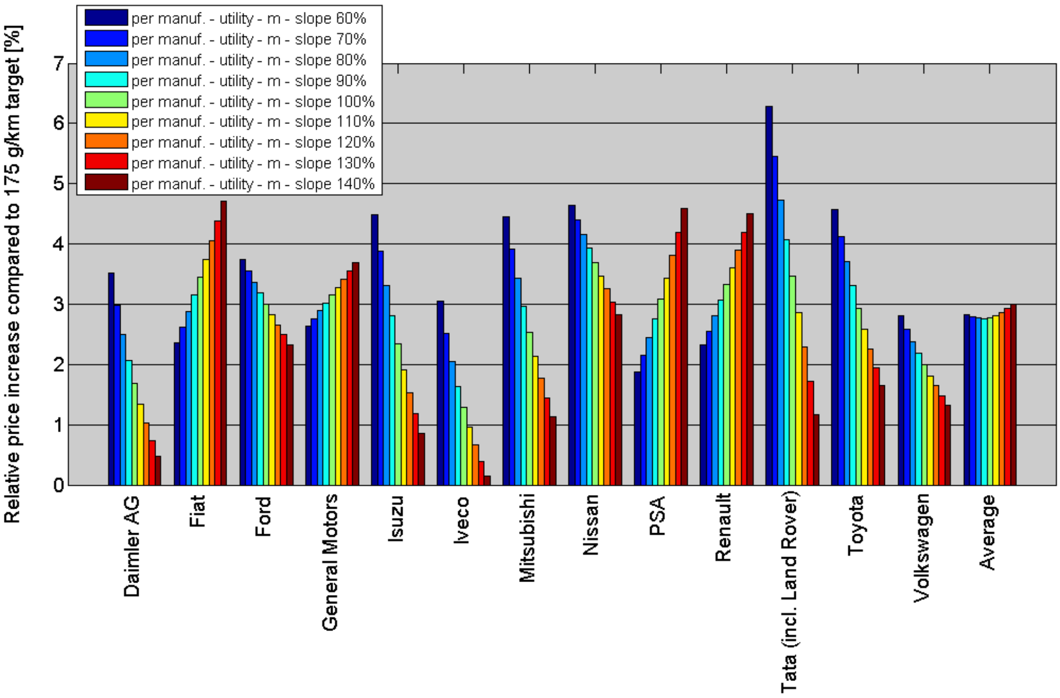

Figure 66 Relative price increase per manufacturer for mass-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

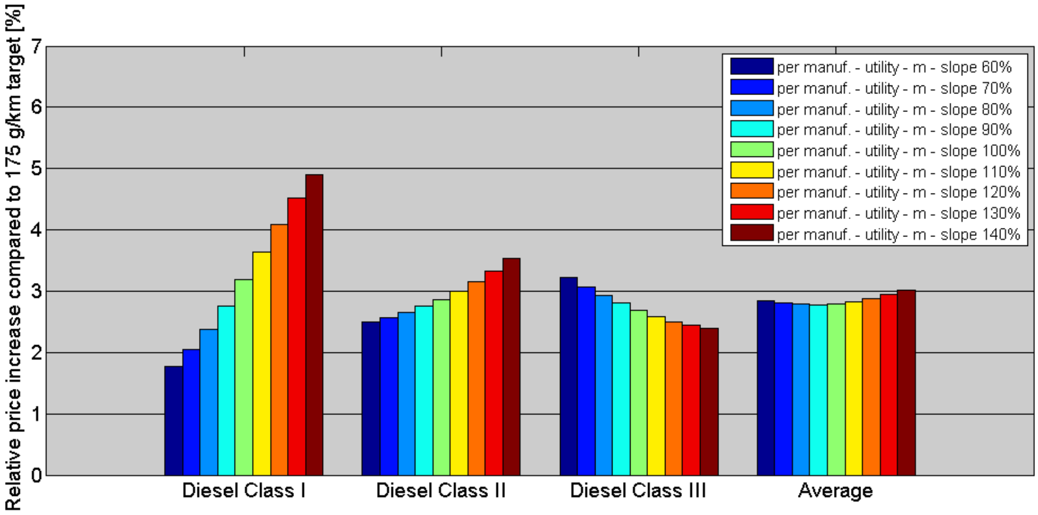

Figure 67 Relative price increase relative per segment for mass-based limits applied per manufacturer , compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

Results expressed as cost impacts relative to 2010

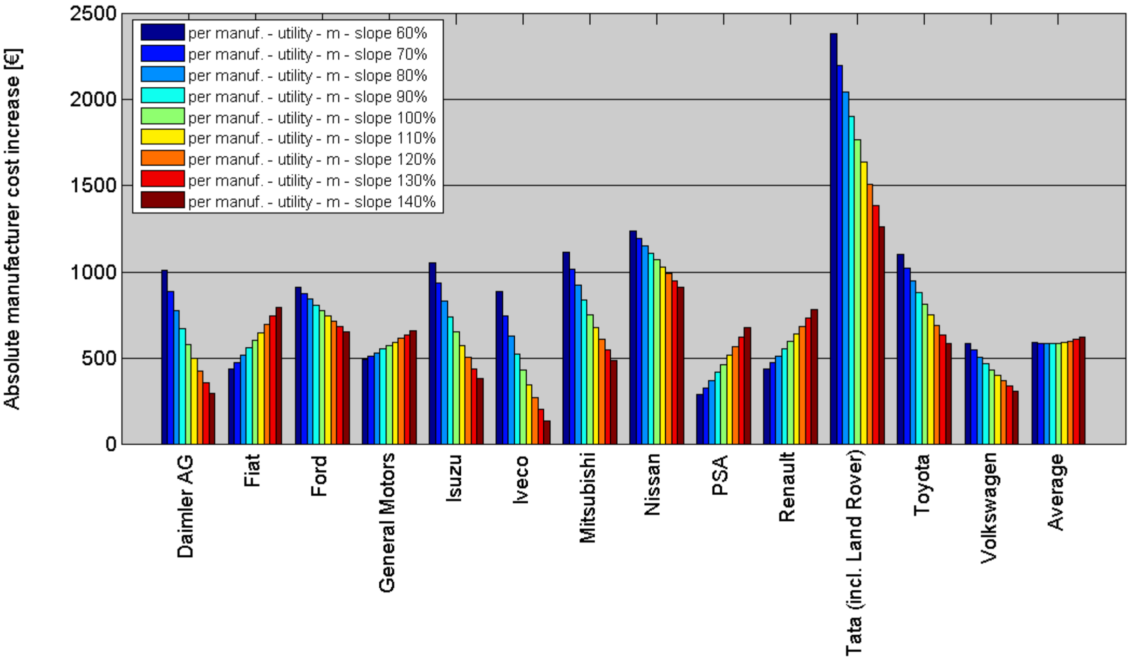

Figure 68 Absolute manufacturer cost increase relative to 2010 per manufacturer for mass-based limits applied per manufacturer.

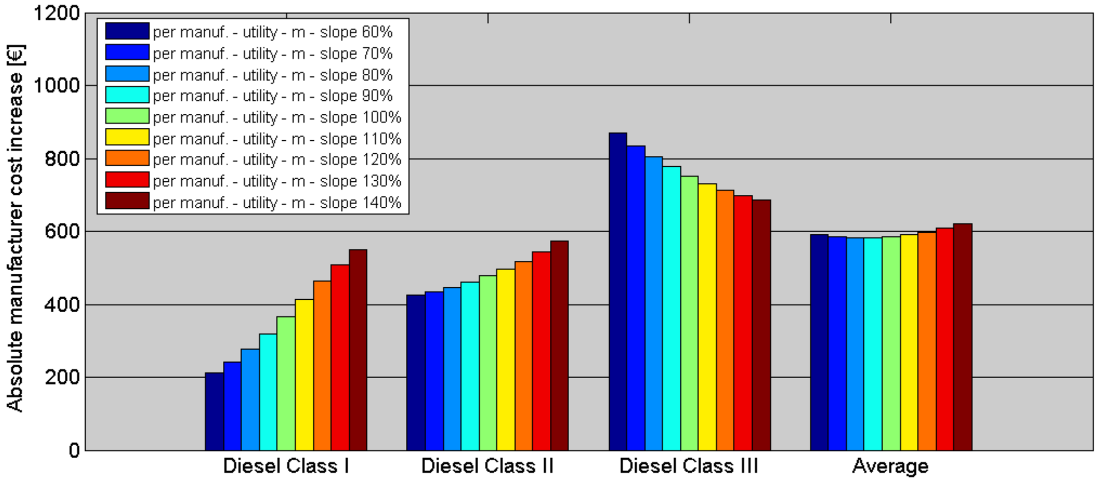

Figure 69 Absolute manufacturer cost increase relative to 2010 per segment for mass-based limits applied per manufacturer .

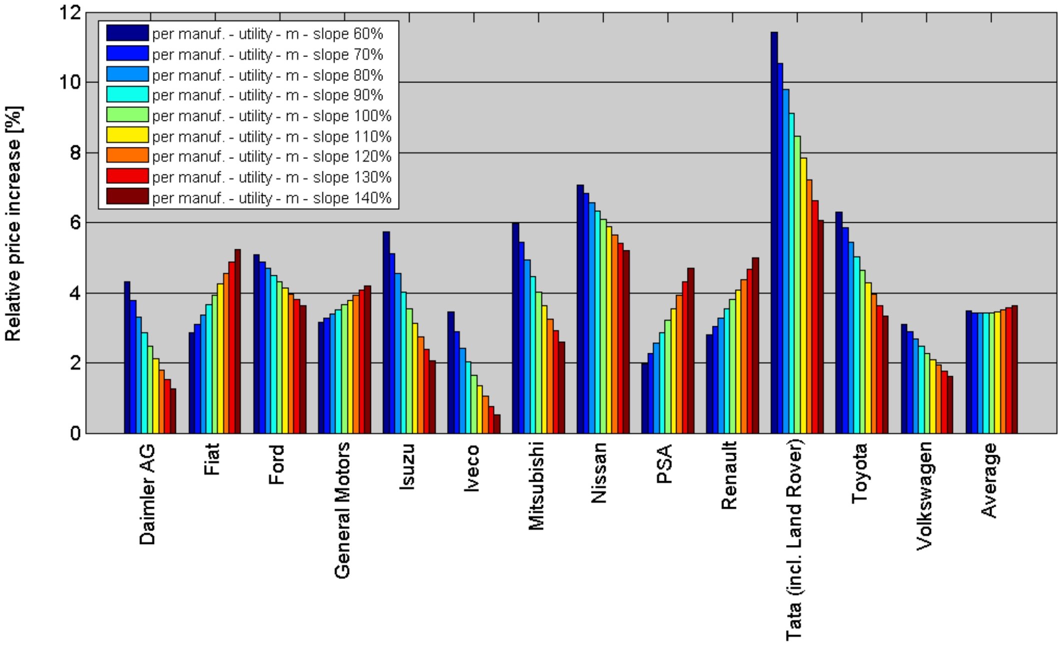

Figure 70 Relative retail price increase compared to 2010 per manufacturer for mass-based limits applied per manufacturer.

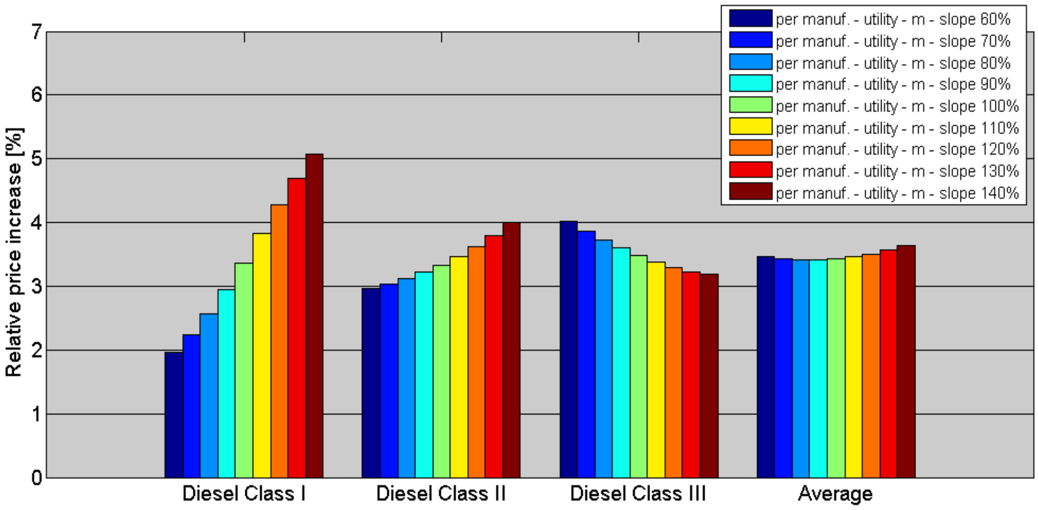

Figure 71 Relative retail price increase compared to 2010 per segment for mass-based limits applied per manufacturer .

Utility parameter: Footprint

Results expressed as cost impacts relative to a baseline in which 175 g/km is maintained between 2017 and 2020

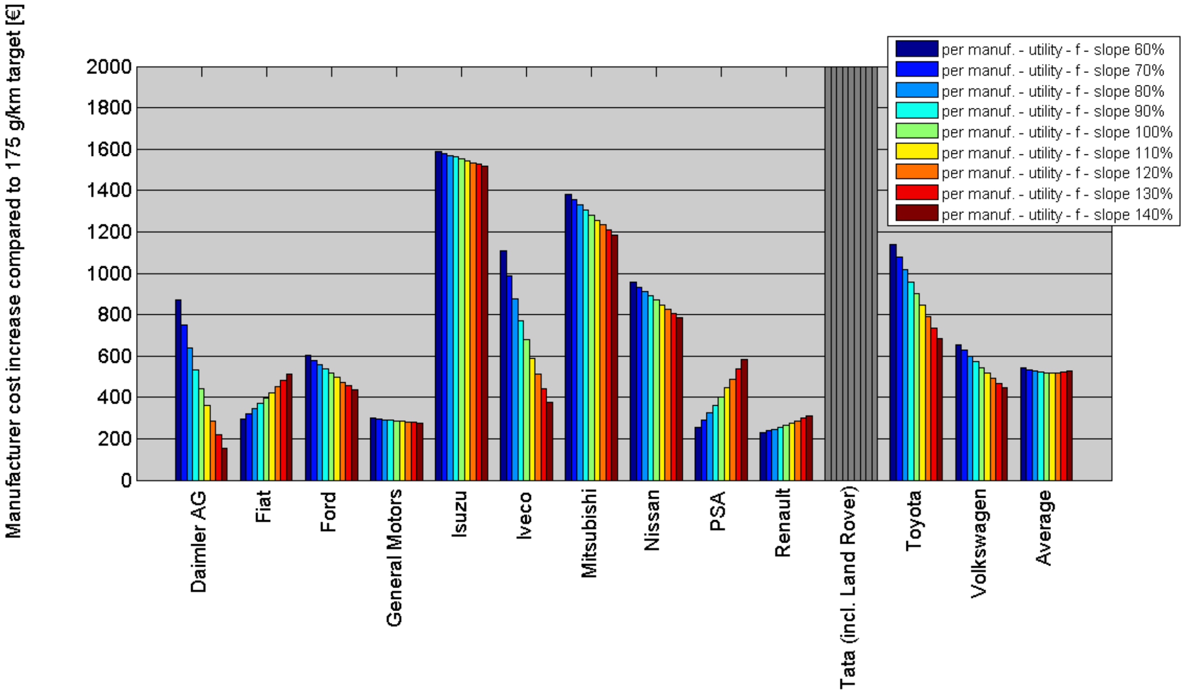

Figure 72 Absolute manufacturer cost increase per manufacturer for footprint-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

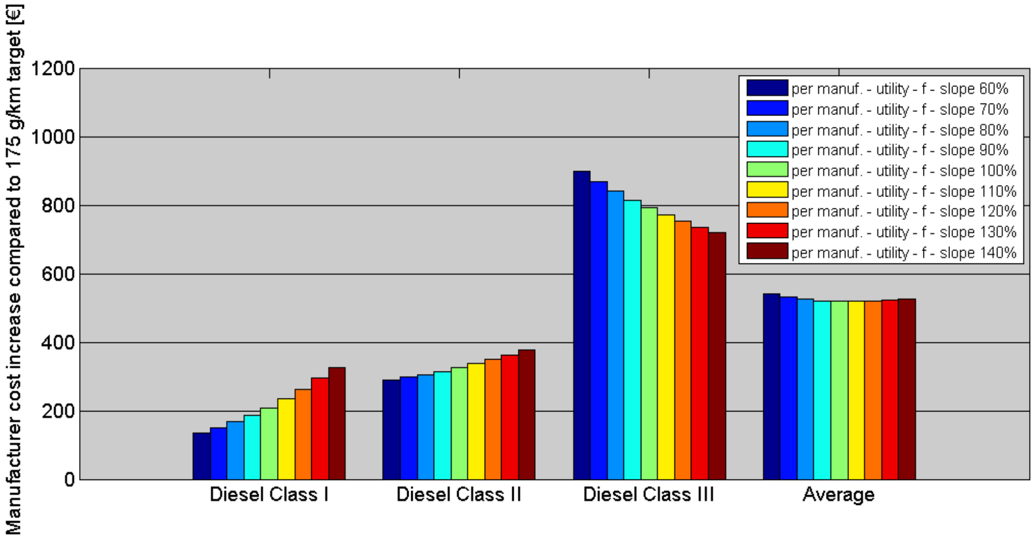

Figure 73 Absolute manufacturer cost increase segment for footprint-based limits applied per manufacturer , compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

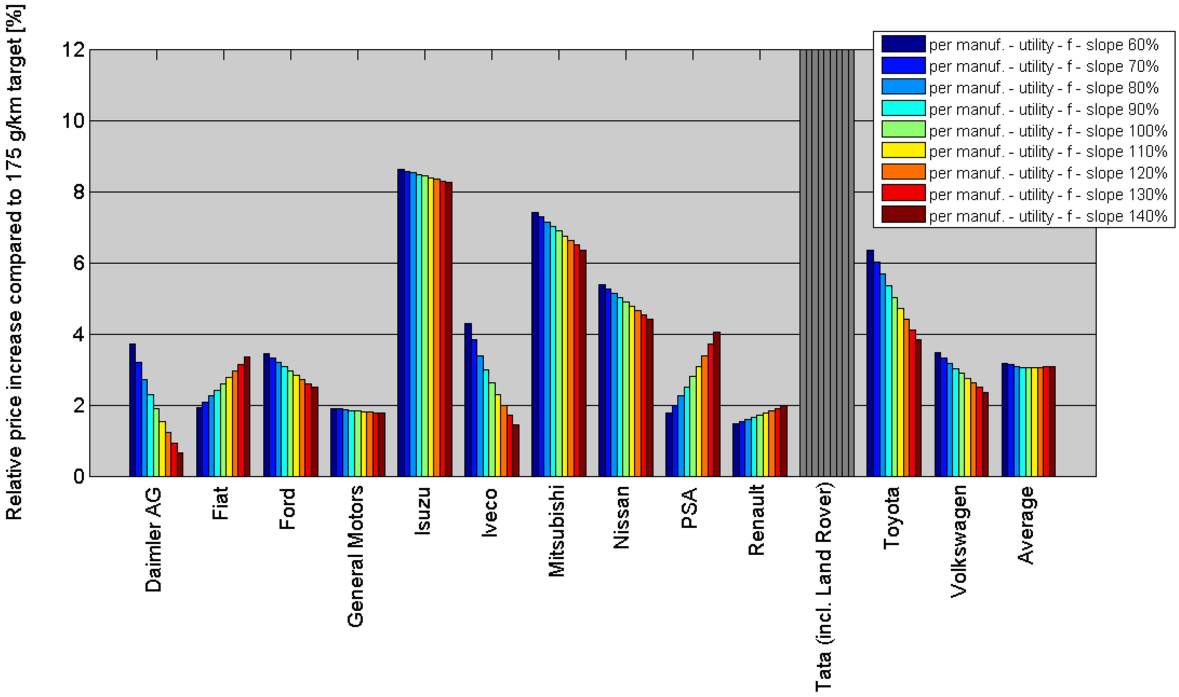

Figure 74 Relative price increase per manufacturer for footprint-based limits applied per manufacturer, compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

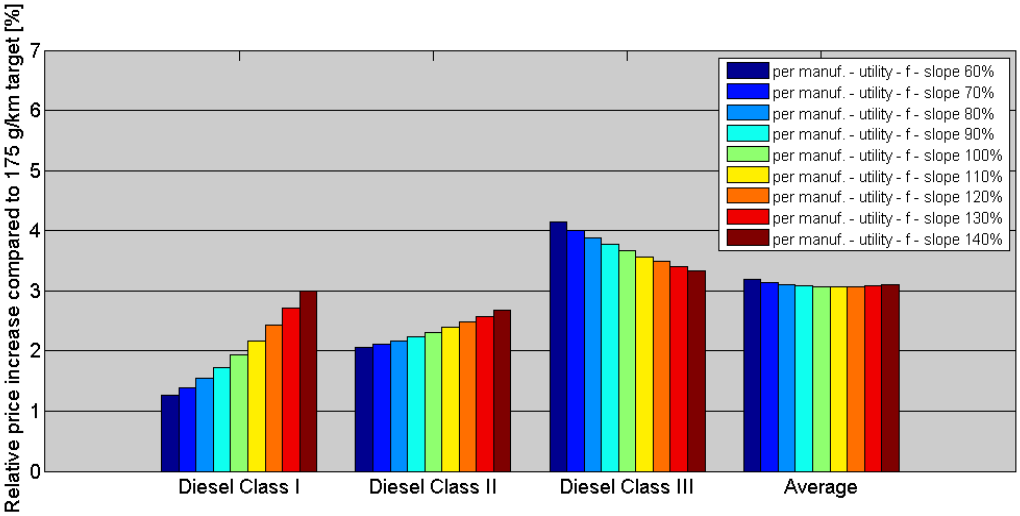

Figure 75 Relative price increase relative per segment for footprint-based limits applied per manufacturer , compared to the situation in which the 175 g/km legislation is maintained between 2017 and 2020.

Results expressed as cost impacts relative to 2010

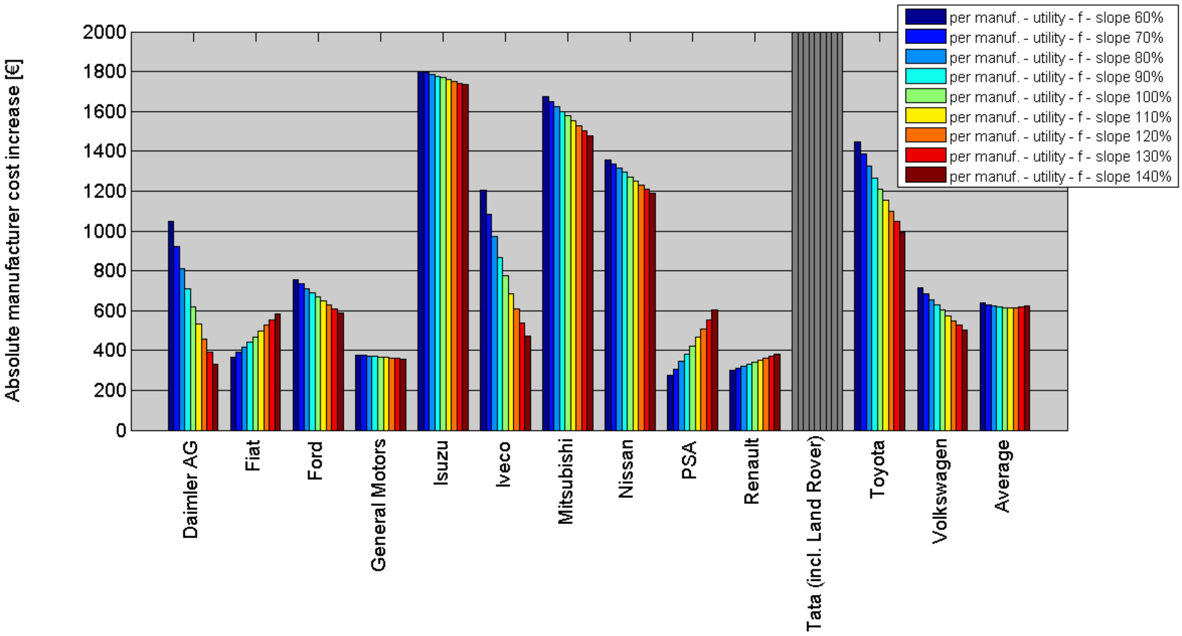

Figure 76 Absolute manufacturer cost increase relative to 2010 per manufacturer for footprint-based limits applied per manufacturer.

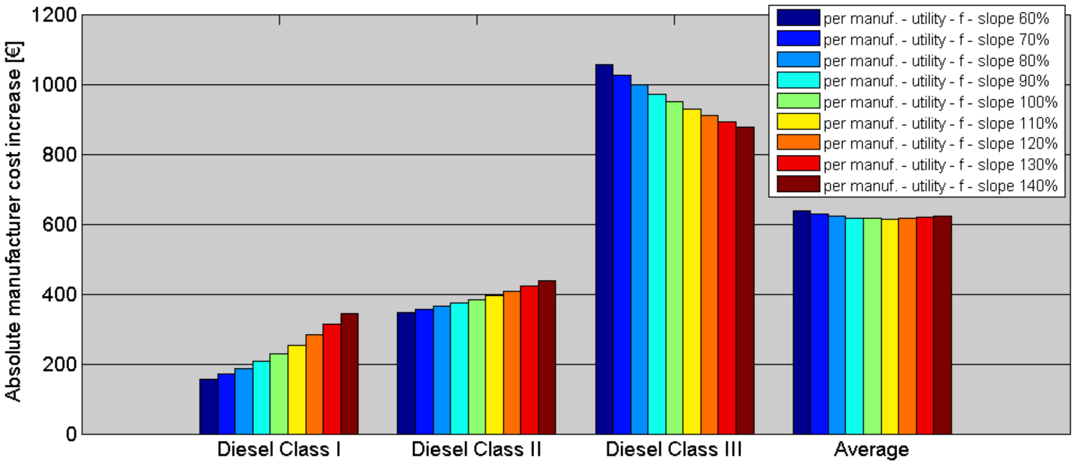

Figure 77	Absolute manufacturer cost increase relative to 2010 per segment for footprint-based limits applied per manufacturer .

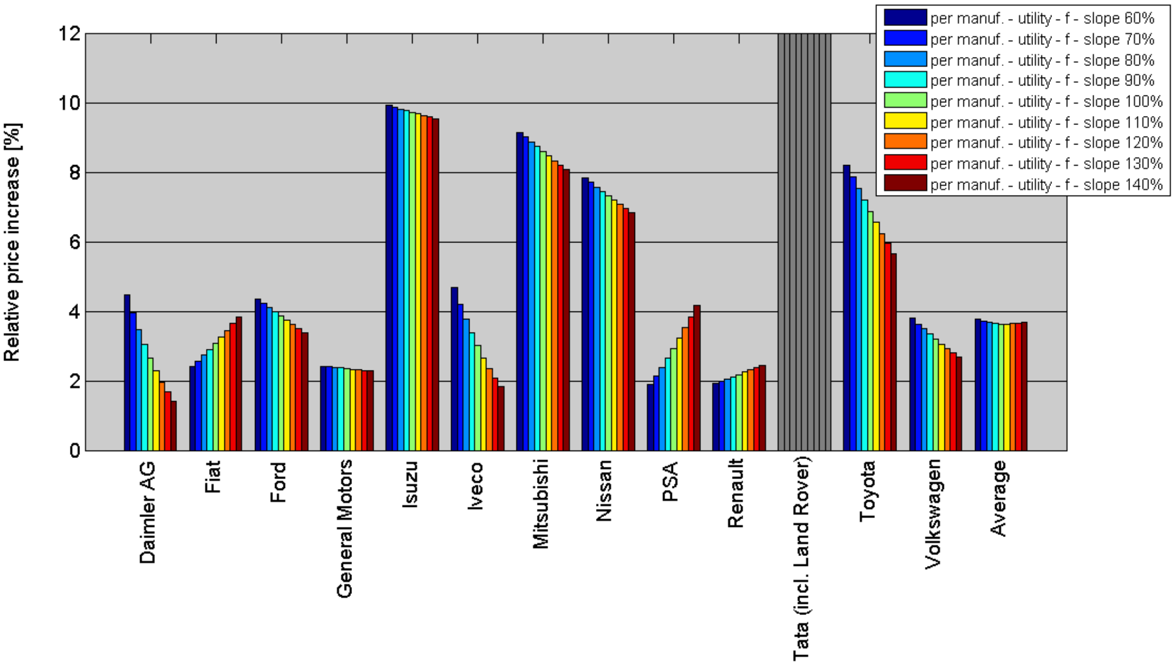

Figure 78	Relative retail price increase compared to 2010 per manufacturer for footprint-based limits applied per manufacturer.

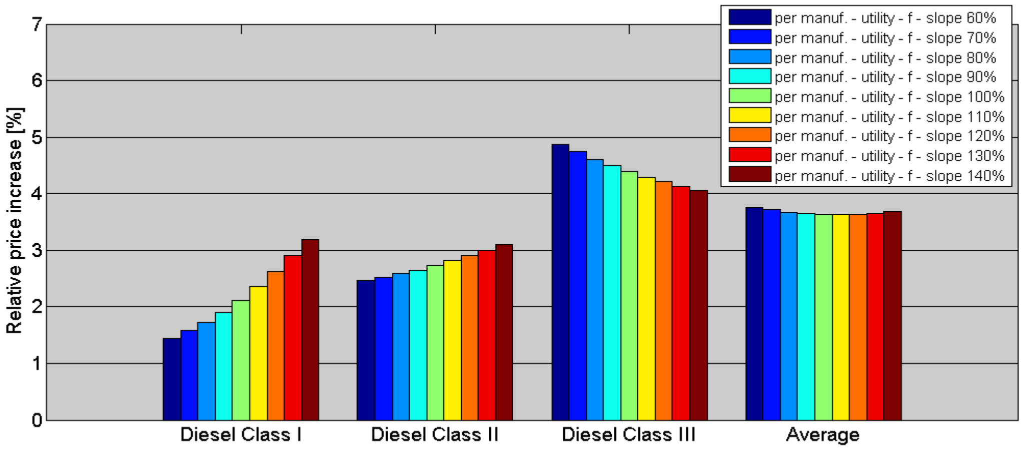

Figure 79 Relative retail price increase compared to 2010 per segment for footprint-based limits applied per manufacturer .

Annex C: Cost curves with absolute CO_2 reduction values

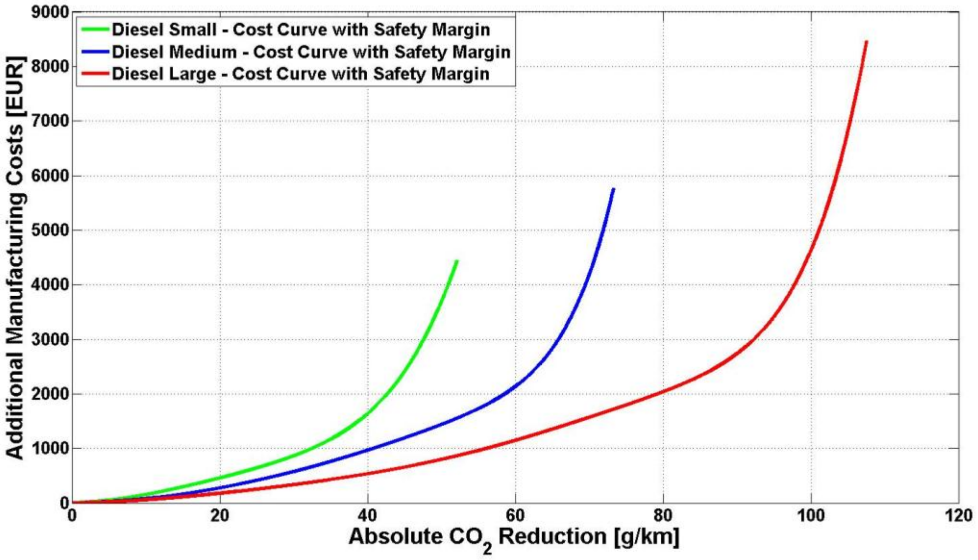

Figure 80 Cost curves for all segments (additional manufacturer costs as a function of absolute reduction in Type Approval CO_2 emission).

Annex D: Summary of aspects of the different potential utility parameters

	Mass in running order	Footprint	Payload
Regulatory status	Is defined as part of the vehicle specification	Traditionally there are no requirements to define, or record its components (track widths and wheel base). This was the parameter with the largest number of “no data available” in the database. However, this is changed in the new provisions for the Monitoring Mechanism.	Can be inferred. However, whilst the kerb-weight (mass in running order) can be measured the gross vehicle weight is a declared value. Both values are recorded as part of the vehicle specification.
Utility parameter as a function of LCV purpose	Not directly linked to either of the key utility parameters of LCV (their ability to move weight and volume). However, given the 3,500 kg upper limit for N1 vehicles, a lower vehicle mass does generate the potential to increase payload.	More closely linked to a key utility parameter – the ability of a vehicle to move volumes. (Though is not a measure of capacity available in m^3.)	More closely linked to a key utility parameter – the ability of a vehicle to move weight of goods. Anomaly exists where larger vans, e.g. long wheel base, have a larger load capacity, but are heavier when empty and with the 3,500 kg GVW limit of N1 LCV, have a lower payload capacity that their short wheel base relatives.
Fitting of utility parameter for all LCV	Linear fit quite a good approximation. Already within regulations.	Linear fit poor. Better would be either a non-linear function, or a linear function up to a threshold, e.g. 8m^2.	Linear fit poorer than for mass in running order. CO_2 emission values above payloads of ~1,900kg misleading. However, this is probably not much of an issue because sales of such vehicles are very low (<1% of all LCVs) Better would be either a non-linear function, or a linear function up to a threshold, e.g. 1,000 kg. However, this would lead to significant methodological changes compared with current car and LCV CO_2 legislation, and therefore probably not preferable. These options could be investigated further.
Manufacturer by manufacturer analysis	Quite a wide spread of masses in running order for different manufacturers. Therefore gradient of the utility function important because changes in the gradient affect manufacturers differently.	6 of the 7 high volume manufacturers have very similar average footprints. For these it is the target value rather than the utility gradient that is key. Single high volume manufacturer may be disproportionately impacted by the gradient dependent on that chosen.	As for mass in running order, quite a wide spread of payloads for different manufacturers. Therefore gradient of the utility function important because changes in the gradient affect manufacturers differently

	Average CO_2 g/km	Average mass in running order (kg)	2020 target from 147 gCO_2/km 100% slope line	Difference between actual and 2020 target (%)	Average CO_2 g/km	Average footprint (m2)	2020 target from 147 gCO_2/km 100% slope line	Difference between actual and 2020 target (%)	Average CO_2 g/km	Av Payload	2020 target from 147 gCO_2/km 100% slope line	Difference between actual and 2020 target (%)
Daimler	226.2	2,039	182.5	-19.3%	226.3	9.31	178.5	-21.1%	226.5	1,236	171.8	-24.2%
Fiat	159.9	1,652	145.7	-8.9%	160.0	6.65	141.0	-11.9%	160.1	845	140.3	-12.3%
Ford	201.9	1,757	155.6	-22.9%	194.2	7.51	153.1	-21.2%	203.1	1,054	157.1	-22.6%
GM	172.6	1,584	139.2	-19.4%	173.1	6.99	145.7	-15.8%	173.1	851	140.8	-18.7%
Hyundai	219.7	2,086	186.9	-14.9%	222.3	7.68	155.5	-30.1%	221.3	1,049	156.7	-29.2%
Isuzu	223.8	1,986	177.4	-20.7%	223.5	6.59	140.1	-37.3%	223.8	1,115	162.0	-27.6%
Iveco	229.0	2,135	191.7	-16.3%	229.0	9.11	175.6	-23.3%	229.0	1,374	182.9	-20.2%
Land Rover	276.9	2,028	181.5	-34.5%	278.7	5.57	125.6	-54.9%	279.8	909	145.5	-48.0%
Mazda	247.1	1,937	172.8	-30.1%	249.4	6.71	141.7	-43.2%	249.4	1,167	166.2	-33.4%
Mitsubishi	225.1	1,937	172.8	-23.2%	226.0	6.75	142.3	-37.0%	226.7	1,020	154.4	-31.9%
Nissan	214.1	1,769	156.8	-26.8%	213.6	6.86	143.9	-32.6%	214.8	1,100	160.8	-25.1%
PSA	157.9	1,486	129.9	-17.7%	158.7	6.27	135.6	-14.6%	158.8	757	133.3	-16.1%
Piaggio	135.5	1,007	84.3	-37.8%	135.5	3.00	89.4	-34.0%	135.5	771	134.3	-0.9%
Renault	167.2	1,519	133.0	-20.4%	167.3	6.91	144.6	-13.6%	169.7	873	142.6	-16.0%
Ssangyong	222.7	2,019	180.6	-18.9%	222.9	6.48	138.5	-37.9%	222.9	724	130.5	-41.4%
Toyota	215.3	1,867	166.1	-22.8%	222.2	7.09	147.1	-33.8%	222.3	1009	153.5	-31.0%
Volkswagen	192.4	1,808	160.5	-16.6%	193.2	7.45	152.2	-21.2%	194.5	960	149.5	-23.1%

Key: Reduction required <10% 10% - 20% 20% - 30% 30% - 45% >45%

Annex E: Levelling off of CO_2 emissions with increasing utility

Introduction

As can be seen in Figure 81,

Figure 82 and Figure 83, the CO_2 emissions of LCVs level off with increasing utility values. This is especially the case for footprint as utility parameter, but to lesser extent also for mass and payload. The reasons for this phenomenon can be divided into issues resulting from

1. the testing procedure and
2. the actual effect an increasing utility value has on the energy consumption and CO_2 emissions of an LCV.

These issues and the way they impact the type approval CO_2 emissions are explained below.

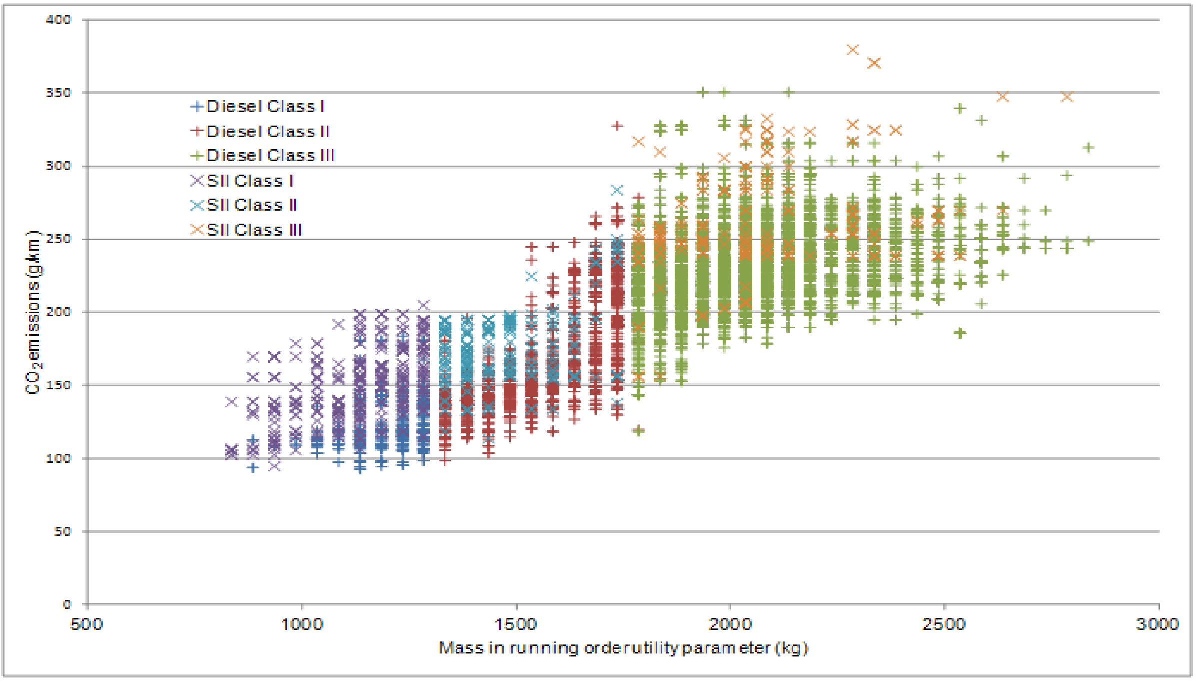

Figure 81 CO_2 and mass in running order values of LCV sales in 2010, for the six different LCV segments

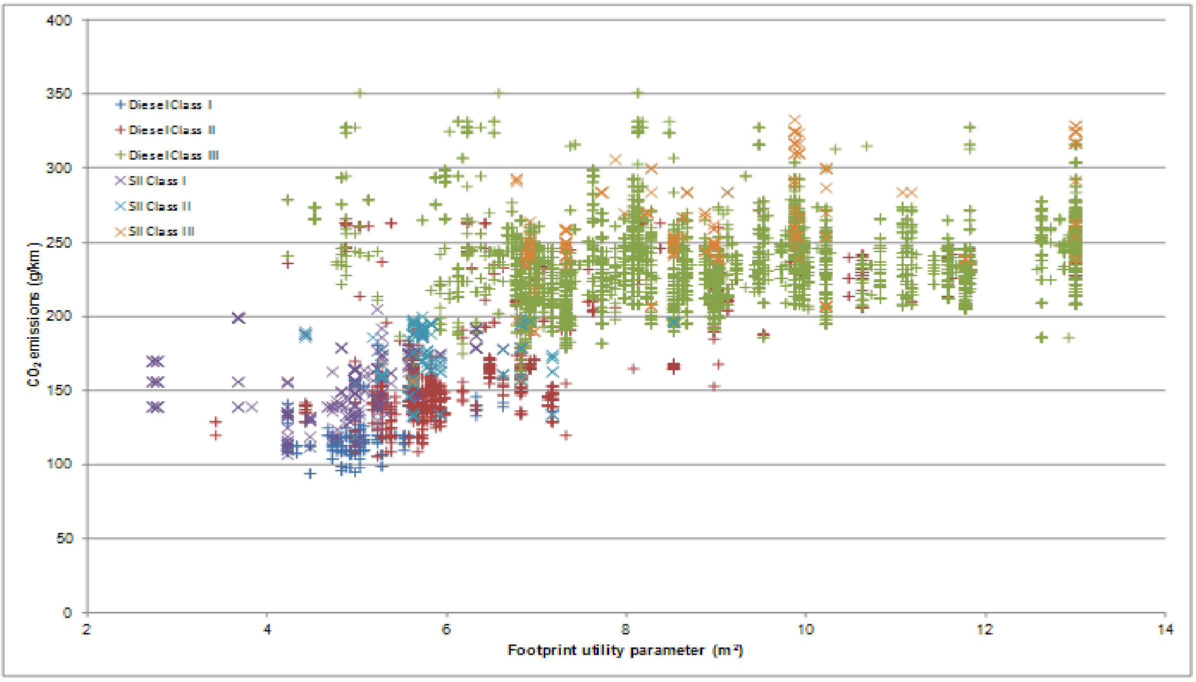

Figure 82 CO_2 and footprint values of LCV sales in 2010, for the six different LCV segments

Figure 83 CO_2 and payload values of LCV sales in 2010, for the six different LCV segments

Testing procedure issues that contribute to the levelling off of CO_2 emissions

Various elements of the chassis dynamometer testing procedure, used to determine the CO_2 [g/km] emissions of a vehicle, affect the outcome of the test in a way that is inconsequential for different vehicles. The identified elements are listed below.

- **Issue:** In Annex 4a of “Agreement Addendum 82: Regulation No. 83 - UNECE”, the table of power and load settings for the dynamometer is presented. According to this table the inertia to be set does not increase beyond 2270 kg for vehicles weighing above 2210 kg, and the

dynamic coefficients do not change for vehicles weighing above 2610 kg. This can be seen in Table 42 in which the road load settings for LCVs are depicted.
Effect on Type Approval CO_2 emissions: Between 2210 kg and 2610 kg, dynamometer settings only change by means of and increasing dynamic coefficients. As a result the relation between size/mass and CO_2 emissions levels off. Above 2610 kg, the dynamometer settings do not change at all and the CO_2 emissions are only defined by the efficiency of the engine. Consequently, the CO_2 emissions level off even more.

- **Issue:** Manufacturers have the option to either use simulated inertia and dyno loading settings depending on the mass class of the vehicle ("cook book values", see Table 42) or to use inertia and dyno loading settings determined from coast down tests with that specific vehicle type.
  Effect on Type Approval CO_2 emissions: The usage of values listed in Table 42 tends to result in higher type approval CO_2 emissions values than the usage of the values resulting from the real world road load test for relatively small vehicles (i.e. low air drag and rolling resistance). For relatively large vehicles (i.e. high air drag and rolling resistance) the values listed in Table 42 tend to result in lower type approval CO_2 emission values compared to the usage of road load test settings derived from coast down testing. As a result, manufacturers tend to use the values resulting from the real world road load test for small vehicles and the values from Table 42 for large vehicles. As a result, the emissions level off towards the upper end of the mass / size range. As the mass bins defining the inertia class of a LCV are rather large (up to 230 kg), leading to a stepwise increase of CO_2 emissions (that is not noticeable in Figure 81 since more vehicle characteristics affect the CO_2 emissions, e.g. engine efficiency).
- **Issue:** In Annex 4a of "Agreement Addendum 82: Regulation No. 83 - UNECE" is stated that for vehicles, other than passenger cars, with a reference mass of more than 1700 kg the dynamometer settings should be multiplied by 1.3.
  Effect on Type Approval CO_2 emissions: Introduction of a step function increasing the CO_2 emissions when testing LCVs of which the mass in running order is greater than 1700 kg.

Table 42 Simulated inertia and dyno loading requirements

Reference mass of vehicle RW (kg)	Equivalent inertia	Power and load absorbed by the dynamometer at 80 km/h		Road load coefficients	
	Kg	kW	N	a (N)	b (N/kph)
RW ≤ 480	455	3.8	171	3.8	0.0261
480 < RW ≤ 540	510	4.1	185	4.2	0.0282
540 < RW ≤ 595	570	4.3	194	4.4	0.0296
595 < RW ≤ 650	625	4.5	203	4.6	0.0309
650 < RW ≤ 710	680	4.7	212	4.8	0.0323
710 < RW ≤ 765	740	4.9	221	5	0.0337
765 < RW ≤ 850	800	5.1	230	5.2	0.0351
850 < RW ≤ 965	910	5.6	252	5.7	0.0385
965 < RW ≤ 1080	1020	6	270	6.1	0.0412
1080 < RW ≤ 1190	1130	6.3	284	6.4	0.0433
1190 < RW ≤ 1305	1250	6.7	302	6.8	0.046
1305 < RW ≤ 1420	1360	7	315	7.1	0.0481
1420 < RW ≤ 1530	1470	7.3	329	7.4	0.0502
1530 < RW ≤ 1640	1590	7.5	338	7.6	0.0515
1640 < RW ≤ 1760	1700	7.8	351	7.9	0.0536
1760 < RW ≤ 1870	1810	8.1	365	8.2	0.0557
1870 < RW ≤ 1980	1930	8.4	378	8.5	0.0577
1980 < RW ≤ 2100	2040	8.6	387	8.7	0.0591
2100 < RW ≤ 2210	2150	8.8	396	8.9	0.0605
2210 < RW ≤ 2380	2270	9	405	9.1	0.0619
2380 < RW ≤ 2610	2270	9.4	423	9.5	0.0646
2610 < RW	2270	9.8	441	9.9	0.0674

Impact of increasing utility values on the resistance of a vehicle

Besides the testing procedures, there are other (mainly physical) elements that lead to the levelling off of CO_2 emissions for larger LCVs.

For vehicles with the same engine, the CO_2 emissions (energy usage) result from the energy required at the wheels, determined by vehicle mass and the air and rolling resistance (neglecting inclination or declination), and the efficiency of the engine. The driving force can be written as:

$$F = F_{acc} + F_{air} + F_{roll} + F_{grade} = m \cdot a + \frac{1}{2} \cdot C_w \cdot A \cdot \rho \cdot v^2 + f_r \cdot m \cdot g \cos(\alpha) + m \cdot g \cdot \sin(\alpha) \quad (1)$$

For horizontal roads this comes down to:

$$F = m \cdot a + \frac{1}{2} \cdot C_w \cdot A \cdot \rho \cdot v^2 + f_r \cdot m \cdot g \quad (2)$$

The rolling resistance essentially depends on friction (wheels and road) and the vehicle mass, while the air resistance is determined by the vehicle’s velocity (quadratic), shape and reference area. The way the increase of the utility value affects these resistances depends strongly on the selected utility parameter. Therefore the effect for all three parameters are described separately.

- **Reference mass:** The energy use and real world CO_2 emissions of vehicles increase linearly with increasing mass (assuming no performance change). This means that the levelling-off of the CO_2 emissions with increasing mass is solely caused by the test procedure. The relation between mass increase and CO_2 emission increase was derived in [Smokers 2006]. According to [Smokers 2006] the weight increase ΔM is translated into a CO_2 emission increase ΔCO_2 for each segment based on the vehicle mass value M for that segment, using the following formula:

  $$\Delta CO_2 / CO_2 = 0.65 * \Delta M / M \tag{3}$$

- **Footprint:** An increasing footprint affects the energy use and CO_2 emissions indirectly via mass increase (extra body work means extra mass) and shape changes affecting c_w (extra length generally reduces c_w [CE 2008]). LCVs with higher footprints are generally fitted with larger engines. As a result, CO_2 emissions may increase much with increasing footprint more than is to be expected solely on the basis of how mass increases with increasing footprint. However, especially at the upper end of the footprint range, vehicle models are available with the same engine and a different length (and wheelbase) as can be seen in
- Figure **82** at the cost of performance. As can be seen in Table 43 and Table 44 the mass increases only limitedly with an increasing footprint (100 – 150 kg/m^2). As a result real world mass increases relatively little for vans with an increasing footprint. This results in limited CO_2 increase with an increasing footprint. Since for large/heavy LCVs the mass bins, defining the inertia classes, are rather large (up to 230 kg), a stretched vehicle with an increased footprint of 1.5m^2 could theoretically be attributed the same inertia settings as the 'unstretched' vehicle. From this we can concluded that the levelling-off of the CO_2 emissions with increasing footprint is not only caused by the test procedure issues discussed above, but also by the type of LCVs sold at the upper end of the footprint range, i.e. stretched LCVs.
  N.B. the 'extra-long' version has quite a bigger cargo area and cargo volume, but the same footprint as the 'long' version. This indicates that footprint is not a perfect proxy for utility.
- **Payload:** Payload is defined as the technically permissible maximum laden mass (GVW) and the mass of the vehicle. It is a declared value that cannot be independently verified. Especially Class III LCVs generally have a GVW of 3500 kg, the maximum value for N1 vehicles. Besides the test procedure issues described above, this issue also contributes significantly to the levelling-off of CO_2 emissions at the upper end of the payload range
  N.B. Since larger (longer or higher) vehicles are heavier than smaller vehicles (given the same drive train, materials etc), the payload decreases with increasing vehicle size. This makes that payload does not correlate well with the CO_2 emissions of a vehicle; so that it is not a good proxy for utility.

Table 43 Characteristics of various versions of the Mercedes Sprinter

Mercedes Sprinter 2011	Footprint [m^2]	GVW [kg]	Payload [kg]	Reference mass [kg]
Compact	5.5	3500	1565	1935
Medium	6.2	3500	1495	2005
Long	7.3	3500	1330	2170
Extra long	7.3	3500	1280	2220

Table 44 Characteristics of various versions of the Volkswagen Crafter

VW Crafter 2011	Footprint [m^2]	GVW [kg]	Payload [kg]	Reference mass [kg]
Compact	5.6	3500	1683	1817
Medium	6.3	3500	1579	1921
Long	7.4	3500	1445	2055
Extra long	7.4	3500	1393	2107

Annex F: Database consolidation steps

Result of the multi-tiered deletion step

Number of vehicles affected by deletion steps					
		No of vehicles suppressed by respective deletion Step			
Make	Initial No of vehicles	1	2	3	Remaining No of vehicles
ABARTH	1		1		
AIXAM	144		144		
ALFA ROMEO	170		170		
AUDI	3289		3289		
BMW	1655		1655		
BONETTI	32	32			
BREMACH	24	24			
BUCHER	66	66			
CADILLAC	11		11		
CHEVROLET	76		76		
CHRYSLER	127		127		
CITROEN	134773				134773
COMAI	6	6			
DACIA	9403				9403
DAIHATSU	2		2		
DODGE	170		170		
EFFEDI	414	414			
FAAM	48	48			
FIAT	140072				140072
FORD	123525				123525
GAZ	9	9			
GIOTTI VICTORIA	342				342
GM	16	16			
GMC	63	63			
GREAT WALL	219				219
HAKO	7	7			
HONDA	27		27		
HUMMER	14		14		
HYUNDAI	2015				2015
INFINITI	4		4		
ISUZU	6715				6715

IVECO	37033				37033
JAGUAR	10	10			
JEEP	297			5	292
JOHN DEERE	1	1			
KIA	176			113	63
KIEFER	20	20			
LADA	104			104	
LAMBORGHINI TRACTORS	1	1			
LANCIA	29		29		
LAND ROVER	7776			680	7096
LANDWIND	1	1			
LDV	100				100
LEOMAR	1	1			
MAHINDRA	148		148		
MARTIN MOTORS	137	137			
MAZDA	886			165	721
MEGA	42	42			
MERCEDES	92471				92471
MINI	3		3		
MITSUBISHI	11728				11728
MITSUBISHI FUSO	1590				1590
MULTICAR	20	20			
NISSAN	26509				26509
OPEL	27310				27310
OTHER	1852	1852			
PEUGEOT	130061				130061
PFAU	141	141			
PIAGGIO	4752				4752
PORSCHE	642		642		
RAM	574	574			
RENAULT	195677				195677
RENAULT TRUCKS	6339				6339
ROMANITAL	104	104			
SANTANA	10	10			
SCARAB	22	22			
SCHMIDT	1	1			
SEAT	449			443	6
SKODA	1802				1802

SSANGYONG	1068				1068
SUBARU	22		22		
SUZUKI	507			497	10
TATA	739			10	729
TEILHOL	1	1			
TORO	6	6			
TOYOTA	13989				13989
VAUXHALL	27417				27417
VOLKSWAGEN	101265				101265
VOLVO	192			102	90
ZASTAVA	2	2			

Data filling

	Without added CO2 value		CO2 value added		After addition		
Make	Total Sales	Average CO2	Total Sales	Average CO2	Total Sales	Average CO2	Change of CO2 [%]
RENAULT	173.686	158,51	19.365	227,91	193.051	165,47	4,39
CITROEN	122.325	153,93	10.442	217,79	132.767	158,96	
PEUGEOT	127.011	155,55	2.376	225,94	129.387	156,84	0,83
FORD	98.579	200,23	21.177	210,28	119.756	202,00	0,89
FIAT	96.885	148,27	21.642	212,44	118.527	159,99	
VOLKSWAGEN	90.422	191,30	9.125	214,52	99.547	193,43	
MERCEDES	69.519	223,70	19.765	235,43	89.284	226,29	1,16
IVECO	12.266	216,49	22.046	236,03	34.312	229,05	5,80
OPEL	22.408	175,27	4.508	223,24	26.916	183,30	4,58
VAUXHALL	26.805	161,96	54	226,31	26.859	162,09	0,08
NISSAN	20.033	199,00	6.378	261,57	26.411	214,11	
TOYOTA	13.833	215,42	3	196,00	13.836	215,41	0,00
MITSUBISHI	11.691	221,87			11.691	221,87	
DACIA	9.384	154,13			9.384	154,13	
LAND ROVER	7.067	276,93	6	276,00	7.073	276,93	0,00
ISUZU	5.030	221,14	1.300	234,40	6.330	223,86	1,23
RENAULT TRUCKS	1.632	239,63	4.044	254,34	5.676	250,11	
PIAGGIO	3.653	134,16	98	199,00	3.751	135,85	1,26
HYUNDAI	1.581	218,60	341	225,00	1.922	219,73	0,52
SKODA	1.758	136,12	1	140,00	1.759	136,13	0,00
SSANGYONG	1.067	222,72			1.067	222,72	0,00
MAZDA	694	247,08			694	247,08	0,00
MITSUBISHI FUSO	616	286,83			616	286,83	0,00
TATA	458	222,98	4	226,00	462	223,00	0,01
GIOTTI VICTORIA	297	167,59			297	167,59	
JEEP	289	240,17			289	240,17	0,00
GREAT WALL	219	190,13			219	190,13	0,00
LDV	100	234,60			100	234,60	0,00
VOLVO	90	186,40			90	186,40	0,00
KIA	17	193,29			17	193,29	0,00
ALL	919.415	174,49	142.675	225,75	1.062.090	181,38	3,95

Payload

CASE	*Payload allowance (kg) [ranges]*	*Payload incl driver (kg) [ranges]*	*Payload incl driver*	*Remarks*	***Fill "Average Payload" with…***
1	Has value (351,161 vehicles)	Same value	Entry "Y"	Column "allowance" has a value that includes the driver.	Average allowance minus 75 kg
2	Has value (285,827 vehicles)	Other (higher range) value	Entry "-"	Column "allowance" has a value that DOES NOT include the driver.	Average allowance
3	Has value (399,506 vehicles)	No value	No entry (Null value or empty string in database)	Means that it is not clear if column "allowance" is with or without driver ??	Average allowance (do not change data)
4	Has no value (166 vehicles)	Has value	Entry "Y" or "-"	Only in 7 rows	Take value of "payload incl driver (kg)", reduce this value if 'payload incl driver' is 'Y'
5	Has value (1,421 vehicles)	Other higher value	No entry (Null value or empty string in database)	Column allowance obviously does NOT include driver.	Average allowance
6	Has value (127 vehicles)	Same value	Entry "-"	All entries are '>=3000'	Average allowance
7	Has value (1,969 vehicles)	Same value	No entry		Average allowance
8	Has value (1 vehicle)	No value	Entry "-"		Average allowance

Impact of remaining M1

Overall (incl. vehicles without mass values) - Polk			**Fulfilling conditions = N1 (Polk)**			**Not fulfilling conditions ≠ N1 (Polk)**			
Manu-facturer	Total Sales	AvCarbon	Manu-facturer	Total Sales	Av Carbon	Manu-facturer	Total Sales	Av Carbon	Difference in CO2 value
Renault	159,785	168,50	Renault	140,415	169.46	Renault	11,314	129.11	0.57%
Citroen	125,805	155.70	Citroen	101,919	155.87	Citroen	17,211	141.77	0.11%
Peugeot	117,360	155.22	Peugeot	96,889	160.37	Peugeot	17,133	121.86	3.32%
Fiat	110,717	166.96	Fiat	93,884	170.75	Fiat	9,968	122.48	2.27%
Ford	108,199	201.23	Ford	95,645	203.27	Ford	2,395	168.12	1.01%
VW	83,774	198.81	VW	69,684	202.45	VW	7,902	171.75	1.83%
Mercedes	78,022	236.02	Mercedes	63,427	237.46	Mercedes	470	161.82	0.61%
Opel	25,596	175.96	Opel	24,558	176.83	Opel	924	147.87	0.50%
Nissan	24,232	239.39	Nissan	22,577	240.88	Nissan	75	146.29	0.62%
Vauxhall	16,899	164.00	Vauxhall	16,789	164.18				0.11%
Toyota	14,962	217.63	Toyota	13,097	224.98	Toyota	800	129.29	3.37%
Dacia	11,360	142.25	Dacia	11,350	142.24	Dacia	10	154.30	-0.01%
Iveco	10,432	242.93	Iveco	9,915	239.72	Iveco	20	254.80	-1.32%
Mitsubishi	9,142	231.38	Mitsubishi	8,205	230.72	Mitsubishi	319	243.37	-0.29%
Land Rover	5,119	265.90	Land Rover	4,894	265.72	Land Rover	71	275.93	-0.07%
Isuzu	3,171	221.93	Isuzu	3,138	222.20				0.12%
Mazda	1,852	231.66	Mazda	1,611	236.51	Mazda	106	127.67	2.10%
Skoda	1,211	143.46	Skoda	1,000	146.77	Skoda	186	125.87	2.31%
Renault Trucks	1,107	254.17	Renault Trucks	1,105	254.15				-0.01%
Hyundai	970	214.37	Hyundai	920	213.61	Hyundai	2	190.00	-0.36%
Tata	873	223.94	Tata	853	225.68	Tata	17	146.65	0.78%
Piaggio	629	145.03	Piaggio	557	157.00	Piaggio	4	0.00	8.25%
Suzuki	621	165.38	Suzuki	570	164.16	Suzuki	51	178.92	-0.73%
Seat	461	120.76	Seat	25	150.20	Seat	363	122.77	24.38%
LDV	387	210.76	LDV	387	210.76				0.00%
Kia	317	220.21	Kia	236	242.92	Kia	71	144.46	10.32%
Jeep	214	253.62	Jeep	110	253.19	Jeep	102	251.59	-0.17%
Ssangyong	209	214.08	Ssangyong	201	213.53				-0.26%
Volvo	204	171.36	Volvo	62	205.11	Volvo	129	155.64	19.70%

Average CO_2 values

Make	Total Sales / Registrations	Sales / Regs having a CO2 value	Average CO2 emissions [g/km]	Sales / Registrations with missing CO2 value
RENAULT	195403	193051	165,47	2352
CITROEN	133977	132767	158,96	1210
PEUGEOT	130055	129387	156,84	668
FIAT	120679	118527	159,99	2152
FORD	120306	119756	202,00	550
VOLKSWAGEN	100289	99547	193,43	742
MERCEDES	91768	89284	226,29	2484
IVECO	36780	34312	229,05	2468
VAUXHALL	27417	26859	162,09	558
OPEL	27307	26916	183,30	391
NISSAN	26509	26411	214,11	98
TOYOTA	13989	13836	215,41	153
MITSUBISHI	11728	11691	221,87	37
DACIA	9403	9384	154,13	19
LAND ROVER	7096	7073	276,93	23
ISUZU	6709	6330	223,86	379
RENAULT TRUCKS	6333	5676	250,11	657
PIAGGIO	4752	3751	135,85	1001
HYUNDAI	2015	1922	219,73	93
SKODA	1802	1759	136,13	43
MITSUBISHI FUSO	1590	616	286,83	974
SSANGYONG	1068	1067	222,72	1
TATA	729	462	223,00	267
MAZDA	721	694	247,08	27
GIOTTI VICTORIA	342	297	167,59	45
JEEP	292	289	240,17	3
GREAT WALL	219	219	190,13	0
LDV	100	100	234,6	0
VOLVO	90	90	186,4	0
KIA	63	17	193,29	46
SUZUKI	10	0		10
SEAT	6	0		6

Average footprint values

Make	Regs/Sales having footprint	Average footprint	Regs/Sales having footprint & CO2 value	Average fooprint for Regs/Sales having footprint and CO2
CITROEN	131793	6,30	131749	6,30
DACIA	9360	6,30	9360	6,30
FIAT	118896	6,67	118218	6,65
FORD	74727	7,51	74535	7,51
GIOTTI VICTORIA	342	4,82	297	4,82
GREAT WALL	219	6,97	219	6,97
HYUNDAI	1864	7,68	1844	7,68
ISUZU	6345	6,61	6157	6,59
IVECO	36524	9,06	34143	9,11
LAND ROVER	6790	5,57	6770	5,57
LDV	100	9,84	100	9,84
MAZDA	661	6,71	661	6,71
MERCEDES	89594	9,35	87507	9,31
MITSUBISHI	11175	6,72	11150	6,72
MITSUBISHI FUSO	1224	7,13	616	7,20
NISSAN	25547	6,86	25481	6,86
OPEL	26989	7,25	26907	7,25
PEUGEOT	125348	6,24	125284	6,24
PIAGGIO	4701	2,94	3751	2,98
RENAULT	192309	6,91	191548	6,90
RENAULT TRUCKS	6330	8,52	5676	8,30
SKODA	1055	5,34	1055	5,34
SSANGYONG	1049	6,48	1049	6,48
TATA	445	6,80	444	6,80
TOYOTA	12774	7,09	12774	7,09
VAUXHALL	26925	6,76	26388	6,72
VOLKSWAGEN	98088	7,47	97879	7,47

Average mass in running order

Make	Regs/Sales having mass	Average mass in running order	Regs/Sales having mass & CO2 value	Average Mass in running order for Regs/Sales having Mass and CO2
CITROEN	132670	1487,5	132627	1487,2
DACIA	9384	1233,8	9384	1233,8
FIAT	119172	1513,6	118495	1512,6
FORD	119714	1757,0	119576	1756,5
GIOTTI VICTORIA	342	1022,4	297	1034,0
GREAT WALL	219	1785,6	219	1785,6
HYUNDAI	1942	2077,9	1922	2085,6
ISUZU	6637	1997,5	6315	1985,6
IVECO	36693	2141,8	34312	2135,2
JEEP	290	2050,4	289	2050,6
KIA	17	2102,1	17	2102,1
LAND ROVER	7093	2028,5	7073	2028,2
LDV	100	1883,5	100	1883,5
MAZDA	694	1937,2	694	1937,2
MERCEDES	91278	2039,0	89099	2039,2
MITSUBISHI	11716	1932,2	11691	1931,9
MITSUBISHI FUSO	1381	2088,0	616	2033,9
NISSAN	26463	1769,0	26398	1768,6
OPEL	26897	1663,9	26873	1663,9
PEUGEOT	129120	1484,8	129055	1484,5
PIAGGIO	4701	1014,1	3751	1033,6
RENAULT	192900	1520,5	192698	1519,5
RENAULT TRUCKS	5947	1971,1	5676	1967,5
SKODA	1759	1338,5	1759	1338,5
SSANGYONG	1067	2018,7	1067	2018,7
TATA	463	1931,4	462	1931,6
TOYOTA	13836	1866,1	13836	1866,1
VAUXHALL	27396	1502,8	26859	1503,7
VOLKSWAGEN	99755	1815,8	99547	1816,2
VOLVO	79	1890,2	79	1890,2

Average payload

Make	Regs/Sales having Payload	Average Payload in running order	Regs/Sales having Payload & CO2 value	Average Payload in running order for Regs/Sales having Payload and CO2
CITROEN	129665	739,7	129621	739,5
DACIA	9303	786,8	9303	786,8
FIAT	118808	846,9	118130	844,8
FORD	118143	1054,6	117997	1054,3
GIOTTI VICTORIA	342	809,9	297	797,5
GREAT WALL	219	973,4	219	973,4
HYUNDAI	1882	1049,5	1862	1049,1
ISUZU	6644	1128,9	6322	1114,6
IVECO	36693	1368,5	34312	1374,3
JEEP	7	560,2	6	557,8
KIA	1	574,5	1	574,5
LAND ROVER	6075	909,7	6055	909,4
LDV	100	1411,5	100	1411,5
MAZDA	661	1167,2	661	1167,2
MERCEDES	90638	1243,5	88455	1236,1
MITSUBISHI	10858	994,8	10833	995,9
MITSUBISHI FUSO	1381	1436,1	616	1440,1
NISSAN	25953	1101,6	25887	1100,4
OPEL	26967	918,6	26885	917,0
PEUGEOT	124084	775,9	124019	775,6
PIAGGIO	4701	750,8	3751	746,7
RENAULT	181450	857,5	180717	855,5
RENAULT TRUCKS	6330	1571,8	5676	1586,4
SKODA	1058	575,8	1058	575,8
SSANGYONG	1050	723,5	1050	723,5
TATA	445	1088,5	444	1088,5
TOYOTA	12659	1008,7	12659	1008,7
VAUXHALL	26928	793,8	26391	783,7
VOLKSWAGEN	96971	965,5	96762	963,8
VOLVO	8	593,3	8	593,3

Annex G: Technology exclusion matrix

This matrix shows the mutually exclusive technologies, indicated with “x”.

	Combustion improvements	Mild downsizing (15% cylinder content reduction)	Medium downsizing (30% cylinder content reduction)	Variable valve actuatior	Optimising Gearbox ratios/downspeeding	Improved M/T Transmissior	downspeeding via slip controlled clutch and DMF deleted	Automated manual transmission	Dual (dry) clutch transmission	Start stop	micro -hybrid (including regenerative braking)	Mild hybrid (Torque boost for downsizing)	Full Hybrid (EV only mode)	Series Range extender with 40-50kW engine	Electric vehicle	BIW lightweighting - mild (~10% reduction)	BIW lightweighting - medium (~25% reduction)	BIW lightweighting - strong (~40% reduction)	Lightweight components other than BIW	Aerodynamics improvement - minor	Aerodynamics improvement - major	low rolling resistance tyres	Reduced driveline friction (mild reduction)	Reduced driveline friction (high reduction)	Thermo-electric generation	Secondary heat recovery cycle	Auxilliary thermal systems improvement	Auxilliary systems improvement (lubrication, vacuum, FIE	Other Thermal management	Electrical power steering
Combustion improvements															x															
Mild downsizing (15% cylinder content reduction)			x									x	x	x	x															
Medium downsizing (30% cylinder content reduction)		x										x	x	x	x															
Variable valve actuation															x															
Optimising Gearbox ratios/downspeeding															x															
Improved M/T Transmission													x		x															
downspeeding via slip controlled clutch and DMF deleted															x															
Automated manual transmission									x				x		x															
Dual (dry) clutch transmission								x					x		x															
Start stop											x	x	x	x	x															
micro -hybrid (including regenerative braking)										x		x	x	x	x															
Mild hybrid (Torque boost for downsizing)		x	x							x	x		x	x	x															
Full Hybrid (EV only mode)		x	x					x	x	x	x	x		x	x															
Series Range extender with 40-50kW engine		x	x							x	x	x	x		x															
Electric vehicle	x	x	x	x	x		x	x	x	x	x	x	x	x										x	x	x	x	x	x	x
BIW lightweighting - mild (~10% reduction)																	x	x												
BIW lightweighting - medium (~25% reduction)																x		x												
BIW lightweighting - strong (~40% reduction)																x	x													
Lightweight components other than BIW																														
Aerodynamics improvement - minor																														
Aerodynamics improvement - major																														
low rolling resistance tyres																														
Reduced driveline friction (mild reduction)																								x						
Reduced driveline friction (high reduction)															x								x							
Thermo-electric generation															x											x				
Secondary heat recovery cycle															x										x					
Auxilliary thermal systems improvement															x															
Auxilliary systems improvement (lubrication, vacuum, FIE)															x															
Other Thermal management															x															
Electrical power steering															x															