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Evaluation of parameter-based vehicle emissions targets in the EU

HOW REGULATORY DESIGN CAN HELP MEET THE 2020 CO_2 TARGET

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EXECUTIVE SUMMARY

The current carbon dioxide (CO_2) emission performance standards for new passenger cars in the European Union are based on vehicle weight. The corresponding Regulation (EC) No 443/2009 defines a long-term target of 95 g/km to be met by 2020 and asks for a review of the exact modalities for reaching this target, including a potential change from mass to another utility parameter, in particular vehicle footprint, for determining emission targets.

A list of assessment criteria was developed and applied to an extended list of potential index parameters. Only few qualified for further investigation. In particular, it was found that a size-based emission target system would provide several advantages compared to the current weight-based system. In contrast to a weight-based system, under a size-based system emission reductions from vehicle weight reduction are fully taken into account, thereby allowing higher emission reductions and more flexibility for manufacturers in meeting their targets at equal or even lower compliance costs. Furthermore, a size-based target system is less prone to gaming (i.e., manufacturers making changes to the characteristics of their vehicles for the purpose of meeting their targets while emissions stay constant or even increase) and correlates better with vehicle utility than weight. When deciding between vehicle footprint or pan area (shadow) as an index parameter, footprint offers several advantages; in particular, footprint data is already systematically collected under the existing Regulation (EC) No 443/2009.

Making use of an extensive database of 2009 sales of passenger cars in the European Union, the effects of different target systems on manufacturers and individual vehicles were analyzed. The results show that differences in the required 2009–2020 emission reductions between the most likely versions of a weight and a size-based system amount to a maximum of 2–4 g/km for the main manufacturers. Similarly, it was found that none of the major vehicle types would be overly penalized or preferred under any of the systems.

Based on these findings it is recommended that not vehicle mass but vehicle size, and preferably footprint, be used as a utility parameter for meeting the 95 g/km target by 2020 and for future European Union CO_2 emission targets.

	Diversity competitively neutral, vertical spread	**Robustness** avoids perverse effects (gaming)	**Flexibility** no discrimination of technologies	**Representativeness** proxy for utility, socially equitable	**Comprehensiveness** avoid adverse effects, safety	**Practicability** data, continuous, definition, complexity
Curb weight	+	-	-	-	o	+
Pan area	++	-	+	+	+	o
Footprint	++	+	+	o	++	+

Index parameter: Meets criterion substantially (++) / meets criterion (+) / does not affect criterion (o) / does not meet criterion in most cases (-) / does not meet criterion at all (--)

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ABBREVIATIONS

ACEA Association des Constructeurs Européens d'Automobiles *(European Automobile Manufacturers' Association)*
AMI Autonomous mass increase
EC European Commission
EPA United States Environmental Protection Agency
GHG Greenhouse gas
VCA Vehicle Certification Agency *(United Kingdom vehicle type approval authority)*
KBA Kraftfahrtbundesamt *(German Federal Motor Transport Authority)*
NHTSA United States National Highway Traffic Safety Administration

1 INTRODUCTION

The European Union (EU) regulation setting carbon dioxide (CO_2) emission performance standards for new passenger cars (Regulation (EC) No 443/2009) defines a long-term target of 95 g CO_2/km to be met by 2020 (EU 2009). At the same time, the regulation requires that a review be carried out by the beginning of 2013, with the aim of defining both the modalities for reaching the target in a cost-effective manner and aspects of the implementation of the target.

In preparation for this upcoming review of Regulation (EC) No 443/2009, and with the aim of providing a comprehensive and objective overview of facts to the public, this report:

- Compiles a systematic assessment of the advantages and disadvantages of potential modalities and aspects of implementation, in particular with respect to the utility parameter chosen when defining the target system
- Draws upon recent data to analyze the effects of different utility parameter emission target systems, with a strong focus on the impacts on the car industry and individual car manufacturers
- Provides recommendations on what utility parameter-based emission target systems are best suited in view of the results of the previous examination

1.1 Structure of this report

The focus of this report is the decision regarding a utility parameter underlying and the parameters defining the shape and slope of the 2020 target curve. Other aspects, such as the excess emissions premium or eco-innovation measures, are not part of this study.

In section 2 a list of potential utility parameters and combinations of utility parameters is compiled. A systematic assessment against a set of selection criteria results in a short list of parameters considered most suitable from a theoretical point of view. Section 3 focuses on the application of the identified utility parameters to the European car market. The effects on the car industry, individual manufacturers, and consumers are described in detail for each parameter, taking into account the shape and slope of different target lines. The results of the analysis are discussed in section 4, and recommendations for policy makers are then derived in section 5 of the report.

1.2 Data sources used

For the analysis a detailed database of the EU-27 car market in 2009 was compiled by the ICCT, including technical information, emission levels, and registration volumes on a car variant level. The database includes information obtained by R. L. Polk from various registration authorities and car manufacturers' and importers' associations, as well as additional detailed data from the United Kingdom Vehicle Certification Agency (VCA), the German Kraftfahrtbundesamt (KBA), and manufacturers' websites.

It should be noted that the weight definition used in this report is based on the mass of the car with bodywork in running order (including driver, fuel, and spare wheel / tools) as stated in the certificate of conformity and defined in section 2.6 of Annex I to Directive (EC) No 46/2007. It is therefore directly comparable to the mass definition used in Regulation (EC) No 443/2009[1].

Car brands, and in some cases car manufacturers, have been aggregated to reflect the fact that CO_2 emission performance targets have to be met on average by the entire manufacturer's fleet and not by individual brands. Furthermore, it is possible for several manufacturers to form a pool for the purposes of meeting their obligations (see Article 7 of Regulation (EC) No 443/2009) or, under certain conditions, to request to be treated under derogation rules (see Article 11 of Regulation (EC) No 443/2009). From today's point of view it is not yet fully clear what the manufacturers' composition will look like in future years. For the analysis it is therefore necessary to make some assumptions, summarized in Table 1.

For reasons of clarity, only manufacturers with a market share higher than 2% are included in the charts presented in the body of this report. Volvo is the exception, due to its significantly different fleet structure and its importance in northern European countries (for example, 17% market share in Sweden).

The total number of vehicles included in the ICCT database is 13.98 million. This number is in line with the number from the 2009 European Commission (EC) CO_2 monitoring report, which also sets the total number of vehicles at 13.98 million (EC 2010). Both values are about 1% lower than the number of 14.16 million that is provided by the European Automobile Manufacturers' Association (ACEA) (ACEA 2010). Information on emissions and technical parameters, necessary to carry out detailed analysis, is missing on some of the records. The EC CO_2 monitoring report includes 13.54 million vehicles with information on CO_2 and vehicle weight. The ICCT database includes 13.17 million vehicles that have information on CO_2, vehicle weight, and footprint.

Table 2 compares the weighted averages for CO_2 and vehicle weight per manufacturer in both databases. The overall differences are marginal, with less than 1% deviation for both CO_2 and weight on average and no more than a 5.1% difference for any individual manufacturer.

1 Currently vehicle mass is reported differently across manufacturers and member states. In some instances the mass of driver, fuel, and wheel / tools (75 kg) is included, while in others it is not. For the database used by the ICCT, which relies on the information published by manufacturers, an average of 50 kg was added to the reported mass for each vehicle in order to account for the discrepancies in definitions and to avoid a systematic underestimation of vehicle mass. This approach is in line with previous studies that were carried out on behalf of the European Commission.

Table 1. Aggregation of manufacturers and EU-27 market shares in 2009

MANUFACTURER	INCLUDES	EU-27 MARKET 2009
BMW	BMW, Mini, Rolls Royce	4.9%
Daimler	Maybach, Mercedes-Benz, Smart	4.7%
Fiat	Alfa-Romeo, Chrysler, Dodge, Ferrari, Fiat, Jeep, Lancia, Maserati	9.0%
Ford	Ford	9.1%
GM	Chevrolet, Opel, Vauxhall	8.8%
Honda	Honda	1.6%
Hyundai	Hyundai, Kia	4.0%
Mazda	Mazda	1.4%
Mitsubishi	Mitsubishi	0.6%
PSA	Citroën, Peugeot	13.2%
Renault	Dacia, Nissan, Renault	12.1%
Suzuki	Suzuki	1.7%
Toyota	Daihatsu, Lexus, Toyota	5.1%
Volkswagen	Audi, Bentley, Bugatti, Porsche, Škoda, Seat, VW	21.2%
Volvo	Volvo	1.3%
Others	e.g. Land Rover, Subaru, Saab	1.2%

Table 2. Comparison of European Commission and ICCT datasets

MANUFACTURER	CO_2 [G/KM]			VEHICLE MASS [KG]		
	EC CO_2 MONITORING	ICCT DATABASE	Δ	EC CO_2 MONITORING	ICCT DATABASE	Δ
BMW	151	151	-0.2%	1,526	1,554	1.8%
Daimler	167	165	-0.8%	1,487	1,516	1.9%
Fiat	134	138	3.0%	1,164	1,146	-1.6%
Ford	141	143	1.4%	1,281	1,331	3.9%
GM	148	148	0.5%	1,301	1,319	1.4%
Honda	147	146	-1.0%	1,354	1,366	0.9%
Hyundai	141	143	1.2%	1,305	1,327	1.7%
Mazda	149	151	0.8%	1,251	1,314	5.1%
Mitsubishi	164	163	-1.0%	1,341	1,347	0.4%
PSA	136	136	0.5%	1,309	1,302	-0.5%
Renault	143	143	0.2%	1,299	1,278	-1.7%
Suzuki	144	143	-0.9%	1,150	1,159	0.7%
Toyota	132	136	3.2%	1,265	1,260	-0.4%
Volkswagen	152	153	0.8%	1,408	1,427	1.4%
Volvo	173	169	-2.4%	1,599	1,636	2.3%
Total market	146	147	0.7%	1,336	1,345	0.7%

2 IDENTIFYING UTILITY PARAMETER INDEX OPTIONS

The least complex way to reduce CO_2 emissions from new vehicles would be to set a uniform target that had to be met by each manufacturer's vehicles, on average, in order to avoid penalties. However, vehicle characteristics vary significantly, and so do fleet compositions across manufacturers. Some have specialized in producing small cars for inner-city use, whereas other focus on larger vehicles for driving long distances. Applying a uniform target would therefore lead to changes of the current competitive balance within the car market. It could also cause manufacturers to limit the availability of larger vehicles, which could further affect the vehicle market situation. These are the reasons for indexing standards to a vehicle attribute that allows a fleet to remain diverse in terms of vehicle shape, size, and functionality and to improve efficiency without compromising vehicle functionality.

The index currently applied in the EU is vehicle mass. A vehicle size-based target system was also discussed and examined in detail during the regulatory process, but was not pursued, mainly due to a lack of data availability (EC 2007; EU 2009). In the United States, following thorough analysis, vehicle footprint was chosen as the most appropriate index (NHTSA 2005). Japan currently uses vehicle mass as the index parameter (ICCT 2010). China has adopted the EU system and uses vehicle mass (Wang, Jin et al. 2010).

There are several vehicle attributes that could serve as a basis for indexing emission targets. In the following section a list of assessment criteria is laid out and explained in detail. This list is then applied to the range of potential index parameters. The goal is to identify a limited number of index parameters that will then be analyzed in more depth and with focus on the EU car fleet in section 3.

2.1 Assessment criteria

The assessment criteria can be aggregated into six categories (see for example EC 2007; Fergusson, Smokers et al. 2007):

- **Diversity**. Ideally, an emission standard should allow a vehicle to improve efficiency and reduce emissions without compromising its functionality. It should focus on the "vertical spread," the difference in emissions across vehicles that have the same functionality, rather than penalizing vehicles that have higher emissions but at the same time offer greater utility to the customer.[2] In doing so it allows for a broad diversity of vehicles on the market and therefore is to be seen as neutral in terms of competitiveness between manufacturers.
- **Robustness**. The overall goal of a standard is to limit and reduce real-world emissions. It should therefore avoid any perverse effects

2 Provided the customer makes use of the greater available utility of the vehicle.

where manufacturers can meet their targets by making changes to the characteristics of their vehicles while emissions stay constant or even increase. These effects are usually referred to as "gaming" and occur whenever it is easier and cheaper to change vehicle characteristics than it is to apply technologies to reduce emissions.

- **Flexibility**. Properly designed attribute-based emission standards do not exclude any technologies that are available for reducing vehicle emissions. Rather, they maximize the range of strategies available to manufacturers to meet their emission reduction targets. Index parameters that lead to an exclusion of certain technological options limit the potential for emission reductions and are likely to increase compliance costs.
- **Representativeness**. An index parameter should act as a proxy for the utility of a vehicle from a customer's perspective. It should reflect the attribute(s) seen as most important by a majority of consumers. To be widely accepted, an attribute-based standard should also be designed to be socially equitable, not penalizing customer groups that have special needs due to their social situation (for example large families).
- **Comprehensiveness**. While the focus of a vehicle emission standard is on reducing environmental impacts, it should avoid adverse effects in other areas. In particular, it should not compromise the safety of passengers and other road users.
- **Practicability**. Availability of relevant data as well as a clear definition are critical criteria for any index parameter. In addition, for adequate differentiation between vehicles, it should be suited to the use of sufficiently small steps. Finally, the complexity of any attribute-based emission standard should be limited as much as possible to avoid any unforeseen perverse effects.

It should be noted that a strong correlation between the index parameter and vehicle CO_2 emissions is *not* an assessment criteria. Some correlation might be needed in order to allow developing a target line granting higher emissions to vehicles with higher utility. However, too much of a correlation is undesirable, mainly for one reason: An index parameter strongly correlated to CO_2 indicates that the index parameter itself is an important part of any effort to reduce emissions.[3] Thus, building an emission standard on this parameter would in fact create a disincentive to reduce emissions. Figure 1 illustrates the correlation observed between several potential index parameters (which will be introduced in more detail in the following section) and CO_2, as well as the resulting horizontal and vertical spread for selected vehicles.

3 See also Smokers, Vermeulen et al. 2006: "... [I]t may be tempting to look for utility parameters that show a strong statistical correlation with the CO_2-emissions of existing vehicles. Such a strong correlation is generally found using parameters that are strong determinants of vehicle efficiency. These, however, are exactly the parameters that should not be used as utility parameters."

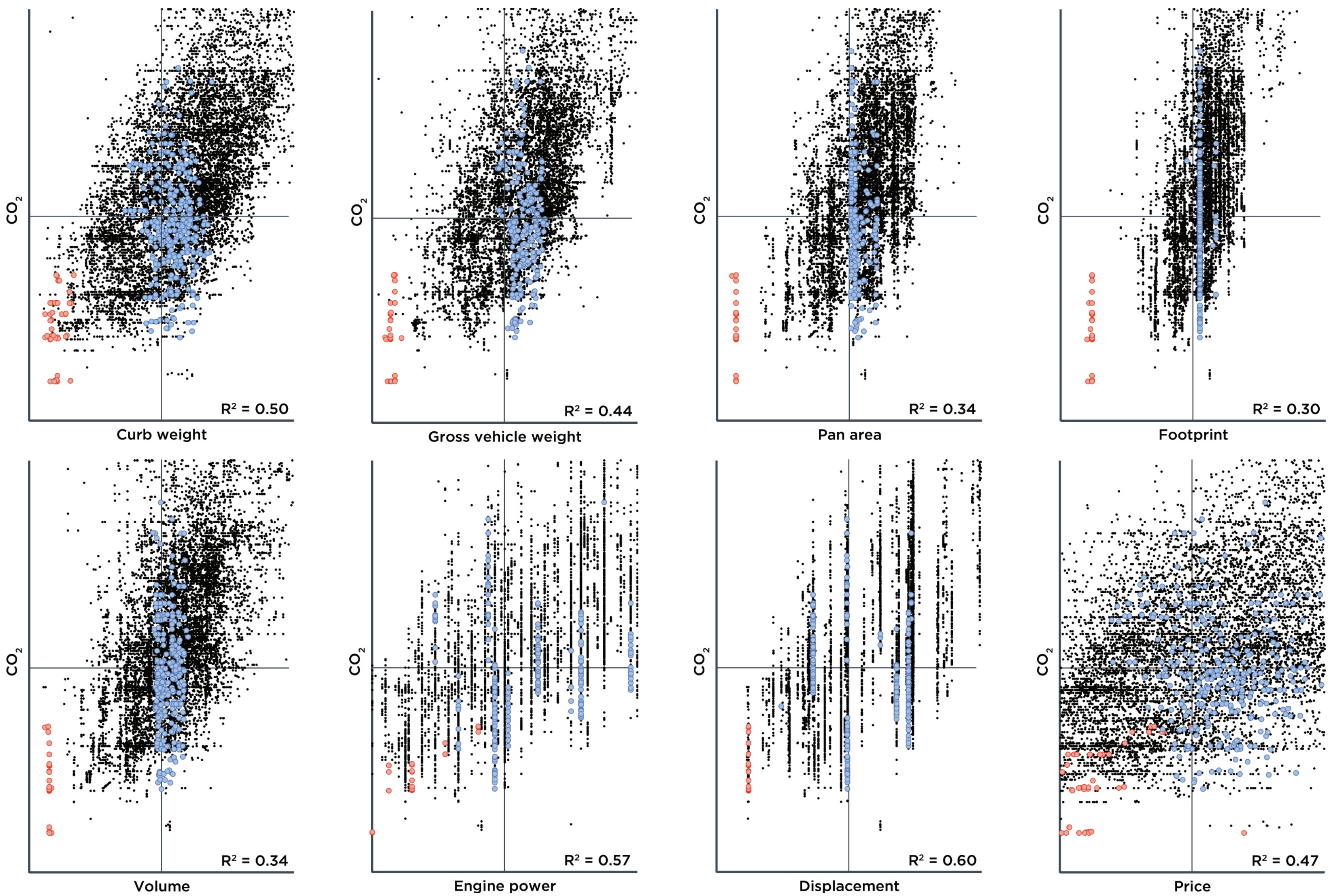

Figure 1. Correlation between potential index parameters and CO_2[4]

4 The scatter plots show the unweighted EU-27 market distribution in 2009. Therefore, each vehicle model variant equals one point on the plot, regardless of the number of sales. All plots are drawn to the same scale, with the sales-weighted average CO_2 emission and sales-weighted average of the respective index parameter in the middle and a level of 50% / 150% of these values on the far end corners of each plot. The red dots represent all model variants of the Smart fortwo, and the blue dots represent the model variants of the VW Golf. For price it should be noted that national sales taxes are included. The R^2 correlation numbers provided are based on the unweighted values.

2.2 Potential index parameters

Following is an extended list of potential index parameters. The relevant assessment criteria discussed in section 2.1 are applied to each of the index parameters in order to assess benefits and shortfalls for each of them. Table 3 summarizes the results.

2.2.1 FLAT STANDARD

Under a flat emission standard, every manufacturer's vehicle fleet has to meet the same emission target, without any consideration of the fleet characteristics and current emission level, in order to avoid penalties. This approach favors manufacturers that are focused on the production of vehicles at the "lower" end of the market spectrum and can set higher barriers for manufacturers of high-end and specialized vehicles. It can interfere with the competitiveness between manufacturers and, therefore, does not fully meet the diversity criteria.

On the other hand, it is a very simple, clearly defined concept, which characteristics help prevent gaming. It offers full flexibility in the sense that it does not discourage any technologies and also fully rewards downward shifts in the manufacturer's fleet composition offered on the market (i.e. selling more "lower-end" vehicles).

However, in the absence of a pooling or trading system (or other mechanism whereby progress on small vehicles can be exchanged to offset the emissions of larger vehicles), a flat standard could encourage upward shifts in vehicle size and less use of efficiency technology by manufacturers with an average emission level lower than the uniform target. This is because (in contrast to an attribute-based standard) it consider the specific characteristics of a manufacturer's fleet in setting the target.

It does not reflect any utility attributes as seen by customers and, unless it is offset by a compensation mechanism, could potentially lead to disadvantages from a social point of view—for example, disadvantaging large families that need vehicles with high passenger and luggage capacity.

2.2.2 CURB WEIGHT

The current CO_2 emission target for vehicles in the EU is based on curb weight.[5] This system allows higher emissions for heavier vehicles and lower emissions for lighter vehicles. CO_2 emissions and curb weight are highly correlated, i.e., heavier vehicles tend to emit more CO_2 than lighter vehicles. Given the differences in weight between the vehicles currently on the market, this means that by applying a weight-based system there is enough "horizontal spread" to maintain a broad diversity of vehicles (see Figure 1).

5 See section 1 for a detailed definition.

The strong correlation between CO_2 and weight follows from the strong physical relationship between the weight of the vehicle and the energy required to accelerate the vehicle and overcome resistances.[6] This means that reducing vehicle weight is an effective way of reducing the energy needed to drive the vehicle and therefore reducing emissions.

However, a weight-based vehicle emission standard discourages the reduction of vehicle weight, as lighter vehicles are subject to a lower CO_2 target. This weakness of a weight-based system is also noted by manufacturers. For example, Volkswagen commented on the 2008–2011 U.S. rulemaking that a weight-based system would discourage investments in vehicle weight reduction (VW 2004; NHTSA 2005).

The discouraging effect on reducing weight can be attenuated, but not eliminated, by choosing a target line that has a flatter slope than suggested by the physical correlation (see section 3). Nevertheless, even an alleviated weight-based emission target system will discourage weight reduction in general and the application of lightweight technologies in particular. It therefore limits the options and flexibilities for manufacturers to meet their targets (German and Lutsey 2010). As literature suggests, some lightweight technologies are already available at modest costs, and more are expected for the future (EPA/NHTSA 2010; Lutsey 2010; NAS 2010). Discouraging these technologies therefore will result in higher compliance costs than would otherwise be necessary.

Vehicle weight is not visible to the customer, does not create value for the customer, and therefore generally is not part of the purchase decision. Curb weight therefore is not a proxy for utility from a customer's perspective. More importantly, this disinterest of consumers toward the weight of their vehicle allows for gaming: manufacturers can, at relatively low cost, increase the curb weight of a vehicle (within certain boundaries) without the customer noticing it, resulting in a higher target for this now heavier vehicle.

Earlier studies have identified two options for increasing weight from a manufacturer's perspective: adding weight (a) without compensating for the loss in performance due to added weight, or (b) compensating for the loss in performance by increasing engine power (Fergusson, Smokers et al. 2007). Applying a slope of less than 80% in case (b) and less than 40% in case (a) can reduce these effects,[7] although it does not provide adequate incentive for light-weighting (AEA 2008; Fergusson, Smokers et al. 2008). However, a low slope causes the system to act more like a flat standard

6 On a plain surface the sum of resistances of a vehicle is: Acceleration resistance + rolling resistance + aerodynamic resistance = $c_1 * m * a + c_2 * f_r * m + c_3 * c_W * A * v^2$, with mass (m) as an integral part of both acceleration and rolling resistance, which are most relevant for inner-city driving situations. Other factors are: acceleration (a), rolling resistance of tires (f_r), aerodynamic coefficient of the vehicle (c_W), frontal area of vehicle (A), velocity (v), and constants (c_x).

7 Slopes in these sources are given based on a 2006 vehicle market regression line.

and can potentially lead to effects that would interfere with the diversity criterion (for a more detailed explanation see section 3).

In the U.S. it was found that using mass as the index parameter for vehicle emission standards is likely to result in higher vehicle and pedestrian crash fatalities compared to a size-based target system. This is mainly due to the fact that in a crash the more energy has to be absorbed by the involved vehicles the heavier they are, and to the improved rollover stability of vehicles with a larger footprint / pan area (ICCT 2009).

In terms of practicability, currently there exist difficulties with reporting harmonized curb weight information across manufacturers and EU member states (see footnote 1). But these difficulties should be overcome with the newly introduced requirements of the EC CO_2 monitoring (EU 2010). In general, data on vehicle mass is available and can be communicated in detail by manufacturers.

2.2.3 PAYLOAD AND GROSS WEIGHT

The amount of load a vehicle can carry is generally defined as payload. The sum of curb weight and payload is labeled gross weight. Both parameters are similar to curb weight in terms of their advantages and disadvantages, except that both index parameters offer significant additional potential for gaming. Gross weight (and as a consequence also payload) is determined predominantly by the dimensioning of suspensions, axles, brakes and tires of a vehicle. Those vehicle parts can be altered relatively easy and cheaply, without the customer necessarily noticing the changes. In addition, neither parameter is seen as a measure of utility by most customers.

2.2.4 PAN AREA (SHADOW)

The size of a vehicle, defined as length times width, is commonly referred to as “pan area,” or “shadow“ of a vehicle. An emission target system based on pan area allows larger vehicles to have higher emissions and requires smaller vehicles to meet lower targets. Pan area has reasonable correlation with CO_2 (Figure 1), i.e., larger vehicles tend to emit more CO_2 than smaller vehicles. Therefore a size-based emission standard allows for a broad diversity of vehicles on the market and ensures high neutrality with respect to competitiveness between manufacturers.

While there is some correlation between size and CO_2, it is weaker than that between weight and CO_2. Therefore, choosing size as an index parameter offers an important advantage: reducing vehicle weight becomes an feasible option for reducing vehicle emissions. A lower weight of the vehicle results in lower emissions (see footnote 6) but does not change the size of the vehicle; hence the target value remains the same. This provides an incentive for manufacturers to make use of all available options to reduce emissions, including lightweight technologies, and therefore leads to lower compliance costs for the same CO_2 reduction or higher CO_2 reductions for the same costs than under a weight-based standard.

Size is regularly identified as one of the top three decision criteria of customers when purchasing a vehicle, together with price (that can be seen as a proxy for size) (see for example Lane and Banks 2010). Customers are very well aware of the size of their vehicle and sensitive to any changes. Especially for inner-city driving, vehicle size is a relevant aspect.[8]

This sensitivity of consumers toward the vehicle size significantly limits the possibilities for gaming, i.e., manufacturers designing larger vehicles for easier compliance with emission targets (NHTSA 2005). While some gaming might be expected (as customers might tolerate minor changes in size) this could be further limited by choosing a target line with a relatively flat slope (see section 3). In any case, changing the size of a vehicle is expected to be much more difficult than changing the weight of a vehicle, in particular as it directly affects the design of a vehicle.

It should also be noted that there are fewer independent pan areas than there are vehicle weights (Figure 1). While the mass of technically identical vehicle models may differ due to variations in the interior design and equipment level, pan area (as well as footprint) allows for a more precise differentiation between vehicle models and comparison of emission levels within a group of technically equivalent vehicles.

Choosing pan area as an index parameter would require a careful definition of length and width of a vehicle. Increasing bumper length and adding parts such as wheel flares and body side moldings are relatively easy and cheap to do, hence these options would have to be excluded by a cautious definition of the vehicle dimensions to prevent gaming (NHTSA 2005). In general, data on vehicle length and width is available and communicated in detail by manufacturers. However, in contrast to footprint, it is not required to be reported by Regulation (EC) No 443/2009, so it is not as readily available as data on footprint.

2.2.5 FOOTPRINT

The product of the distance between the tires of a vehicle (wheelbase times track width) is called footprint. The characteristics of a footprint-based system are similar to those of a pan-area-based system, with some minor exceptions.

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8 Studies for the U.S. show that vehicle volume (data on pan area / footprint is only available for recent years) increased by less than 6% between 1980 and 2010 while during the same period vehicle weight increased by 13% (average annual increase is 0.2% for volume and 0.5% for weight) (EPA 2010). For the EU similar data on a vehicle fleet level is not available, but data for the VW Golf shows that the weight of the smallest gasoline version increased by more than 60% from 1974 to 2011, while pan area only increased by 25% (Buhl 1997; manufacturer data).

Vehicle footprint is difficult to change between model years, as it is a more integral part of a vehicle's design than pan area (NHTSA 2005). However, while this is true for a given vehicle design, it is possible to change vehicle footprint when completely redesigning a vehicle, i.e., when going from one model cycle to the next. It is likely that customers will not notice changes in vehicle footprint as easily as changes in pan area. Nevertheless, as it is difficult to increase track width much without changing overall width, and as increasing the wheelbase increases the turning radius and makes the vehicle more difficult to maneuver in urban settings, the potential for gaming is also sufficiently limited in a footprint-based emission target system.

One advantage of footprint versus pan area is that increasing track width and wheelbase helps reduce fatalities caused by vehicle rollovers; this effect is not necessarily as pronounced for pan area (NHTSA 2005).

Availability of data on footprint has been a problem in the past. It was in many cases provided by manufacturers but generally not included in the vehicle registration process at the EU member state level. Due to the requirements set by Regulation (EC) No. 443/2009, data on footprint will be readily available starting in 2011 (EU 2010).

2.2.6 VOLUME

Vehicle length times width times height defines the volume of a vehicle. A main disadvantage of a volume-based emission target system is the fact that the height of a vehicle can be altered relatively easily, simultaneously reducing the stringency of the emission target and increasing real-world emissions by worsening the aerodynamic shape of the vehicle and therefore increasing aerodynamic resistance. In general, technical measures to reduce aerodynamic resistance are more limited under a volume-based system than an area-based system, i.e., full flexibility is not given.[9] In addition, taller vehicles have higher centers of gravity, which can result in increased facilities and injuries due to degraded handling and additional rollovers (NHTSA 2005).

2.2.7 PERFORMANCE

In this context, performance refers to engine power, engine displacement, and top speed. Engine power and engine displacement both correlate well with CO_2 and allow for a wide "horizontal spread" of vehicles (Figure 1). Also, in those countries where vehicle taxation and / or insurance is based on one or more of these performance criteria, they are often

9 Aerodynamic resistance of a vehicle is defined by $c * c_w * A * v^2$, with the frontal area of the vehicle (A) calculated by multiplying width and height of the vehicle. Whereas under a volume-based target system both dimensions are affected, a size-based standard has implications only for the width of a vehicle. Other factors are: Aerodynamic coefficient of the vehicle (c_w), velocity (v), and constants (c).

identified as decision criteria of customers when purchasing a vehicle. A severe disadvantage of performance-based metrics is the level of gaming they allow. For a manufacturer it is relatively easy to add more engine power or displacement to the vehicle or increase the nominal top speed, thereby weakening the mandated emissions standard. In addition, decreasing power and displacement is an important measure to reduce emissions of a vehicle but would be penalized under a performance-based target system. With the advent of turbochargers, which allow downsizing engine displacement, this is especially true for displacement as an index parameter. All three performance criteria are also questionable with respect to their social implications, as more emissions are allowed for vehicles with higher power / displacement / top speed. The discontinuity of engine displacement data and the upper limit usually set electronically for top speed also pose problems regarding practicability of the parameters.

2.2.8 CAPACITY

The number of seating positions and the luggage compartment volume (boot volume or trunk volume) might be considered as being part of the customer's attention to size when purchasing a vehicle (Lane and Banks 2010) and as a good proxy of a vehicle's transport function. Especially in cases of purchasing a vehicle with more than five seats, the number of seats is expected to be an important decision-making criterion. Both parameters show a large "vertical spread," i.e., two vehicles with the same number of seats or the same boot volume can have significantly different CO_2 emissions. However, any use of the number of seats or boot volume would require a careful definition of these variables. Despite some existing regulation,[10] it might be challenging to accurately define the number of legitimate seats and boot volume for all vehicles (including hatchbacks, station wagons, vans, sport utility vehicles (SUVs)). These difficulties might result in an increased potential for gaming. Also, both seats and boot volume could encourage larger vehicles, with impacts on aerodynamics. Finally, in terms of practicability, boot volume is generally not reported at the moment, and the number of seats as a parameter does not allow for a small-step target function, therefore requiring a combination with other parameters.

2.2.9 PRICE

While vehicle price as an index parameter would be fully technology neutral, it would most likely not be considered socially equitable by most customers. It would mean, for instance, that two vehicles that are identical in construction but are sold under two different brands

10 See for example ISO 3832.

would have to meet different emission targets, with the one that is more expensive having the less stringent target. Furthermore, vehicle price is influenced by a number of exogenous factors, including taxes, inflation, and exchange rates. In particular, manufacturers that sell more cars in countries with a generally lower price level (e.g., Poland) would have to meet more stringent targets than manufacturers that sell similar vehicles but focus on markets with a higher price level (e.g., Germany). Another drawback of price as an index parameter is the potential it offers for gaming. The price of a vehicle can be set at will, without any technical modifications necessary. The only limitation for gaming is customers' price sensitivity. This generally is very high for lower segments of the market and less so for the top segments of the vehicle market. Hence, while there would be close to zero potential for manufacturers to game in the lower segments, it is to be expected that there would be significant potential for gaming in the premium segments of the market.

Table 3 summarizes the results of the assessment. Only a few index parameters meet the criteria previously set to a reasonable extent and are selected for an in-depth analysis in section 3: pan area; footprint; and a combination of pan area, seating capacity, and boot volume.

Both pan area and footprint are top-ranked in Table 3, and footprint is explicitly mentioned in Regulation (EC) No 443/2009 as a potential index parameter (EU 2009). While generally a combination of several criteria adds to the complexity of a standard, a combination of pan area, seats, and boot volume is included in order to mirror customer awareness of utility as closely as possible and to demonstrate the effects of a combination of parameters.

In addition, curb weight, although not favorable based on the analysis above, is included for comparison, as it is the index parameter currently used in the EU.

Table 3. Overview of potential index parameters including assessment

		Diversity competitively neutral, vertical spread	**Robustness** avoids perverse effects (gaming)	**Flexibility** no discrimination of technologies	**Representativeness** proxy for utility, socially equitable	**Comprehensiveness** avoid adverse effects, safety	**Practicability** data, continuous, definition, complexity
	Flat standard	-	++	++	--	o	++
WEIGHT	**Curb weight**	+	-	-	-	o	+
	Payload	+	--	-	-	o	+
	Gross weight	+	--	-	--	o	+
SIZE	**Pan area**	++	-	+	+	+	o
	Footprint	++	+	+	o	++	+
	Volume	++	-	o	o	-	+
PERFORMANCE	**Engine power**	+	--	-	-	o	+
	Displacement	+	--	-	-	o	-
	Top speed	+	--	-	-	o	-
CAPACITY	**Seats**	++	-	+	++	o	-
	Boot volume	++	-	+	++	o	-
	Price	++	-	++	--	o	-

Index parameter: Meets criterion substantially (++) / meets criterion (+) / does not affect criterion (o) / does not meet criterion in most cases (-) / does not meet criterion at all (--)

3 APPLYING A UTILITY PARAMETER INDEX

Following the identification of potential utility parameters for a CO_2 emission reduction target system, these parameters are applied to the European vehicle market in order to analyze effects on manufacturers and individual vehicles. Some general principles are discussed prior to this specifically European analysis.

3.1 General principles

Besides the decision regarding the utility index parameter itself, there are three other important design aspects that need to be considered for a utility-based CO_2 emission target system and that are universal for all utility parameters: the form and the slope of the target curve, as well as an autonomous increase of utility.

3.1.1 FORM OF THE CURVE

The current CO_2 emission performance targets for passenger cars in the EU are based on a linear target curve. The regulation specifies that "CO_2 targets for passenger cars should be defined according to the utility of the cars on a linear basis." (EU 2009). Other systems, for instance the GHG emission standards for light-duty vehicles in the U.S., share this linear approach (EU 2009). Nevertheless, it is in principle possible to design target systems with other curve shapes.[11]

Another aspect of the form of the target curve is the range of vehicles covered by the system. Under the U.S. GHG regulation for passenger cars, vehicles with a footprint size between 3.90 m^2 and 5.20 m^2 are subject to a linear increasing target line, while vehicles below or above these constraint limits are subject to a flat target (see Figure 8). As a result, manufacturers could potentially reduce the size of their smallest vehicles and improve the efficiency of these vehicles without any impact on the manufacturers' targets. This could then help to offset emissions of other vehicles that are above the target line, reducing the requirement to actually improve the efficiency of those vehicles. This effect becomes especially critical if not only a few special vehicles are affected but also a significant number of high-selling cars. On the other hand, the flat part at the large end of the U.S. GHG system encourages manufacturers to reduce the size of their largest vehicles, which has safety benefits by making the fleet more compatible.

11 For example, for the NHTSA 2008-2011 light-truck fuel economy standard a logistic function was used (NHTSA 2006). Generally, a concave function can be designed in such a way that it allows for setting higher target values for vehicles with larger utility (as is also the case for a linear function) while at the same time ensuring diminishing marginal increases, i.e., less emissions allowed for each additional unit of utility (which is different from a linear target system).

3.1.2 SLOPE OF THE CURVE

Provided that a linear function is chosen for the target system, the slope of the target line has to be defined. This is generally carried out in three steps (Figure 2):

1. Determine the sales-weighted trend line of all vehicles currently on the market.
2. Shift the trend line downward by applying the desired percentage reduction[12] to all points on the trend line. This implies that each vehicle / manufacturer needs to reduce emissions by the same percentage, although the absolute emission reductions required will vary depending on the baseline emission level. This approach ensures taking into account technological improvements. Whereas previously on average *x* g/km CO_2 were emitted per utility unit (for example *x* g/km per kg of vehicle curb weight) due to technological improvements, now only *x*(1 - *y*%) g/km per utility parameter unit are emitted. This new technological situation is reflected by the derived target line, which is called "100% slope curve."
3. Rotate the 100% slope curve around the set pivot point. For example, for an average target of 95 g/km the pivot point would be 95 g/km. The main reason for rotating the slope curve is that larger and heavier vehicles tend to have higher performance and proportionally more powerful engines. A 100% slope curve includes this performance differential, creating a slope with an artificial incentive to increase vehicle size/weight.

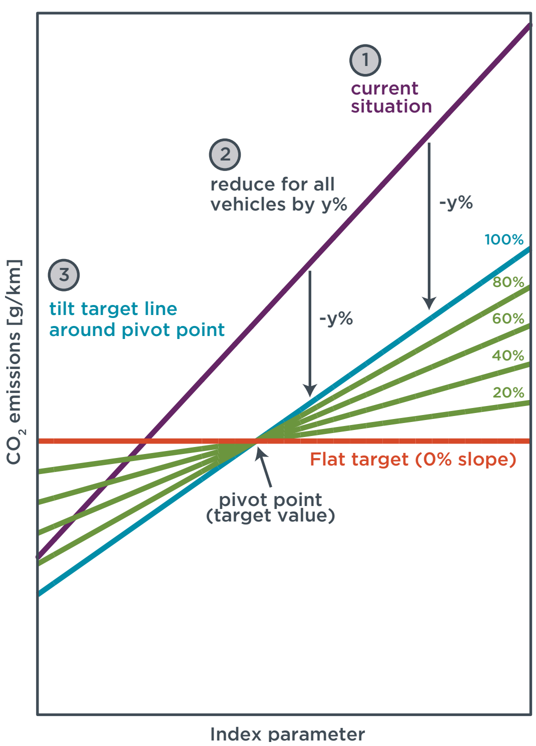

Figure 2. Schematic illustration for determining the slope of a target line

Thus, the goal is to find a compromise between the advantages and disadvantages of a flat and a utility-based emission reduction standard. A flat standard (i.e., with a slope of zero) imposes the same target value for each manufacturer and therefore does not meet the diversity criteria but at the same time avoids any opportunities for gaming (see section 2). On the other hand, a standard with a 100% slope curve fully takes into account utility of a vehicle but might be prone to gaming. The slope applied under the current weight-based target system in Europe is 60%, based on a 2006 market situation. Previous studies came to the conclusion that to fully prevent gaming under a weight-based system, a slope of less than 40% would have to be chosen (AEA 2008; Fergusson, Smokers et al. 2008).

The three-step approach described above was used for setting up the current EU regulation and is explained in more

12 Another feasible approach would be to apply an absolute reduction to all points instead of a percentage reduction.

detail in Fergusson, Smokers et al. (2007). Its generic principle is independent of the utility index parameter chosen and can be applied to any of the utility index parameters selected for in-depth analysis in section 2.

3.1.3 AUTONOMOUS INCREASE OF UTILITY

Historically, vehicle weight continuously increased over time. For example, data for the VW Golf shows that the weight of the smallest gasoline version increased by more than 60% from 1974 to 2011 (Buhl 1997, Volkswagen 2004). At the EU level, average weight for the new passenger car fleet increased by 2.4% from 2004 to 2007 (approximately 0.8% per year). In 2008 and 2009 the average weight decreased by 0.4% and 2.6% (EC 2010). However, preliminary data for 2010 suggests that average weight again increased by approximately 2%.

In the 2007 impact assessment this autonomous mass increase (AMI) effect was taken into account and three scenarios (increases of 0%, 0.82%, and 1.5% per year) were evaluated (EC 2007). The final regulation accommodated the historically observed AMI effect and set the expected average vehicle weight for 2015 higher than the average weight in 2006 (EU 2009). As the CO_2 emission target function is adapted on a regular basis to reflect any changes in the average weight of the new vehicle fleet, this AMI effect also has to be taken into account in the following analysis (see AEA (2008) for a detailed discussion of the issue). An annual increase of 0.5% is assumed. To be consistent, a similar autonomous increase is assumed for other utility parameters (footprint, pan area, and combined-utility). The rate of increase is always set at 0.5% per year.

It should be noted that from a general market point of view, taking autonomous parameter increase into account is necessary to achieve the overall objective in terms of g/km emissions. However, at the same time there might be opportunities for gaming for individual carmakers as increasing the average of one’s fleet faster than the market as a whole will give a competitive advantage. Conversely, manufacturers that increase their average less might be comparatively penalized.

3.2 Effects on the European passenger vehicle market

This section analyzes the effects of various systems specifically for the European passenger car market. The analysis starts by looking at the situation in 2006 and 2009 and then focuses on each of the four target systems identified earlier: curb weight, footprint, pan area, as well as a combination of seats, pan area, and trunk or boot volume.

3.2.1 THE SITUATION IN 2006 / 2009 AND THE 2015 TARGET

Figure 3 shows in grey color 98% of all passenger cars being sold in the EU-27 in 2009. The dark blue line represents a sales/registrations-weighted average line for 2009. The average CO_2 emission was 147 g/km, and the average vehicle mass was 1,345 kg.[13] Averages for individual manufacturers are represented by bubbles, with the size of the bubble representing the market share and the color indicating the region of origin for each manufacturer (e.g., green = France, blue = Germany, yellow = Italy, red = Asia). Table 4 includes the detailed data points per manufacturer.

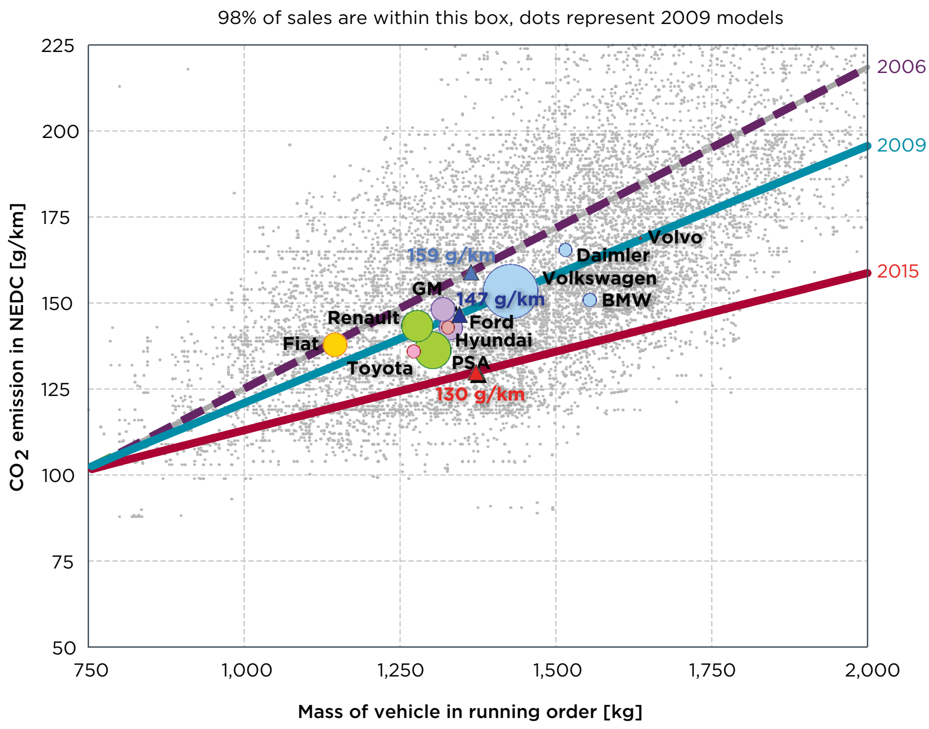

Figure 3. European market situation in 2006 / 2009 and target line 2015

The line in purple indicates the situation as it was in 2006, according to a report on behalf of the European Commission at that time (Fergusson, Smokers et al. 2007). The average CO_2 emission for the passenger car market in 2006 was 159 g/km and the average mass of the empty vehicle

13 The slope of the 2009 curve is: (x - 1345) × 0.0747 + 147

was 1,289 kg. This translates into approximately 1,364 kg when applying the mass definition used by the European Commission and in this report.[14] The average level of CO_2 emission decreased by approximately 8% between 2006 and 2009, and the average mass decreased slightly by approximately 1%.

The red line shows the target line as defined in Regulation (EC) No 46/2007 for 2015 (EU 2009). An average value of 130 g/km is to be achieved for an assumed average vehicle weight of 1,372 kg.[15]

Table 4. Sales/registrations-weighted averages per manufacturer in 2009

	CO_2 [g/km]	Ref. mass [kg]	Footprint [m²]	Pan area [m²]	Seats	Trunk vol. [l]	Combined utility factor	Sales/ Registrations
BMW	151	1,554	4.1	7.9	4.6	380	3.1	646,258
Daimler	165	1,516	4.0	7.5	4.4	429	3.1	622,101
Fiat	135	1,119	3.5	6.5	4.5	266	2.5	1,144,877
Ford	143	1,331	3.9	7.6	5.0	352	3.0	1,164,666
GM	148	1,319	3.8	7.3	5.1	311	2.9	1,169,527
Honda	146	1,366	3.8	7.5	5.4	424	3.3	212,754
Hyundai	143	1,327	3.8	7.0	5.0	334	2.9	527,292
Mazda	151	1,314	4.0	7.5	5.1	339	3.0	191,014
Mitsubishi	163	1,347	3.9	7.4	5.2	223	2.7	80,624
Other	196	1,664	4.0	8.3	5.0	451	3.4	154,527
PSA	136	1,302	3.8	7.2	4.9	427	3.2	1,780,144
Renault	143	1,278	3.9	7.3	5.0	368	3.0	1,621,076
Suzuki	143	1,159	3.5	6.5	4.6	237	2.5	226,405
Toyota	136	1,272	3.8	6.9	4.9	306	2.8	605,022
Volkswagen	153	1,427	4.0	7.7	4.9	386	3.1	2,828,545
Volvo	169	1,636	4.3	8.4	4.9	482	3.5	158,265
Average market	**147**	**1,345**	**3.9**	**7.3**	**4.9**	**364**	**3.0**	**13,172,918**

Based on the 2006 / 2009 market situation, Figure 4 summarizes the emission reduction efforts per manufacturer needed in order to reach the individual 2015 target levels according to Regulation (EC) No 2009/443. There were significant differences in burden sharing across manufacturers in 2006 While PSA, Renault and Fiat had to reduce emissions by approximately 14–19%, the reduction requirements for Daimler and BMW (with higher performance vehicles) were about 27%. By 2009 the average reduction needed for all manufacturers was now 12%, compared to 19% in

14 The slope of the 2006 curve is: (x - 1364) × 0.0934 + 159
15 The slope of the 2015 curve is: (x - 1372) × 0.0457 + 130

2006, but the progress made differed significantly by manufacturer, with BMW having made the biggest leap from a formerly reduction requirement of 27% to now 8%[16].

Figure 5 more clearly illustrates the remaining emission reduction requirements as of 2009 based on the 2015 target line. Daimler, Volvo, GM and Volkswagen still need to reduce their average fleet emissions by more than the market average requirements of approximately 12%.

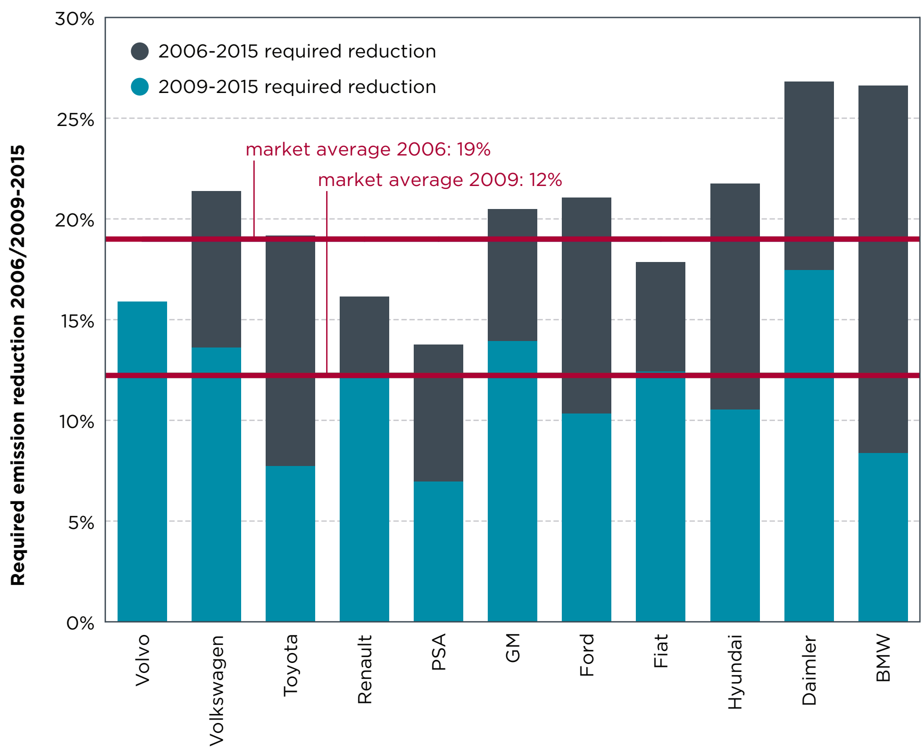

Figure 4. CO_2 emission reduction requirements per manufacturer in 2006 and 2009[17]

16 A more detailed analysis of the progress by manufacturer can be found in T&E (2010). The actual numbers vary from the numbers used in this report due to different datasets used (see definitions in chapter 1 of this report).

17 Target values are based on 2015 target line. 2006–2015 reduction requirements are based on 2006 vehicle mass data, 2009–2015 reduction requirements are based on 2009 vehicle mass data. 2006 data for Daimler includes Chrysler, data for Ford includes Volvo.

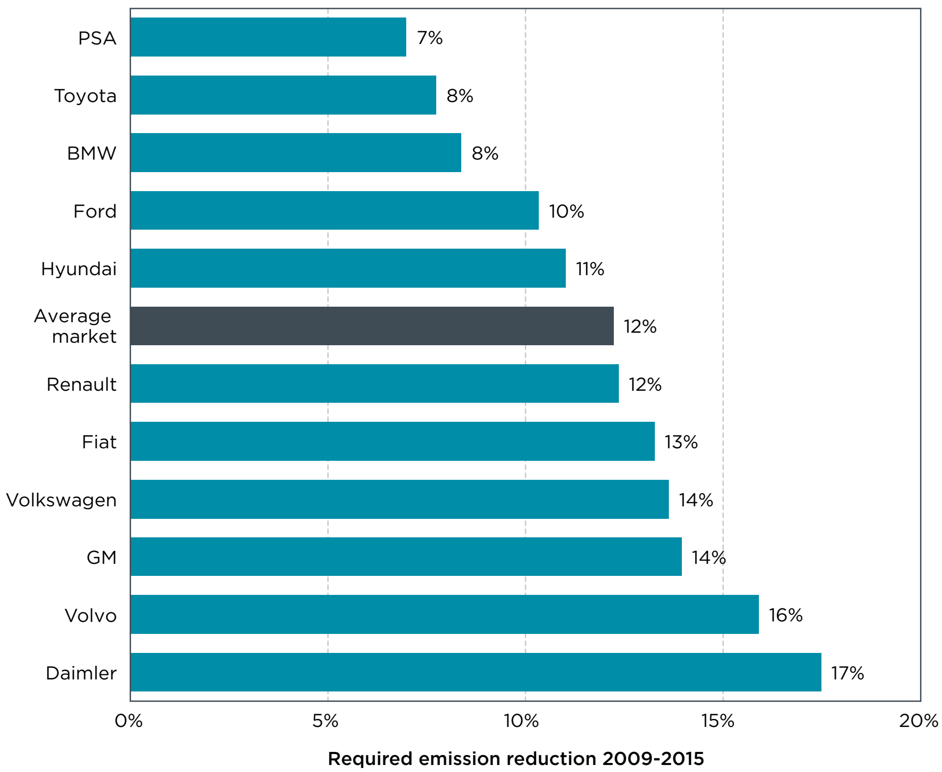

Figure 5. CO_2 emission reduction requirements per manufacturer in 2009[18]

18 Based on market situation in 2009 and 2015 target line.

3.2.2 A WEIGHT-BASED 95 G/KM TARGET

The 100% target line for 2020 in Figure 6 is derived by equally lowering the 2009 line by 35% and taking into account an AMI of 0.5% per year[19] (for a general explanation see section 3.1). This 100% target line can then be rotated around the 95 g/km pivot point to obtain a target line with a lower slope or ultimately a flat standard that would impose a target level of 95 g/km for all vehicles, regardless of their weight.

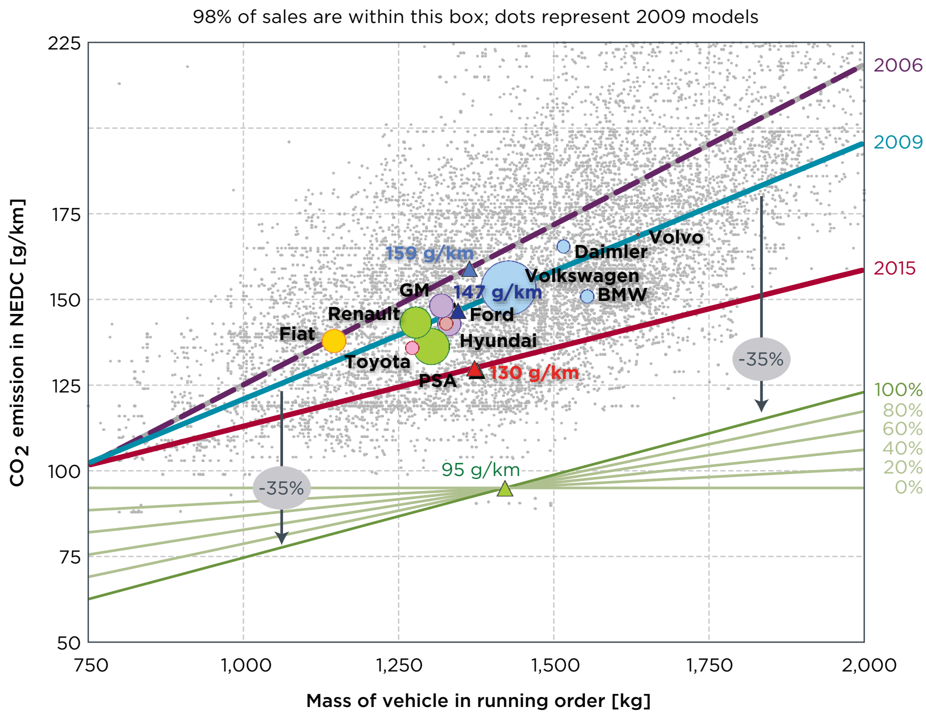

Figure 6. Options for a mass-based target system for reaching 95 g/km.[20]

Figure 7 illustrates the effect of changing the slope of the target line. It can be observed that for some manufacturers changing the slope has only a minimal effect or none at all with respect to the emission reduction required from 2009 to 2020.[21] These are generally the manufacturers that have a vehicle fleet with an average mass close to the average value for the entire vehicle market. Others, selling lighter vehicles (like Fiat) or heavier (Volvo, BMW and Daimler), are significantly affected by changes in the slope of the target line. The heavier the vehicle fleet the more advantageous is a higher slope weight-based emission standard system for the manufacturer.

19 The 35% decrease reflects the necessary reduction to get from 147 g/km in 2009 to 95 g/km in 2020. As the average vehicle weight in 2009 is lower than the assumed vehicle weight in 2020 (due to an AMI of 0.5% per year), the resulting decrease in emissions, based on the 2009 weight, is 39%.

20 The slope of the 100% target line is (x - 1345) × 0.0484 + 95.

21 An AMI of 0.5% per year is assumed.

There are trade-offs when determining the optimal slope of the target line. A system with a higher slope weight-based proportion of the target function carries a higher risk of gaming, as an increase in vehicle mass is less discouraged or eventually even encouraged (see sections 2 and 4). Furthermore, manufacturers of lighter vehicles are penalized compared to manufacturers of heavier vehicles. On the other hand, a flatter standard, not taking weight into account to a great extent, could disturb the current market structure and alter the variety of vehicles on the market. Earlier studies have suggested that a weight-based system with a slope of 40% or less (based on 2006 market data) is needed to ensure avoiding of any gaming (AEA 2008; Fergusson, Smokers et al. 2008). The current EU system makes use of a 60% slope, and it is likely that some up-weighting would have had occurred in absence of the general economic downturn of the past few years.

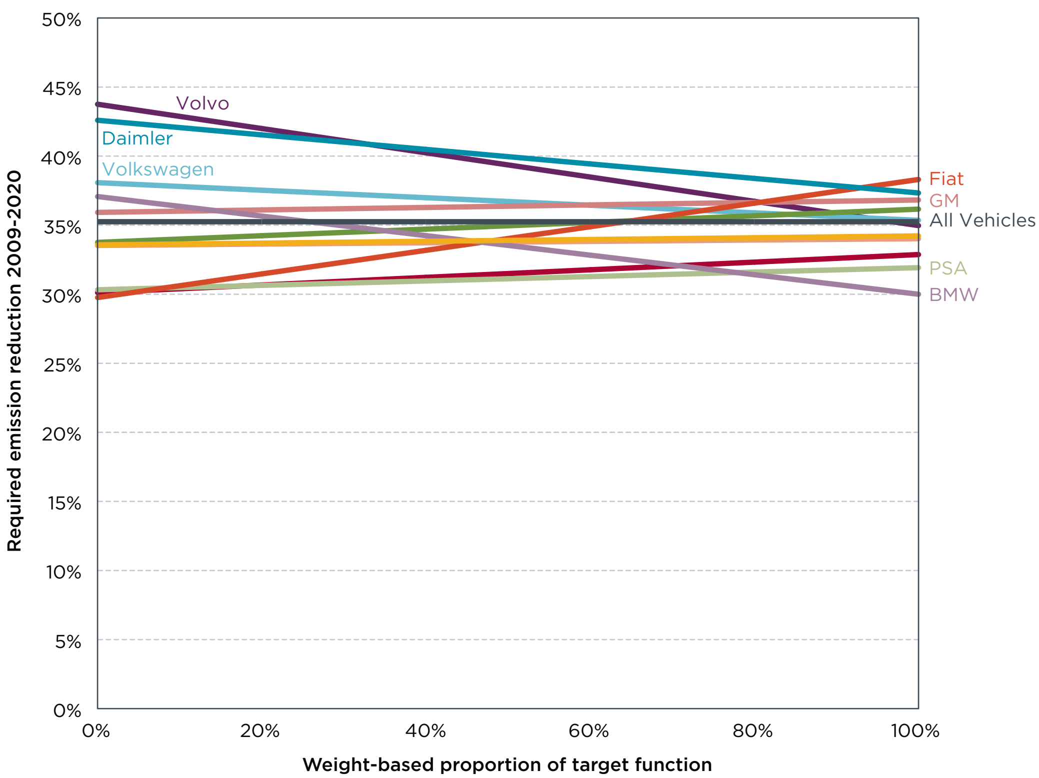

Figure 7. Effects of varying the emission target line slope (weight-based system)[22]

22 0% = flat target, 100% = weight fully taken into account.

3.2.3 A FOOTPRINT-BASED 95 G/KM TARGET

Figure 8 illustrates the situation when choosing footprint as a utility parameter. The grey dots, representing the available vehicle models, are less spread than under a weight-based system. The reason is that, even for different configurations with different weights, many vehicle variants of a model series share the same platform and therefore have the same dimensions. Whereas most cars tend to be in the 3.5–4.5 m^2 footprint range, the Smart fortwo has an exposed position with approximately 2.3 m^2 footprint.

The average footprint decreased from approximately 3.94 m^2 in 2006[23] to 3.87 m^2 in 2009. When comparing with Figure 6 for the mass-based system, it can be noted that the horizontal spread is less under a footprint-based system, with most vehicles in the range between 3.5 and 4.5 m^2 (ratio of 1.29) compared to a range of 1,000 kg to 1,750 kg (ratio of 1.75). This is also reflected by the fact that the fleet averages for most manufacturers are closer together than in a weight-based system. At the same time the vertical spread is distinctive within each footprint category. Generally, Fiat is selling the vehicle fleet with the lowest average footprint and Volvo the one with the highest average. BMW and Daimler, slightly set apart from the other manufacturers under a weight-based system, are now closer to the market average. (For detailed values, see Table 4).

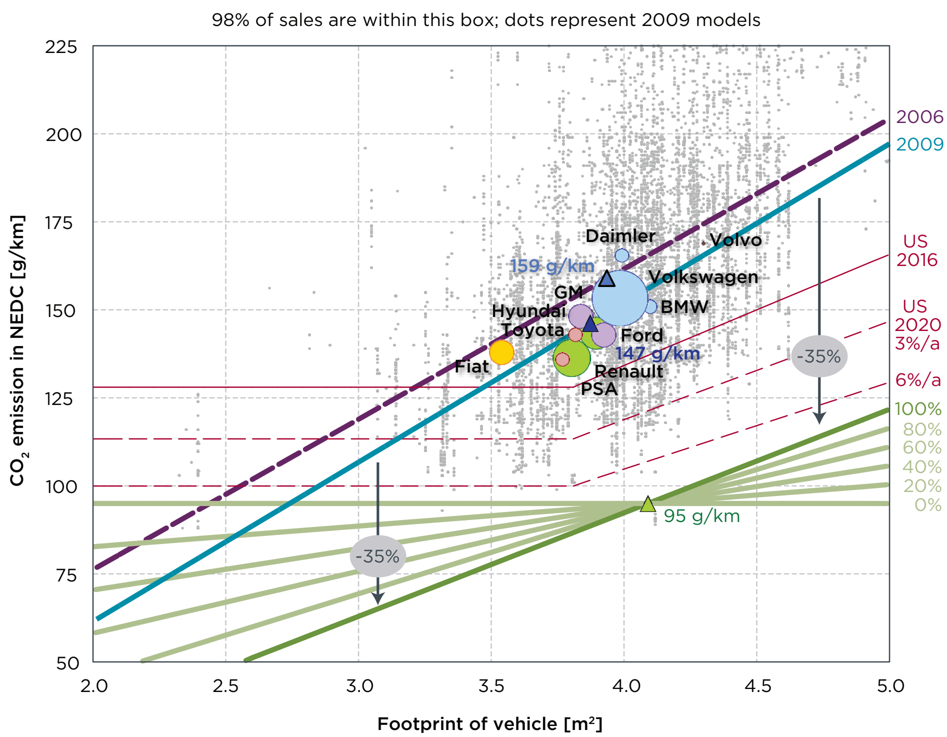

Figure 8. Options for a footprint-based target system for reaching 95 g/km.[24]

23 The 2006 footprint value was derived by taking the 2006 slope for pan area from Fergusson, M., R. Smokers, at al. (2007) and applying a conversion factor for going from pan area to footprint, derived in an earlier memo (it was found that for converting overall width of a vehicle into track width a factor of 0.86 should be used and for converting overall length into wheelbase a factor of 0.62) (ICCT 2010).

24 The slope of the 2009 curve is: (x - 3.87) × 45.2 + 147. The slope of the 100% target line is: (x - 4.09) × 29.4 + 95.

The 100% 95 g/km target line as well as 0–80% slope target lines are included in the chart. In addition, for comparison the respective footprint based greenhouse gas (GHG) emission target lines for passenger cars under the U.S. system are included.[25] The 2020 target is still under discussion, with a range of alternatives between 3% and 6% annual decrease. It can be seen that the 2016 U.S. target is lower than the 2009 average EU market situation and, depending on the outcome of discussions, the 2020 U.S. target line is likely to be close to the 2020 EU target. This is remarkable when keeping in mind the initially much higher emission level of the U.S. fleet.[26]

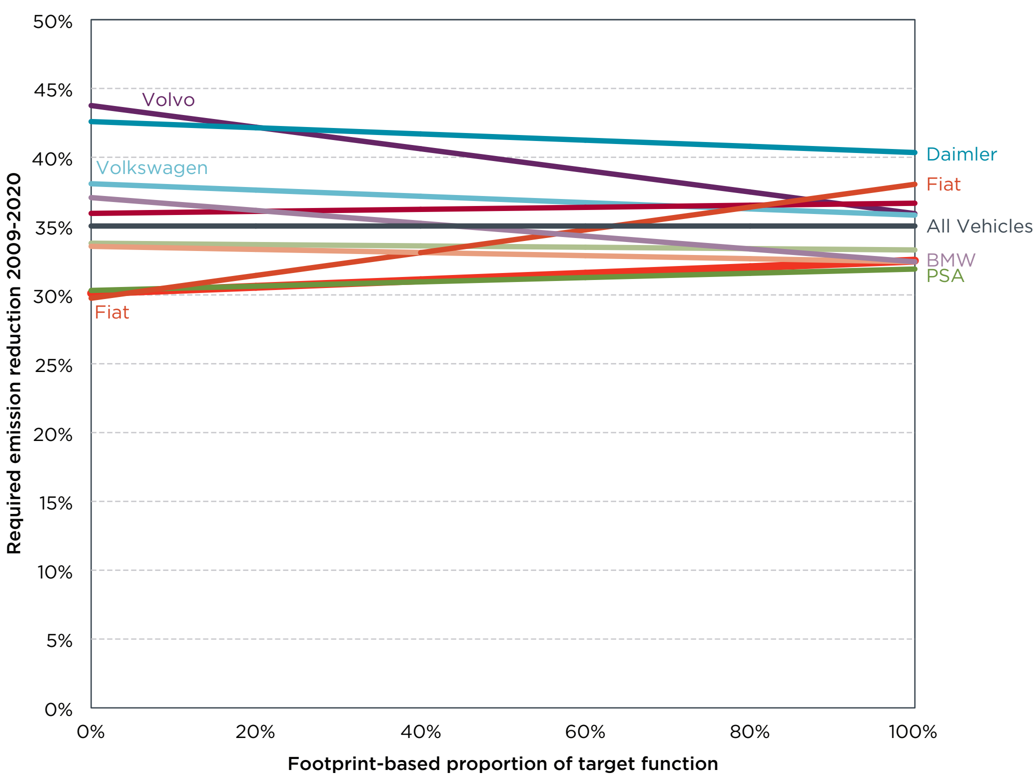

Figure 9. Effects of varying the emission target line slope (footprint-based system)[27]

From looking at the band of lines in Figure 9 one could conclude that a system with a footprint-based proportion of the target function of 100% would be most suited to ensuring similar emission reduction requirements for all manufacturers. However, although the potential for gaming is less under a size-based standard than under a weight-based system, the potential does still remain and should be further limited to the extent feasible. This issue has been discussed in the literature, and a slope for the target line of 60% or lower (based on 2006 market data) was suggested (Fergusson, Smokers et al. 2008).

25 Passenger cars make up approximately 50% of the new light duty vehicle fleet in the U.S.

26 280 g/km (U.S. passenger vehicles) vs. 154 g/km (EU) in 2008 (without conversion of test cycles).

27 0% = flat target, 100% = footprint fully taken into account.

3.2.4 A PAN-AREA-BASED 95 G/KM TARGET

Differences between the effects of a footprint-based and a pan-area-based target system are marginal (Figure 10 and Figure 11). The average pan area in 2009 was approximately 7.35 m^2 compared to approximately 7.40 m^2 in 2006. The horizontal spread is larger, with most vehicles in between 6.0 m^2 and 9.0 m^2 (ratio of 1.5) and manufacturers' averages being less clustered around the market average.

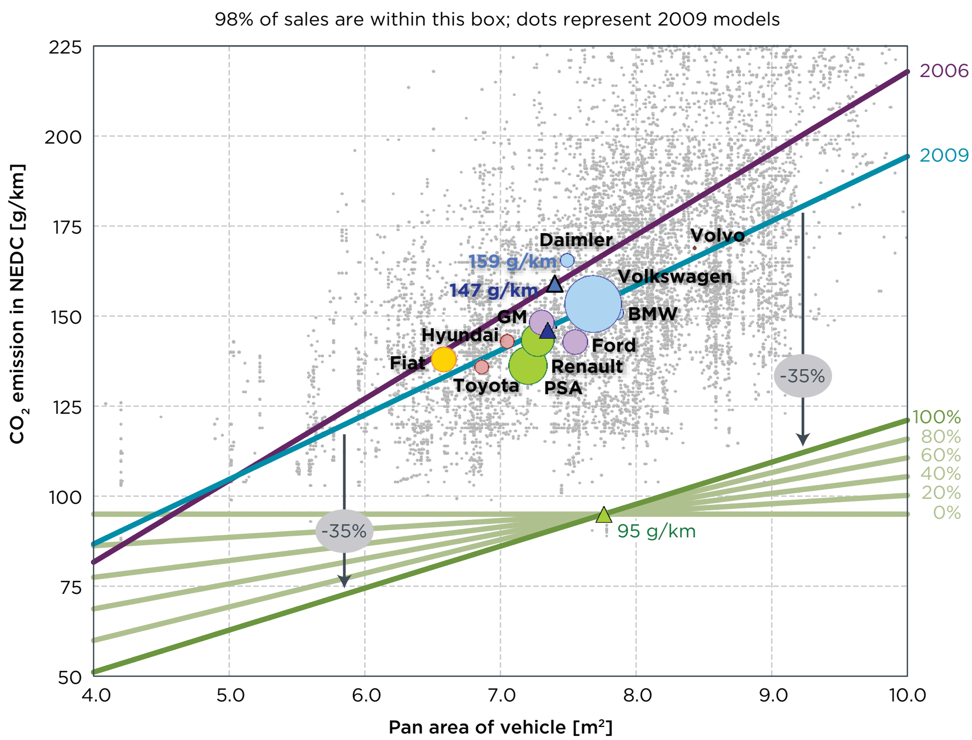

Figure 10. Options for a pan-area-based target system for reaching 95 g/km[28]

28 The slope of the 2009 line is (x - 7.76) × 17.9 + 147. The slope of the 100% target line is (x - 7.35) × 11.7 + 95.

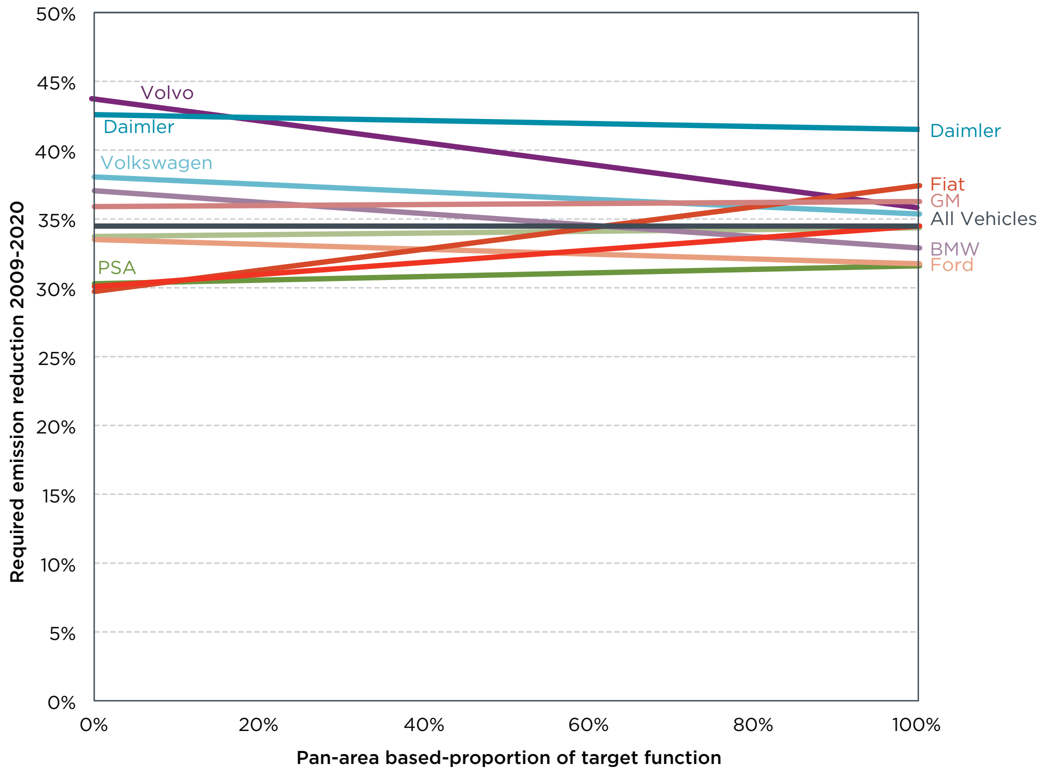

Figure 11. Effects of varying the emission target line slope (pan-area-based system)[29]

29 0% = flat target, 100% = pan area fully taken into account.

3.2.5 A COMBINED-UTILITY-BASED 95 G/KM TARGET

In order to show the effects of a combined-utility index parameter, the number of seats per vehicle, pan area, and trunk or boot volume[30] were chosen as appropriate individual indicators for customer interest and combined into a single utility parameter. This was done by normalizing each of the individual parameters by dividing by the average of the entire market and then summing up the three normalized indicators.[31] This ensures that each of the factors is weighted equally.

Figure 12 shows the result if this system is applied to the 2009 vehicle market. It can be observed that the horizontal spread for individual vehicles is larger than for any of the target systems analyzed previously. Most vehicle are now in between a utility of 2.0 and 4.0 (ratio of 2.0) and the chart covers a range from 1.5 to 4.5 (ratio of 3.0) compared to a ratio of about 1.5–1.75 for other index parameter-based systems analyzed earlier.

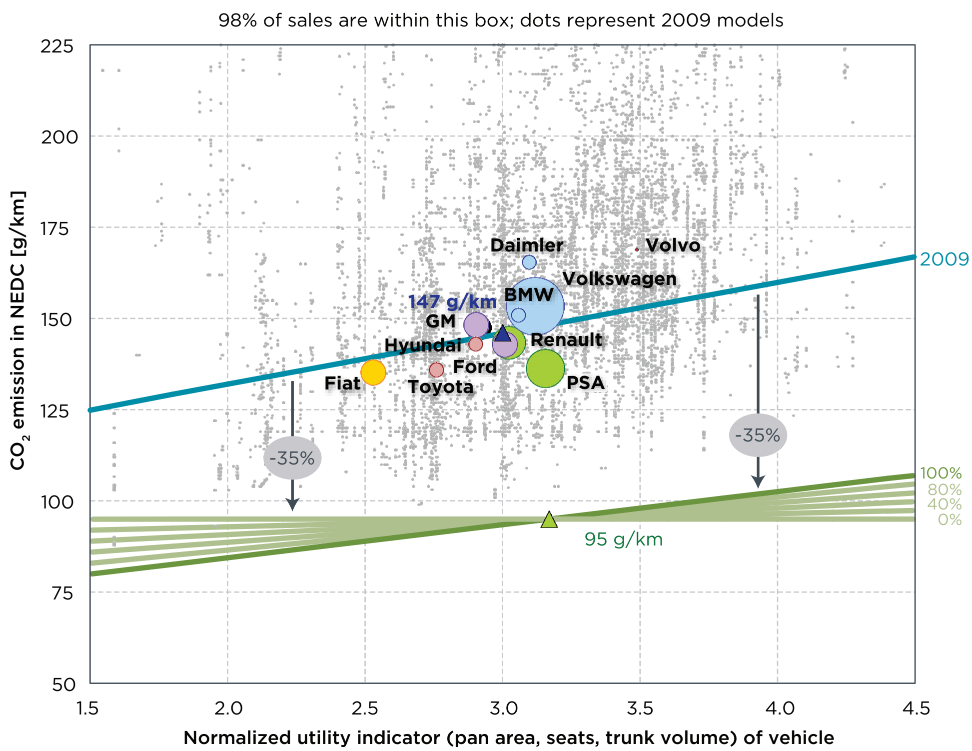

Figure 12. Options for a combined-utility parameter-based target system for reaching 95 g/km[32]

30 For the analysis the trunk volume with all seats in upright position is used.

31 For example, if a vehicle has 5 seats, a pan area of 7.30 m², a trunk volume of 1,305 liters and the market average is 4.9 seats, a pan area of 7.30 m² and a trunk volume of 1,193 l then the normalized indicators are 0.98, 1.00 and 1.09. The sum is 3.07 compared to the market average of 3.00, hence the vehicle has a slightly higher utility than the average vehicle on the market.

32 The slope for the 2009 line is (x -3) × 13.9 + 147. The slope for the 100% target line is: (x - 3) × 9.1 + 95.

For a given utility there are now vehicles on the market that can have significantly different CO_2 emissions. This results in a rather flat regression line, and the combined-utility indicator chosen for the analysis is quite similar to a flat target for all manufacturers (Figure 13).

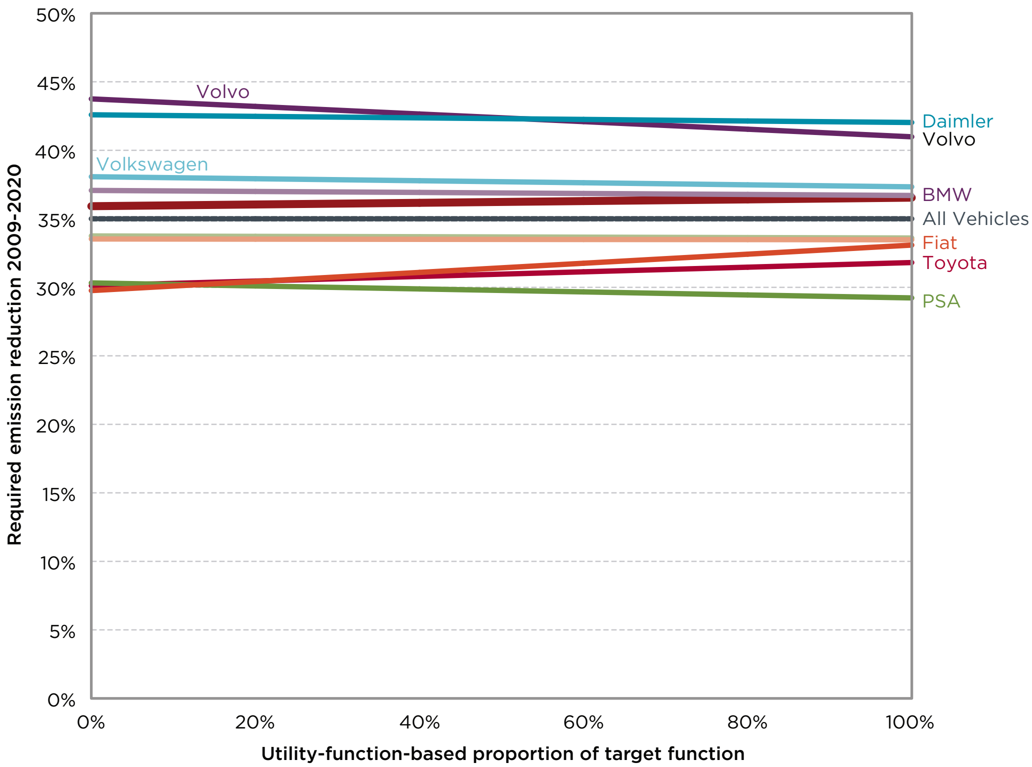

Figure 13. Effects of varying the emission target line slope (combined-utility-based system)[33]

33 0% = flat target, 100% = number of seats, pan area and trunk volume fully taken into account.

4 DISCUSSION OF RESULTS

In this section the potential emission target systems identified earlier are compared to each other and conclusions are drawn from comparing the effects of the various systems on manufacturers' averages and individual vehicles.

4.1 Selecting appropriate target systems for comparison

In section 2.2 a shortlist of potential index parameters was derived, consisting of pan area, footprint, curb weight, and a combination of pan area, seats, and boot volume. For each of the parameters a number of target systems can be designed, with varying slopes of the target line. For a meaningful comparison between different target systems it is necessary to select appropriate system configurations.

Generally, there are trade-offs when determining the optimal slope of the target line. A system with a higher slope carries a higher risk of gaming, while a flatter standard could disturb the current market structure and variety of vehicles on the market.

For a weight-based target system it is necessary to distinguish between the effects of small changes in weight (typically found when increasing weight to arrive at a less stringent emission target, i.e., gaming) and larger changes in weight (when reducing weight as a measure to reduce CO_2 emissions of a vehicle).

Larger changes in weight are generally linked to an adjustment of engine power and the transmission system to accommodate the new weight situation and ensure constant vehicle performance characteristics. The CO_2 effect of changes in weight, in combination with this engine and transmission system optimization, is specified by various sources at approximately 6.5% change in CO_2 per 10% change in weight, or approximately 7 g/km CO_2 for 100 kg of weight[34] (FKA 2007; EPA/NHTSA 2010; Koffler and Rohde-Brandenburger 2010).

Smaller changes in weight, however, may not be accompanied by a resizing of the powertrain of a vehicle. The resulting changes in CO_2 tend to be less noticeable and are quantified to be in the order of approximately 2%–4% change in CO_2 per 10% change in weight, or approximately 3–6 g/km CO_2 for 100 kg of weight (FKA 2007; EPA/NHTSA 2010; Koffler and Rohde-Brandenburger 2010). To reflect this relationship between change in weight and change in CO_2 emissions a slope of 0.03 is necessary; i.e., a weight-based target system with a slope of less than 0.03 is balanced in such a way that there is no incentive to increase or decrease vehicle weight significantly. In earlier studies, based on 2006

34 Calculation based on a vehicle weight of 1,345 kg and CO_2 emission of 147 g/km (equals EU-27 2009 average new vehicle).

vehicle market data, it was suggested that this corresponds to a target line slope of 40% or less (AEA 2008; Fergusson, Smokers et al. 2008). New calculations with 2009 vehicle market data show that this would correspond to a target line with a slope of 60% (the 2009 vehicle market regression line is flatter than the 2006 line). In view of these findings for the following comparisons a curb-weight based system with a 60% slope (based on 2009 vehicle market data) is selected.

Making changes to the size of a vehicle is expected to be much more difficult than changing the weight of a vehicle, as explained in section 2.2. Earlier studies suggested that a slope of 60% (based on 2006 market data) for a size-based emission target system should be sufficient to avoid gaming (Fergusson, Smokers et al. 2008). For the following comparison, and also to be in line with the slope for the weight-based target system, a 60% slope is therefore selected for both the footprint as well as the pan-area-based emission target system.

For a combined-utility parameter-based system similar estimates for an appropriate slope of the target line do not exist. A slope of 60% is selected for the assessment to be in line with the slopes for the mass- and size-based systems, but it should be noted that a combined-utility-parameter system is most likely prone to gaming and might require a lower slope than size-based systems.

4.2 Comparison of analyzed target systems at the fleet level

An overall comparison of the different index parameter-based target systems and varying target-line slopes discussed earlier reveals that the differences in terms of emission reductions required are relatively small (Figure 14 and Tables 5a and 5b). The average required reduction effort under a weight- or size-based system is 35%, with a range from 31% to 42% for the main manufacturers (when comparing 60% slope systems).

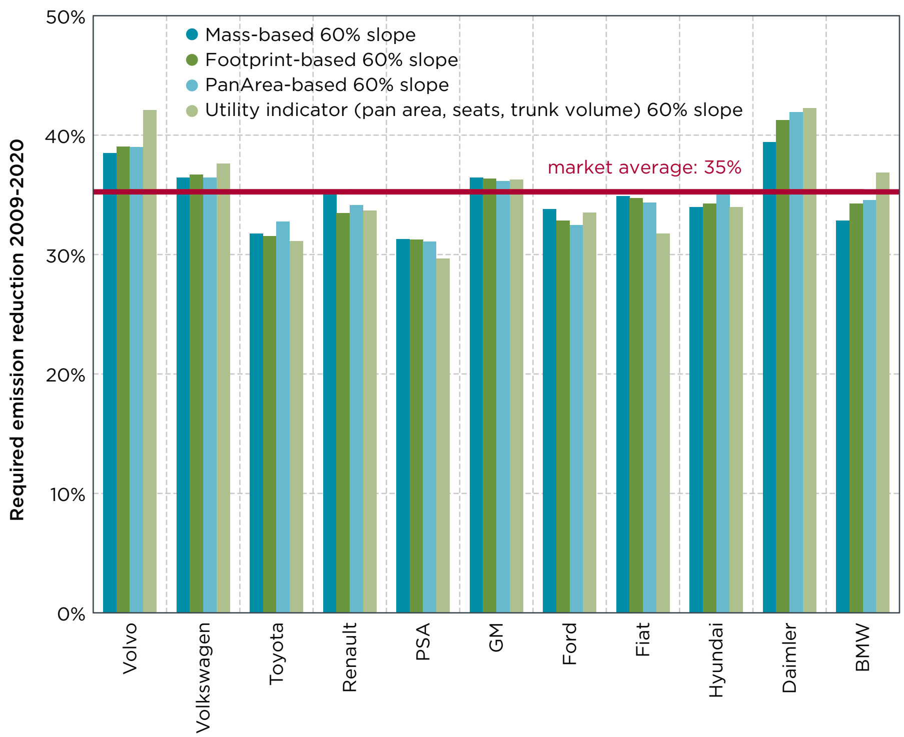

Figure 14. Required emission reductions 2009-2020 under different systems / slopes

In fact, most manufacturers are affected hardly at all by changes in the target system. For all main manufacturers except BMW and Daimler, the differences between a 60% weight-based and a 60% size-based target system in terms of required 2009–2020 emission reductions are between 0g and 2 g/km CO_2. BMW and Daimler, due to the structure of their fleets, are the manufacturers most affected by changes in the target system. The difference between the current 60% weight-based and a 60% size-based system is 2–4 g/km CO_2 for both manufacturers, which is still relatively small compared to their overall reduction requirements of approximately 50–70 g/km CO_2.

The differences between a footprint-based and a pan-area-based system are negligible for most manufacturers. The combined-utility index parameter-based target system leads to more significant differences in reduction targets among manufacturers, even though most manufacturers are still little affected. Yet, for BMW, Daimler, Fiat and Volvo the differences between a 60% weight-based and 60% utility index parameter-based target system amount to 4–6 g/km CO_2, with Fiat being subject to less reductions than under a weight-based system and BMW, Daimler and Volvo being required to reduce emissions more than under a weight-based system.

Table 5a. Required emission reductions for different systems and target line slopes, in percent.

	Curb weight			Footprint			Pan area			Pan area, seats, trunk volume		
Slope	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**
BMW	34%	33%	31%	35%	34%	33%	35%	35%	34%	37%	37%	37%
Daimler	40%	39%	38%	42%	41%	41%	42%	42%	42%	42%	42%	42%
Fiat	34%	36%	37%	34%	36%	37%	34%	35%	37%	32%	33%	34%
Ford	34%	34%	34%	33%	33%	33%	33%	32%	32%	34%	33%	33%
GM	36%	36%	37%	36%	36%	37%	36%	36%	36%	36%	36%	36%
Honda	35%	34%	34%	35%	36%	36%	34%	34%	34%	34%	34%	33%
Hyundai	34%	34%	34%	34%	34%	35%	35%	35%	36%	34%	34%	34%
Mazda	37%	38%	38%	36%	36%	36%	36%	36%	36%	37%	37%	37%
Mitsubishi	42%	42%	42%	42%	42%	42%	42%	41%	41%	42%	43%	43%
Other	48%	46%	45%	51%	50%	50%	49%	48%	47%	51%	50%	50%
PSA	31%	31%	32%	31%	31%	32%	31%	31%	31%	30%	30%	29%
Renault	35%	35%	36%	34%	33%	33%	34%	34%	34%	34%	34%	34%
Suzuki	36%	37%	39%	37%	38%	40%	36%	38%	39%	35%	35%	36%
Toyota	31%	32%	32%	31%	32%	32%	32%	33%	34%	31%	31%	31%
Volkswagen	37%	36%	36%	37%	37%	36%	37%	36%	36%	38%	38%	37%
Volvo	40%	38%	37%	41%	39%	37%	41%	39%	37%	43%	42%	42%
Average market	**35%**	**35%**	**35%**	**35%**	**35%**	**35%**	**35%**	**35%**	**35%**	**35%**	**35%**	**35%**

Table 5b. Required emission reductions for different systems and target line slopes in g/km.

	Curb weight			Footprint			Pan area			Pan area, seats, trunk volume		
Slope	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**
BMW	52	50	47	53	52	50	53	52	51	56	56	56
Daimler	67	65	64	69	68	68	70	69	69	70	70	70
Fiat	47	49	51	47	49	51	47	49	51	45	45	46
Ford	48	48	48	47	47	47	47	46	46	48	48	48
GM	54	54	54	54	54	54	53	54	54	54	54	54
Honda	50	50	50	51	52	52	50	50	50	50	49	49
Hyundai	48	49	49	49	49	49	49	50	51	48	49	49
Mazda	56	57	57	55	54	54	55	54	54	56	56	56
Mitsubishi	68	68	68	68	68	68	68	68	67	69	70	70
Other	94	91	88	99	98	97	96	94	91	99	98	98
PSA	42	43	43	42	43	43	42	42	43	41	40	40
Renault	50	50	51	48	48	48	49	49	49	48	48	48
Suzuki	51	53	55	52	55	57	52	54	56	50	51	52
Toyota	42	43	44	42	43	44	43	45	46	42	42	43
Volkswagen	57	56	55	57	56	56	57	56	55	58	58	58
Volvo	68	65	62	69	66	63	69	66	63	72	71	70
Average market	**51**	**51**	**51**	**51**	**51**	**51**	**51**	**51**	**51**	**51**	**51**	**51**

A comparison at the manufacturers' fleet level leads to the conclusion that the differences in 2009–2020 emission reduction requirements are minor, with negligible variations for most manufacturers and a maximum variation of 4 g/km CO_2 for the main manufacturers when comparing a 60% weight-based target and a 60% size-based target system. Stronger effects of a change in the index parameter are only observed for some low-volume manufacturers (that are likely to be covered by derogation rules) and the combined-utility index parameter-based target system.

4.3 Comparison of analyzed target systems at the vehicle level

Analyzing the effects of different target systems and slopes on individual vehicles can be helpful to understand and illustrate the consequences at the manufacturers' averages level. Such an analysis at the vehicle level is also important in order to ensure that no important types of vehicles are unintentionally favored or disfavored to a great extent under a specific target system.

For the following analysis eight different vehicle models were chosen to represent major types of vehicles found on the European vehicle market:

- **Smart fortwo** (currently the smallest high-volume selling car on the market)
- **Fiat Panda** (top-selling small car)
- **VW Golf** (top-selling compact car)
- **Toyota Prius** (hybrid vehicle)
- **Renault Scenic** (high sales volume family mini-van)
- **Mercedes-Benz S-Class** (high-end premium car)
- **BMW X5** (high sales volume sport utility vehicle)
- **Porsche 911** (relatively high-volume sports car)

Figure 15 illustrates and compares the required 2009–2020 emission reductions for each vehicle model under different target systems and slopes.

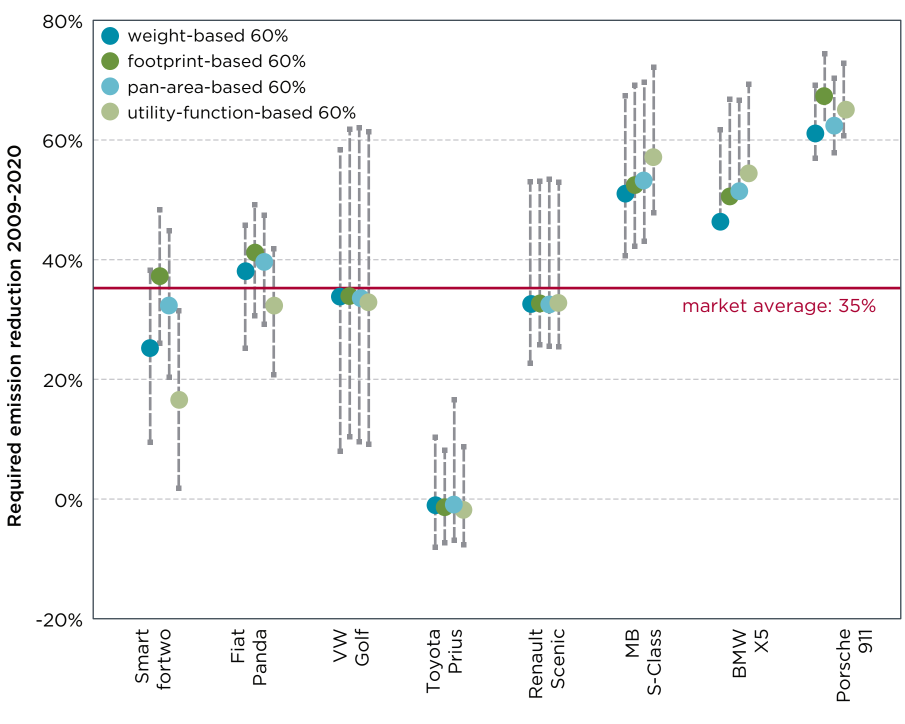

Figure 15. Emission reduction requirements (2009–2020) for individual vehicles[35]

35 The dashed lines indicate the range of available variants for each of the vehicle models in 2009, with the solid circle being the sales-weighted average of all model variants sold in the EU-27 in 2009.

The average CO_2 emissions of the Smart fortwo models on the market are approximately 104 g/km, with a range from 86 g/km to 126 g/km, depending on the model variant. Being currently the vehicle with (for some variants) the lowest CO_2 emissions on the European market the Smart fortwo would benefit most from a flat emission target level. Hence, the average emission reduction required under a utility-function-based system (that was shown to lead to similar results as a flat target) is 17%, compared to 25% under a 60% weight based target system. The reductions required in a size-based system are higher, 32% or 37% under a 60% footprint-based or pan-area-based target system. Nevertheless, the required reduction would likely still be less than for the average market, and there are variants within the Smart fortwo model range that require less than 20%–30% emission reduction to meet 2020 targets under any of the target systems analyzed.

Similar to the Smart fortwo, the Fiat Panda faces a lower emission reduction target under utility-function-based system. However, a 60% weight- or size-based system would have comparable effects. The average emission level (133 g/km) is higher than for the Smart fortwo, and the emission reduction required is generally slightly above the market average.

For the VW Golf, average required emission reduction is always slightly below the market average, with almost no differences between the various utility parameter systems. Especially interesting about the Golf are the differences within the model family. While the average emission level is at approximately 143 g/km, there are variants, such as the 77 kW TDI BlueMotion (99 g/km), that are close to meeting the required emission level of 2020 already today.

Similarly, the Toyota Prius meets the emission target levels envisaged for 2020 now. The current average CO_2 emission of this Toyota model is approximately 95 g/km, which is low for a vehicle of its size thanks to the applied hybrid propulsion system. As a result, the Prius meets the average market emission reduction required under all systems.

For the Renault Scenic (on average 146 g/km CO_2 emissions), the required emissions reductions are slightly above the market average, with no noticeable differences between the systems.

The Mercedes-Benz S-Class is both relatively heavy and relatively large compared to the average car on the market. Again, the differences between a weight-based and a size-based system are minor in terms of required CO_2 emission reductions. The average current emission level for the S-Class family is approximately 230 g/km.

For the BMW X5, the average emission level is at around 218 g/km. There are some higher-emission model variants with up to 286 g/km, but those are sold only in low numbers. Given its weight, around 2,200 kg, the X5 benefits from a mass-based target system. The required emissions reduction under a mass-based target system is approximately 46%, compared to 51% under a size-based target system.

The average CO_2 emissions of the Porsche 911 are approximately 260 g/km, more than the X5 though it weighs significantly less (1,590 kg). As a result, the required emission reduction level is approximately 60%. The difference between the weight-based and the pan-area-based systems is negligible, but the difference in emissions reduction is about 5% compared to a footprint-based system. It should be noted in this context that the Porsche 911 features a unique rear-engine design that affects its footprint and does not apply to other vehicles. A combined-utility index parameter-based target function slightly disfavors the 911, mainly due to its very limited trunk volume.

As a result of the comparison of different attribute parameter target systems at an individual vehicle level, the conclusion can be drawn that none of the vehicle models analyzed is overly preferred or discriminated against by any of the target systems.

4.4 Assessment of overall benefits and shortfalls

As was shown in the previous section, from a competitiveness point of view a weight-based system with an appropriate slope to avoid gaming and a size-based system are very similar. Neither at the manufacturers' fleet level nor at the level of individual vehicles were effects found that would prohibit a change from the current weight-based to a size-based system. Only a combined-utility index parameter-based target function was found to have somewhat more significant effects for some of the manufacturers, and it will therefore not be considered in the following section.

Table 6 summarizes the benefits and shortfalls of target systems based on curb weight, pan area, and footprint. The differences between both size-based systems are minor, with footprint having some advantages in terms of safety issues and pan area potentially being more representative from a customer's perspective of view. Also, data on footprint will be readily available beginning in 2011, due to requirements in Regulation (EC) No 443/2009.

However, in comparison to a size-based system, the curb weight-based system has some systemic shortfalls and, from a consumer's point of view, represents the utility of a vehicle far less accurately than size. Unlike size, the weight of the vehicle is not important, or even generally known, to the consumer. As discussed earlier, changing the weight of a vehicle is expected to be much easier than changing its size, so that the curb weight-based system is likely to be more prone to gaming. This shortfall can be absorbed to some degree by choosing a flat slope of the target line.

Table 6. Summary of assessment for key attribute parameter options

	Diversity competitively neutral, vertical spread	**Robustness** avoids perverse effects (gaming)	**Flexibility** no discrimination of technologies	**Representativeness** proxy for utility, socially equitable	**Comprehensiveness** avoid adverse effects, safety	**Practicability** data, continuous, definition, complexity
Curb weight	+	-	-	-	o	+
Pan area	++	-	+	+	+	o
Footprint	++	+	+	o	++	+

Index parameter: Meets criterion substantially (++) / meets criterion (+) / does not affect criterion (o) / does not meet criterion in most cases (-) / does not meet criterion at all (--)

Another major shortfall of a weight-based target system cannot be fully corrected: its lack of technology neutrality and in particular the way it discriminates against lightweighting as a measure to increase efficiency and reduce CO_2 emissions. Figure 16 illustrates this major drawback of any weight-based emission target system:

- A manufacturer with a vehicle or fleet average meeting its individual emission target can expect a certain amount of CO_2 emissions reduction from decreasing the weight of a vehicle or its entire vehicle fleet (approximately 6 g/km CO_2 per 100 kg of weight-variation). However, under a weight-based target system any decrease in weight results in a lower, more stringent, emission target.
- With a 100% slope this leads to the effect that the manufacturer's vehicle or fleet, which previously met its emission target, is now again located on the target line, i.e., it barely meets its new emissions target. Therefore, under a 100% weight-based system there is no incentive to apply lightweighting as a measure to reduce CO_2 emissions.
- This effect is less pronounced under a 60% weight-based system. Here the manufacturer's vehicle or fleet, following a 100 kg weight reduction, is located slightly below the target line, i.e., the target is met but there is only limited advantage from the manufacturer's perspective compared to the situation before weight reduction (as the target was also met before applying lightweighting). Therefore, compared to a 100% weight-based system, a 60% slope does not discourage the application of lightweighting to the same extend, but it also does not provide any strong incentive toward lightweighting.

Under a size-based target system, on the other hand, a change in vehicle weight does not result in any change of the emission target to be met. Therefore, any CO_2 benefits from reducing weight are fully taken into account for meeting a manufacturer's target, and there is a strong incentive for manufacturers to reduce the weight of their vehicles. Under a size-based system, lightweighting is a full-fledged measure to reduce CO_2 emissions and can help to meet future emissions targets more effectively at lower costs than would otherwise be necessary. For example, a 10% decrease in the weight of the EU passenger car fleet would result in approximately 8 g/km lower CO_2 emissions and therefore contribute about 15% of the total required emissions reduction between 2009 and 2020, or more than 20% of the required reduction between 2015 and 2020.

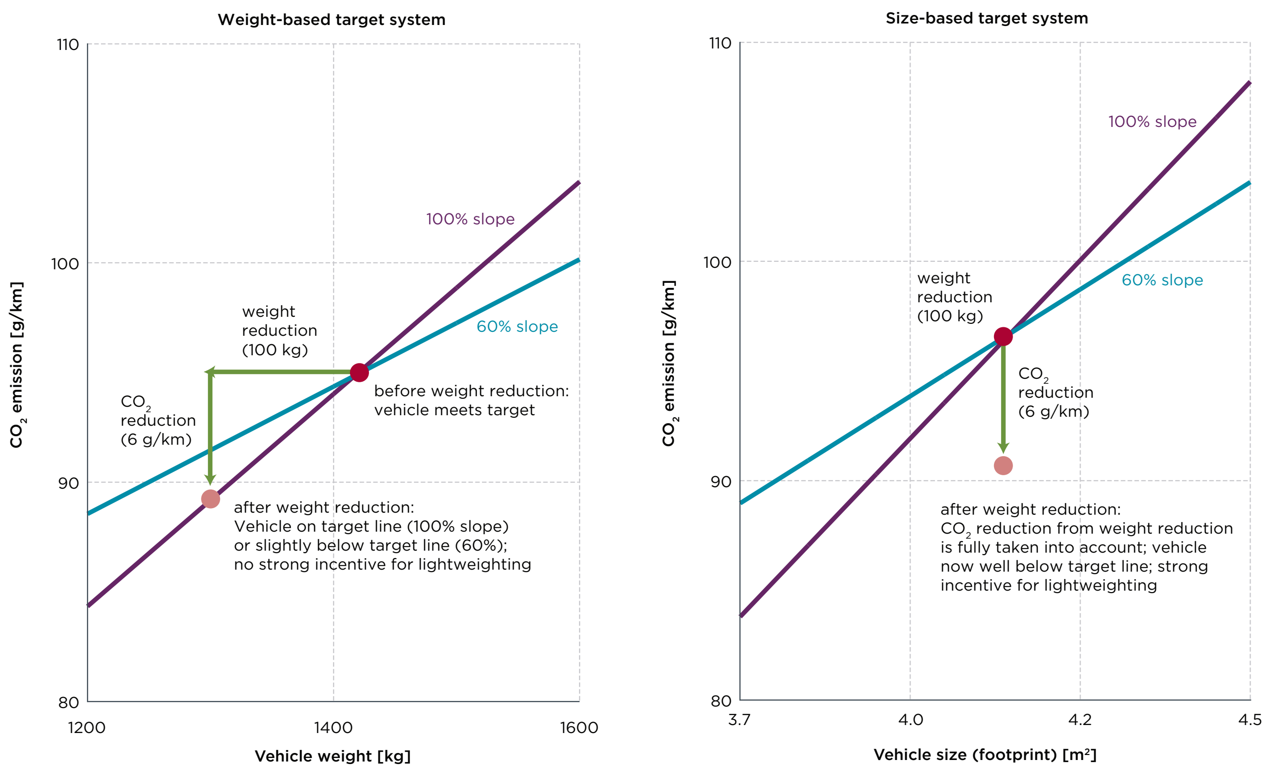

Figure 16. Impact of lightweighting under a weight and size based emission target system.

The importance of fully taking into account the benefits of lightweighting is even more evident when considering synergies between a lower vehicle weight and other vehicle components. For example, a lower vehicle weight allows the use of smaller batteries for hybrid electric vehicles, thereby saving costs and ensuring a better cost/benefit ratio for meeting future emission targets. Furthermore, it should be noted that costs for lightweight technologies in general are expected to drop significantly in the near future, with high-volume production and new possibilities in computer-aided design of vehicle structures (Lutsey 2010).

5 CONCLUSIONS AND RECOMMENDATIONS

The analysis provided shows that neither a footprint- nor a pan-area-based emission target system requires significantly different emission reductions from manufacturers than under the current weight-based system. From a competitiveness point of view, all three systems are very similar.

At the same time a size-based target system makes it more easy and cost effective for manufacturers to comply with their targets, by ensuring that lightweighting is treated as a full-fledged measure to increase efficiency and reduce CO_2 emissions. This is not the case for a weight-based system, where reduction of vehicle weight is discouraged or, at best, not encouraged.

Based on the findings of this analysis, it is therefore recommended to change the underlying index parameter for the 95 g/km CO_2 emission target from weight-based to size-based, in order to fully permit and reward emission reductions from applying lightweight materials and down-weighting in general, allowing future emission targets to be met more easily and cost-effectively. The choice between footprint- and pan-area-based systems is secondary, with some advantages for a footprint-based system, in particular with respect to availability of data. Maximum attention should be paid to carefully defining the size parameter used in order to prevent gaming.

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