

# **CO<sub>2</sub> Emission Reduction Potential for Passenger Cars and Light Commercial Vehicles Post 2020**

## **Management Summary 123320**

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Institut für Kraftfahrzeuge  
Strategy and Consulting

## Management Summary

# CO<sub>2</sub> Emission Reduction Potential for Passenger Cars and Light Commercial Vehicles Post 2020

Project Number

123320

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## 1 Key Results of the Study

The present study analyzes the technologically realizable and economically viable CO<sub>2</sub> reduction potential for passenger cars and light commercial vehicles by 2025 and 2030. Therefore, a scenario based analysis is performed. A range of consistent developments is projected from three scenarios (conservative, trend, progressive) and compared with currently discussed target values. The EU legislation requires that the average CO<sub>2</sub> emission from new passenger cars (PC) in Europe have to be reduced to 95 g CO<sub>2</sub>/km towards the end of 2020 (ca. -33 % compared to 2010), while the target value for light commercial vehicles (LCV) amounts to 147 g CO<sub>2</sub>/km in 2020 (ca. -21 % compared to 2011). With regard to the further development of the CO<sub>2</sub> legislation, the European Commission has stated an indicative target range of 68 – 78 g CO<sub>2</sub>/km for PCs in 2025 for a comprehensive impact assessment.

Based on the results of a technology screening, it is shown that a reduction of the average CO<sub>2</sub> fleet emission is enabled by the introduction of innovative technologies and the evolutionary enhancement of existing technologies also in the context of the accompanying decrease of production costs. For a reduction of complexity, the identified single technologies are combined to technology packages, which successively build upon each other and extend the relevant technological measures for each step. The technology packages are representative vehicle, respectively drive train variants for each vehicle segment which are available as technology alternatives in the future and are used in the following modelling.

In a first step, the theoretical minimum CO<sub>2</sub> fleet emission level in Europe which could be realized in a pure technical assessment is determined for each technology package, assuming its fleet wide implementation (100 % market penetration). To take account of autonomous demand driven changes of the fuel mix and the vehicle segments until 2030, a so-called market structure effect is defined. Therefore the results show, depending on the scenario, that CO<sub>2</sub> fleet emission levels for passenger cars of 86 to minimal 77 g CO<sub>2</sub>/km in the year 2025 and 81 down to minimal 66 g CO<sub>2</sub>/km in the year 2030 would theoretically result by an overall introduction of technology packages based on combustion engines. With a fleet wide introduction of hybrid technologies, without external recharging possibilities of the regular grid, emissions could ideally be reduced to 72 to minimal 64 g CO<sub>2</sub>/km (2025) respectively 67 to minimal 54 g CO<sub>2</sub>/km (2030). Assuming a theoretic fleet wide use of Plug-In Hybrids (PHEV), emission levels of 32 to minimal 30 g CO<sub>2</sub>/km (2025) or 30 to minimal 26 g CO<sub>2</sub>/km (2030) would result within the current framework of the NEDC testing procedure. The corresponding additional production costs to achieve the minimal CO<sub>2</sub> fleet emissions of passenger cars increase progressively while moving from conventionally based technology packages via hybrid drive trains to Plug-In Hybrids. In the case of a 100 % market penetration of the lowest available emission technology package level, the additional production costs per vehicle in the year 2025 would amount up to € 3,550 (€ 4,150) for conventional technologies, € 5,400 (€ 5,750) for hybrid technologies and up to € 8,050 (€ 8,250) for PHEV technologies.

In the market of light commercial vehicles, a fleet wide implementation of conventional technology packages would theoretically lead to an emission level of 120 down to minimal 109 g CO<sub>2</sub>/km in the year 2025 and 116 down to minimal 97 g CO<sub>2</sub>/km in the year 2030. By an overall usage of hybrid technologies, emission levels of 101 to a minimum of 90 g CO<sub>2</sub>/km (2025) respectively 97 to a minimum of 78 g CO<sub>2</sub>/km (2030) would result. A complete PHEV fleet in Europe would yield an emission level of 50 down to minimal 46 g CO<sub>2</sub>/km in the year 2025 or 48 down to minimal 41 g CO<sub>2</sub>/km in the year 2030. The corresponding costs increase progressively with lower-emission technology packages, in analogy to PC. In the case of a 100 % market penetration of the particular lowest available emission technology package, the additional production costs per vehicle in the year 2025 would amount up to € 5,000 (€ 5,300) for conventional technologies, € 7,250 (€ 7,350) for hybrid technologies and up to € 9,000 (€ 8,900) for PHEV technologies.

As a second step, after the derivation of the theoretical technological realizable CO<sub>2</sub> fleet reduction potential, a scenario based analysis concerning the economic viability for PC and LCV is carried out. Therefore, the end customer's perspective is considered. Consequently, it is assumed that additional production costs can be passed on to the end customer and that they benefit from the fuel cost savings over the assumed average period of vehicle ownership. The end customers buy the technology packages for a retail price which is assumed to be on average about 60 % higher than the production costs due to value added taxes, distribution and sales as well as guarantee costs, provisions and the profit margin of the manufacturer. Based on the modelled investment decisions of private and commercial customers it is shown which technology packages would amortize in the periods up to 2025 and 2030 for each vehicle segment. Within the trend scenario for PC, which takes a moderate increase of fuel prices into account, the expected reduction of fleet emissions to 96 g CO<sub>2</sub>/km (-32 % - including the market structure effect) by 2025 is achieved on the basis of conventional technologies, which appear to be most cost effective from the customer's perspective. By 2030 both hybrid and PHEV technology packages will become economically attractive especially in higher segment vehicles, thereby reducing fleet emissions to 79 g CO<sub>2</sub>/km (-44 % - including the market structure effect). As a consequence of the increasing hybridization and usage of PHEV in higher vehicle segments, the CO<sub>2</sub> fleet emissions would increasingly be decoupled from the vehicle mass, thus causing a flattening of the corresponding CO<sub>2</sub> regression line in the market.

The derived theoretical technologically realizable and economically viable CO<sub>2</sub> fleet emission levels represent objective guidelines for the further development of the CO<sub>2</sub> regulation of PC and LCV. The results show that by 2025 fleet emissions of 96 g CO<sub>2</sub>/km would be achieved in the trend scenario. The discussed target range of 68 – 78 g CO<sub>2</sub>/km for PC in the year 2025 would result in significantly higher production costs, which could not be amortized solely by the corresponding fuels savings in an end customer perspective. A theoretical adopted target value of 68 g CO<sub>2</sub>/km by 2025 would increase the production costs per vehicle by € 3,200 – 4,100, assuming a cost optimal technology mix. Thus, a subsequent raise of vehicle retail prices would be caused, which would not fully amortize within the assumed average period of vehicle ownership. Vehicle manufacturers would need to take over the non-

amortizing additional production cost, so that the end customer would decide for the emission reduced drive train version and the specific fleet target could be met. These remaining costs would amount to € 500 in the progressive scenario and € 3,300 in the conservative scenario. Due to the progressive character of the cost curve for innovative technologies, a linear update of the emission target value would result in high financial burdens for vehicle manufacturers. Even under the most favourable conditions within the progressive scenario merely an emission level of 78 g CO<sub>2</sub>/km would be achievable by 2025, taking the end customer's consideration of economic efficiency into account.

Regarding LCV, CO<sub>2</sub> fleet emissions would decrease towards the level of 140 g CO<sub>2</sub>/km (-25 %) by 2025 and 135 g CO<sub>2</sub>/km by 2030 under the prevailing conditions. Within the trend scenario, this reduction of the CO<sub>2</sub> emissions would be achieved merely by the use of conventional technology packages. To date, no explicit target value proposals for the period after 2020 have been published for LCV.

With regard to an improvement of the economic CO<sub>2</sub> emission target achievement, it is further to examine, how it can be optimized, so that ambitious CO<sub>2</sub> fleet targets become economically viable for manufacturers and end customers. A pure forward projection of the current system would not achieve this. A flexibilisation of the objectives, considering their substance and temporal definition, would offer new possibilities for vehicle manufacturers to achieve the targets cost efficiently. Here, eco-innovations could take an emission reduction potential in real world driving into account which is not measureable in the standardized testing procedure. Another option is a banking/borrowing system, which offers the vehicle manufacturers a better innovation planning over several model cycles. Furthermore, an emission trading system, with or without an intersectoral integration, is discussed in this study, which may reduce or eliminate the disadvantages of the current CO<sub>2</sub> regime. These disadvantages are among others the progressive increasing marginal abatement costs and the violation of the not given technology neutrality due to the mass based definition of the emission targets. The current study suggests further research considering the possible design and impact of such a system.

The future task for the European Commission is to ensure a neutral to competition, socially compatible and sustainable legislation for both PC and LCV. The long-term competitive neutrality of future CO<sub>2</sub> regulations needs also be assured when various conventional and electrified drive train concepts compete in the market. The European Commission should investigate in an impact assessment which alternatives and additions to the currently implemented CO<sub>2</sub> legislation with specific fleet targets arise, so that the long term climate targets of the European Union are achievable in an economically reasonable way. Pure forward projections of the current system for new vehicles will foreseeable reach economic limits.

## 2 Introduction and Methodological Approach

The European Union is committed to the goal of reducing the anthropogenic greenhouse gas (GHG) emission within the community by 80 – 95 % until the year 2050 compared to 1990. For this purpose the transportation sector is expected to contribute a considerable share. According to the EU Agenda “A Roadmap for Moving to a Competitive Low Carbon Economy in 2050” [EUR11a] and the Transport White Paper [EUR11b], the transportation sector is expected to reduce its greenhouse gas emissions by at least 60 % until 2050. The CO<sub>2</sub> emission from road transport is responsible for about 22.4 % of the anthropogenic CO<sub>2</sub> emission of the EU28 [EEA14a].

Regulating the CO<sub>2</sub> emissions from new passenger cars (PC) and light commercial vehicles (LCV) is a key instrument at European level to reduce emissions from road traffic. According to the recently amended regulation (EG) No. 443/2009 the average CO<sub>2</sub> fleet emissions for PC in Europe must be reduced to 130 g CO<sub>2</sub>/km by 2015 and 95 g CO<sub>2</sub>/km by the end of 2020. Further the CO<sub>2</sub> emissions for new LCV must be reduced to 147 g CO<sub>2</sub>/km by 2020 according to regulation (EG) No. 510/2011. The Council and the European Parliament have given the task to the European Commission to review both regulations until the end of 2015 and to submit proposals for the amendment of acts, including the definition of realistic and achievable fleet targets for new passenger cars and light commercial vehicles for the period after 2020 [EUR14b] [EUR14c].

The Federal Ministry of Economics and Energy in Germany (BMWi) assigned the Institute for Automotive Engineering at RWTH Aachen University (Institut für Kraftfahrzeuge - ika) to perform a study on the technologically realizable and economically viable CO<sub>2</sub> reduction potential for PC and LCV by 2025 and 2030. The methodological approach is structured as follows. The first step is a purely technological scenario based analysis, taking into account the available technologies in the mass market, their respective reduction potentials and corresponding additional production costs. In the next step, all technologies are further examined regarding their market penetration potential, based on the end customer demand. End customers of commercially used vehicles are expected mainly to decide for a technology if the higher retail price would fully amortize by the corresponding fuel cost savings. Customers of privately used vehicles are modelled in a more complex way by defining five customer groups with a different willingness to pay more than the economically reasonable price.

The results regarding the CO<sub>2</sub> fleet target values and corresponding curves derived in the present study constitute objective guidelines for the development of a CO<sub>2</sub> regulation after 2020/2021. Furthermore, the impact of changes on key parameters regarding the CO<sub>2</sub> fleet emissions is analyzed for German and European vehicle manufacturers. Finally, possible measures to improve both the costs and economic efficiency of CO<sub>2</sub> regulations are considered. The results contained in the present study are expected to be included in the upcoming discussions at EU level on the development of CO<sub>2</sub> regulations on passenger cars and light commercial vehicles.

### 3 Environmental Analysis

The average CO<sub>2</sub> emission of new PCs sold in Europe in 2010 (reference year for PCs) was 141 g CO<sub>2</sub>/km [EEA11] [ERN12], while new LCVs reached an average of 187 g CO<sub>2</sub>/km in their reference year 2011 [POL12] [ERN13]. When comparing these values to the mass-based CO<sub>2</sub> target value specifications for PCs and LCVs, high demands on absolute and relative reduction in CO<sub>2</sub> fleet emission emerge. While the target value for PCs declines from 130 g CO<sub>2</sub>/km in 2015 to 95 g CO<sub>2</sub>/km by the end of 2020, the target for LCVs goes down from 175 g CO<sub>2</sub>/km in 2017 to 147 g CO<sub>2</sub>/km by 2020. With regard to the further development of the CO<sub>2</sub> legislation, the European Commission has stated an indicative target range of 68 – 78 g CO<sub>2</sub>/km for PCs in 2025 for a comprehensive impact assessment [EUR14]. This corresponds (in absolute terms) to a linear development of the current legislative CO<sub>2</sub> reduction path, thus representing the most challenging target values in a global comparison.

In order to evaluate future target values all framework assumptions, for example regarding demand shifts between vehicle segments or drive concepts, have to be taken into account. Therefore, a scenario based continuation of the data basis from previous studies [ERN12] [ERN13] is utilized for the period up to 2030. The core results of the environmental analysis are summarized in Fig. 3-1 and Fig. 3-2.

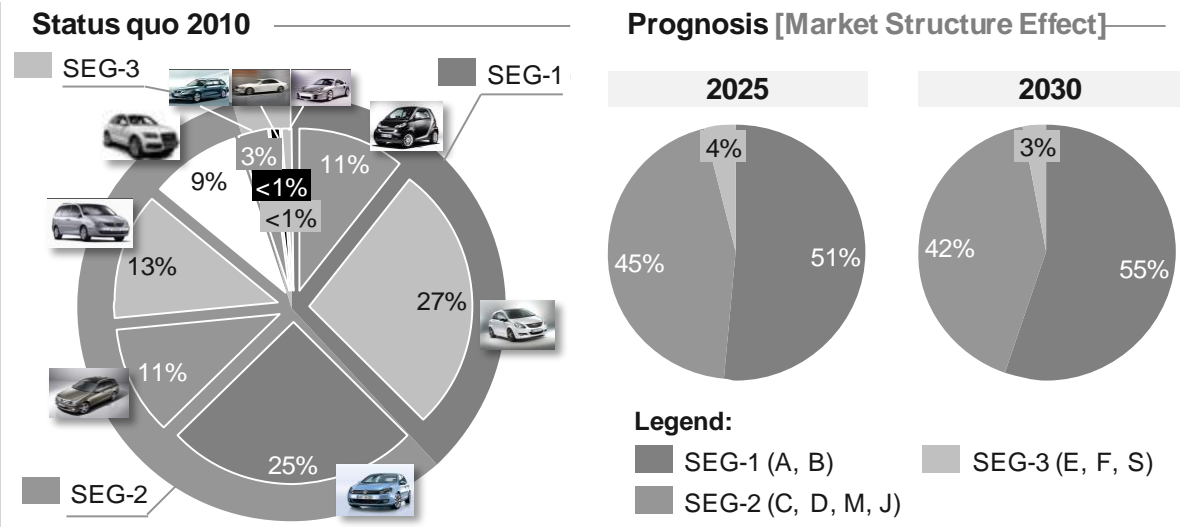
The highest volume segment in the European car market is the SEG-2 with 58 %, dominated by middle class vehicles. With a market share of 38 % SEG-1 follows, consisting of micro and small vehicles. SEG-3 (upper and luxury class) is characterized by relatively high specific CO<sub>2</sub> emissions but represents only 4 % of all new vehicle registrations within the EU. In the context of the market structure effect, which is based on a shift in demand between segments and fuel types, an increasing proportion of micro and small cars of the SEG-1 is expected in the future at the expense of the previously dominant SEG-2. However, since further predictions show opposite trends, for example an increasing demand for SUV-type vehicles, the influence of the market structure effect will always be shown separately in the results.

For LCVs most vehicle registrations relate to class III vehicles (reference mass > 1,760 kg), followed by medium sized vehicles (class II), usually based on car platforms, and small commercial vehicles (class I). For the future, a constant segment distribution is assumed for LCVs, since there are no signs of a significant demand shift.

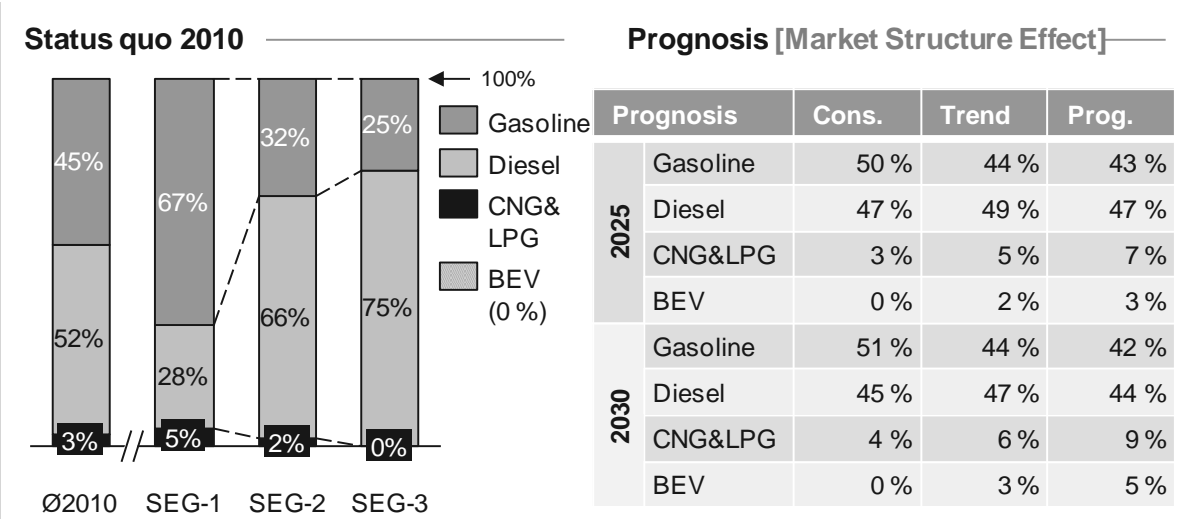
Within the scope of micro and small cars, gasoline-powered vehicles account for two-thirds of all new registrations, while diesel-powered vehicles dominate in higher segments. For LCVs the diesel engine largely dominates the market. In the context of the independent market structure effect, an increasing proportion of pure battery electric vehicles (BEV) and gas-powered vehicles (LPG & CNG) is expected especially for smaller vehicles.



**Fleet Distribution**



**Drive Train Type**



**CO<sub>2</sub> Fleet Emission 2013 [EEA13]**

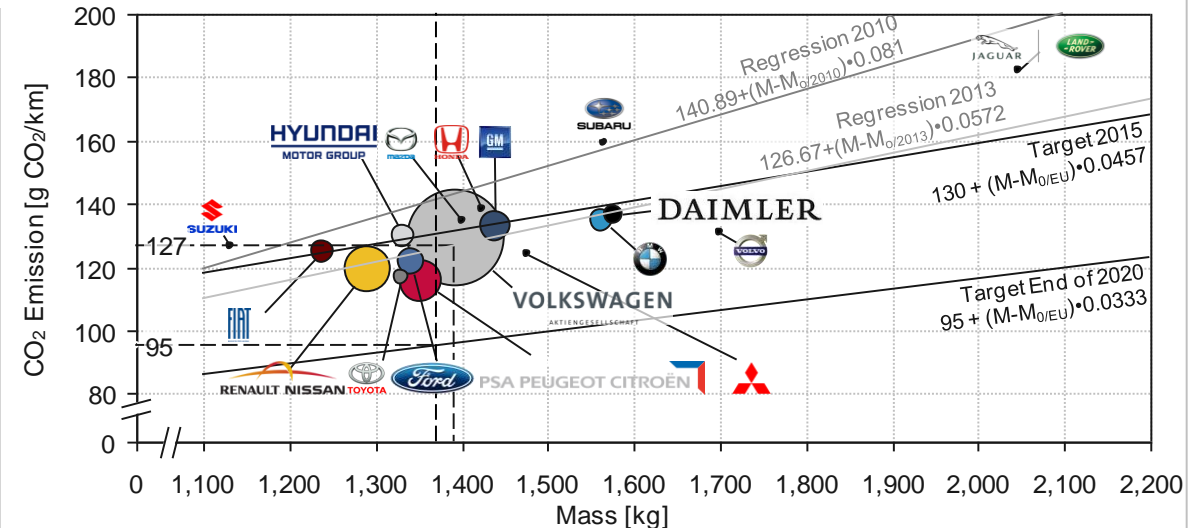
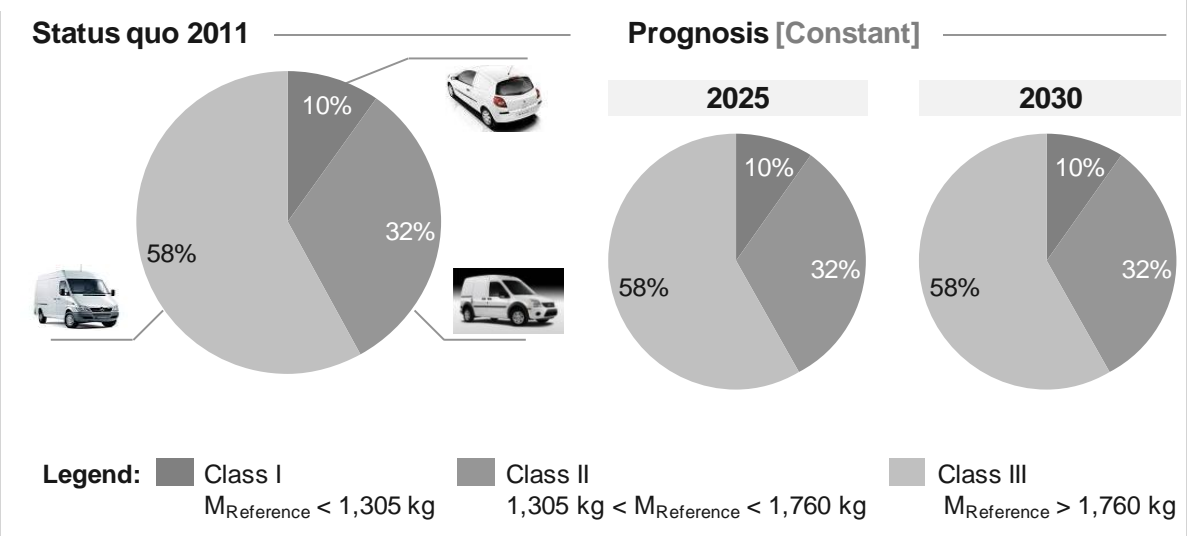
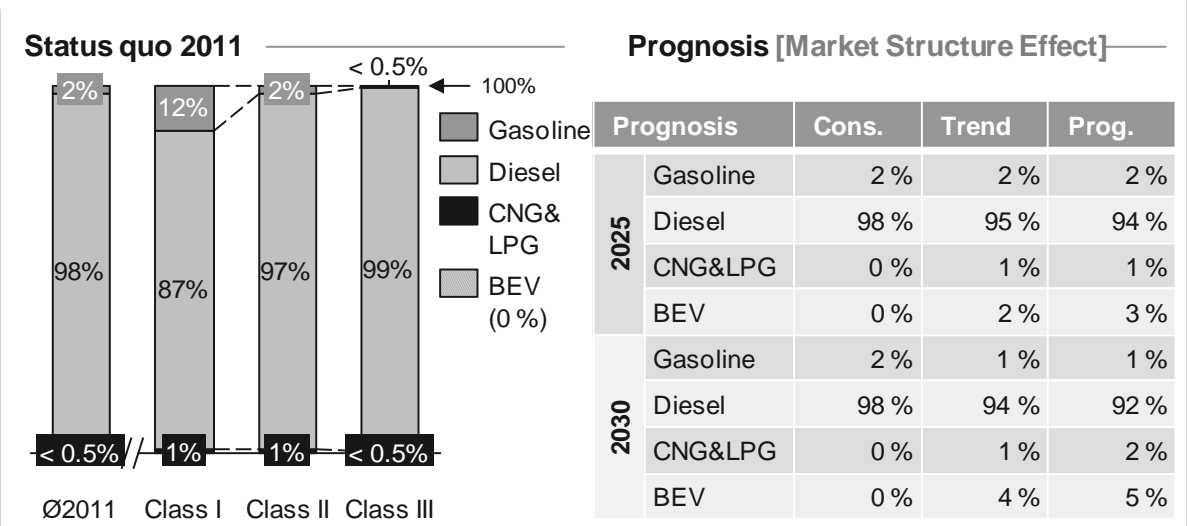


Fig. 3-1: Key findings of the environmental analysis for passenger cars

**Fleet Distribution**



**Drive Train Type**



**CO<sub>2</sub> Fleet Emission 2011 [ERN13] [POL12]**

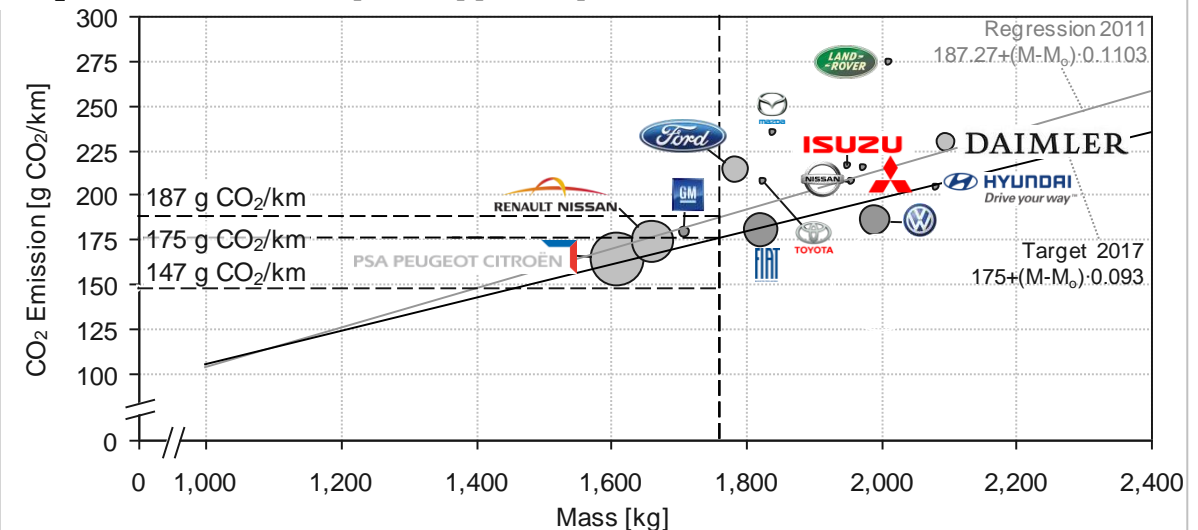


Fig. 3-2: Key findings of the environmental analysis for light commercial vehicles

#### 4 Technological CO<sub>2</sub> Reduction Potential until 2025 and 2030

In the following, it is analyzed which CO<sub>2</sub> reduction potential can theoretically be achieved for PCs and LCVs in the period up to 2030 within a purely technological consideration. In the first step, representative reference vehicles are defined and CO<sub>2</sub> reduction technologies for the mass market until 2030 are specified. Afterwards, these technologies are consolidated to technology packages and projected onto the market in order to calculate the CO<sub>2</sub> reduction potential of the new vehicle fleet and the correlating average additional production costs.

The calculated CO<sub>2</sub> reduction potentials are compared to reference vehicles from the before mentioned reference years 2010 (for PCs) and 2011 (for LCVs), so as to build on the findings of the previous studies, compare Fig. 4-1. The technological specifications are representative for the entire European market.

Segment		Share in SEG	Fuel type	Mass [kg]	Consumption [l/100km]	CO <sub>2</sub> [g/km]	Displacement [l]	Engine	DI	Transmission	Power [kW]	Example
Passenger Cars	SEG-1 (A,B)	67 %	Gasoline	1,067	5.4	127	1.2	4-Cyl.	-	Manual, 5-Gear	60	Fiat Panda
		28 %	Diesel	1,194	4.1	111	1.4	4-Cyl.	x	Manual, 5-Gear	60	
		5 %	Gas	1,112	6.1 l <sub>LPG</sub> /100 km	106	1.2	4-Cyl.	-	Manual, 5-Gear	60	
	SEG-2 (C,D,M,J)	32 %	Gasoline	1,396	6.8	159	1.6	4-Cyl.	-	Manual, 6-Gear	90	MB C-Class
		66 %	Diesel	1,573	5.4	145	2.0	4-Cyl.	x	Manual, 6-Gear	90	
		2 %	Gas	1,331	7.9 l <sub>LPG</sub> /100 km	137	1.6	4-Cyl.	-	Manual, 6-Gear	90	
	SEG-3 (E,F,S)	25 %	Gasoline	1,635	9.1	213	2.8	6-Cyl.	x	Automatic, 6-Gear	170	BMW 5series/7series
		75 %	Diesel	1,795	6.1	164	3.0	6-Cyl.	x	Automatic, 6-Gear	170	
		<0.5 %	Gas	1,853	10.1 l <sub>LPG</sub> /100 km	177	2.8	6-Cyl.	x	Automatic, 6-Gear	170	
Light Commercial Vehicles	Class I	12 %	Gasoline	1,140	6.3	149	1.4	4-Cyl.	-	Manual, 5-Gear	55	Fiat Fiorino
		87 %	Diesel	1,225	4.3	115	1.4	4-Cyl.	x	Manual, 5-Gear	55	
		1 %	Gas	1,250	7.3 l <sub>LPG</sub> /100 km	128	1.4	4-Cyl.	x	Manual, 5-Gear	55	
	Class II	2 %	Gasoline	1,465	7.3	174	1.6	4-Cyl.	-	Manual, 5-Gear	65	Peugeot Partner
		97 %	Diesel	1,476	5.4	142	1.6	4-Cyl.	x	Manual, 5-Gear	65	
		1 %	Gas	1,550	9.2 l <sub>LPG</sub> /100 km	160	1.6	4-Cyl.	x	Manual, 5-Gear	65	
	Class III	100 %	Diesel	2,089	8.4	223	2.2	4-Cyl.	x	Manual, 6-Gear	90	MB Sprinter

Fig. 4-1: Technological specifications of the reference passenger cars (2010) [EEA11] [ERN12] and light commercial vehicles (2011) [POL12] [ERN13]

The CO<sub>2</sub> emissions of the defined reference vehicles can be reduced by the use of various technologies. Based on the driving resistance equation a reduction in fuel consumption and CO<sub>2</sub> emissions can be achieved by either improving the efficiency of energy conversion or by reducing the energy demand. In the previous ika-study “CO<sub>2</sub> reduction potential for passenger cars until 2020” several technologies were identified for the period until 2020. These technologies remain relevant within the timeframe from 2020 to 2030 [ERN12]:

- **Combustion engine:** Homogeneous Direct Injection, Downsizing, Variable Valve Timing, Cylinder Deactivation
- **Electrification of the drive train:** Micro, Mild, Full and Plug-in Hybrids
- **Transmission:** Transmission optimization / Downspeeding, CVT, Dual Clutch Transmission, Improved Automatic Transmission (7/8/9 speed)
- **Overarching Measures:** Reduction of friction in the drive train, Electrification of auxiliary consumers, Thermal management
- **Driving resistances:** Reduced rolling-resistance tires, Aerodynamic improvements on design and component level, Lightweight bodywork and components

In addition to the already mentioned technologies, further innovative CO<sub>2</sub> reduction technologies will be available for the mass market within the observation period. In general terms, the biggest improvement potential can be identified for internal combustion engines, whereas gasoline engines offer a higher development potential than diesel vehicles. Gas vehicles are characterized similar to gasoline vehicles due to the common combustion process. Significant technological improvements after 2020 are also expected in heat recovery. In addition, an optimization of the existing hybrid technologies is expected. Plug-in hybrid and range-extender vehicles (REEV) are expected to gain importance within the observation period. A further reduction of the driving resistances is expected to be achieved mainly through the expansion of lightweight measures on body and component level.

The quantification of each CO<sub>2</sub> reduction potential and the correlated production cost as well as the mass effect is based on several ika-internal and external sources. The technology data was validated and complemented by scientific publications in technical journals, e.g. the technical automotive journal ATZ and the MTZ engine technology magazine. Further information has been added through external and internal expert assessments and telephone interviews. The overall technological and economical forecasts made in the study were presented for discussion and validated during a workshop with representatives of the automotive industry and science.

In the next step, the identified CO<sub>2</sub> reduction technologies are consolidated into so called technology packages in order to reduce the complexity. Therefore, the technologies are applied into the portfolio, shown in Fig. 4-2 (left), with the dimensions “CO<sub>2</sub> reduction potential” and “production costs”. The technologies are clustered into technology packages taking the previously identified technological impacts into account. Further, the technology packages are distinguished into five levels (TP1-TP5) according to their efficiency and temporal availability, compare Fig. 4-2 (right). Due to the fundamental differences between conventional

and hybridized drive trains a differentiation is made between conventional technology packages ("C"), hybrid technology packages ("H") and technology packages for PHEV or REEVs. In total 13 different technology packages are defined.

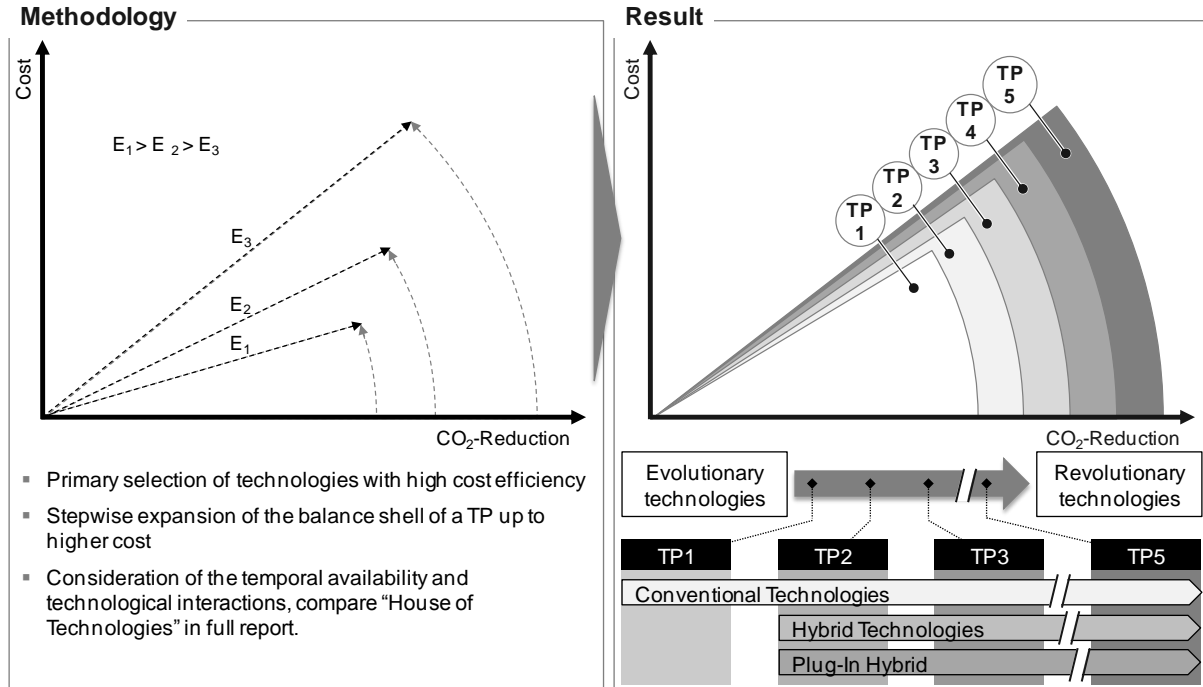


Fig. 4-2: Methodology and qualitative results of the formation of technology packages

The temporal changes of all evaluations are considered through increasing CO<sub>2</sub> reduction potentials, due to technological progress, as well as decreasing production costs, due to learning effects and economies of scale. Particularly high learning effects are expected for hybrid technologies. The strength of the modelled learning effects and the technological progress varies within the considered scenarios.

Assuming a 100 % market penetration and without considering the economic efficiency analysis of the end customer, the theoretical minimum CO<sub>2</sub> fleet emission level is determined, as shown in Fig. 4-3. For conventional technology packages emission levels of 66 – 81 g CO<sub>2</sub>/km for PCs and 97 – 116 g CO<sub>2</sub>/km for LCVs would theoretically be achieved taking into account the market structure effect. With the use of hybrid technologies the emission of PCs would be reduced to 54 – 67 g CO<sub>2</sub>/km while emission levels of 78 – 97 g CO<sub>2</sub>/km would be achieved for LCVs. Within the framework of the NEDC a complete use of PHEVs would reduce emission levels to 26 – 30 g CO<sub>2</sub>/km for PCs and 41 – 48 g CO<sub>2</sub>/km for LCVs. The correlated additional production costs for PC (LCV) would amount up to € 4,150 (€ 5,300) for the conventional technology path, up to € 5,750 (€ 7,350) for the hybrid technologies and up to € 8,250 (€ 9,000) for the PHEV technology path.

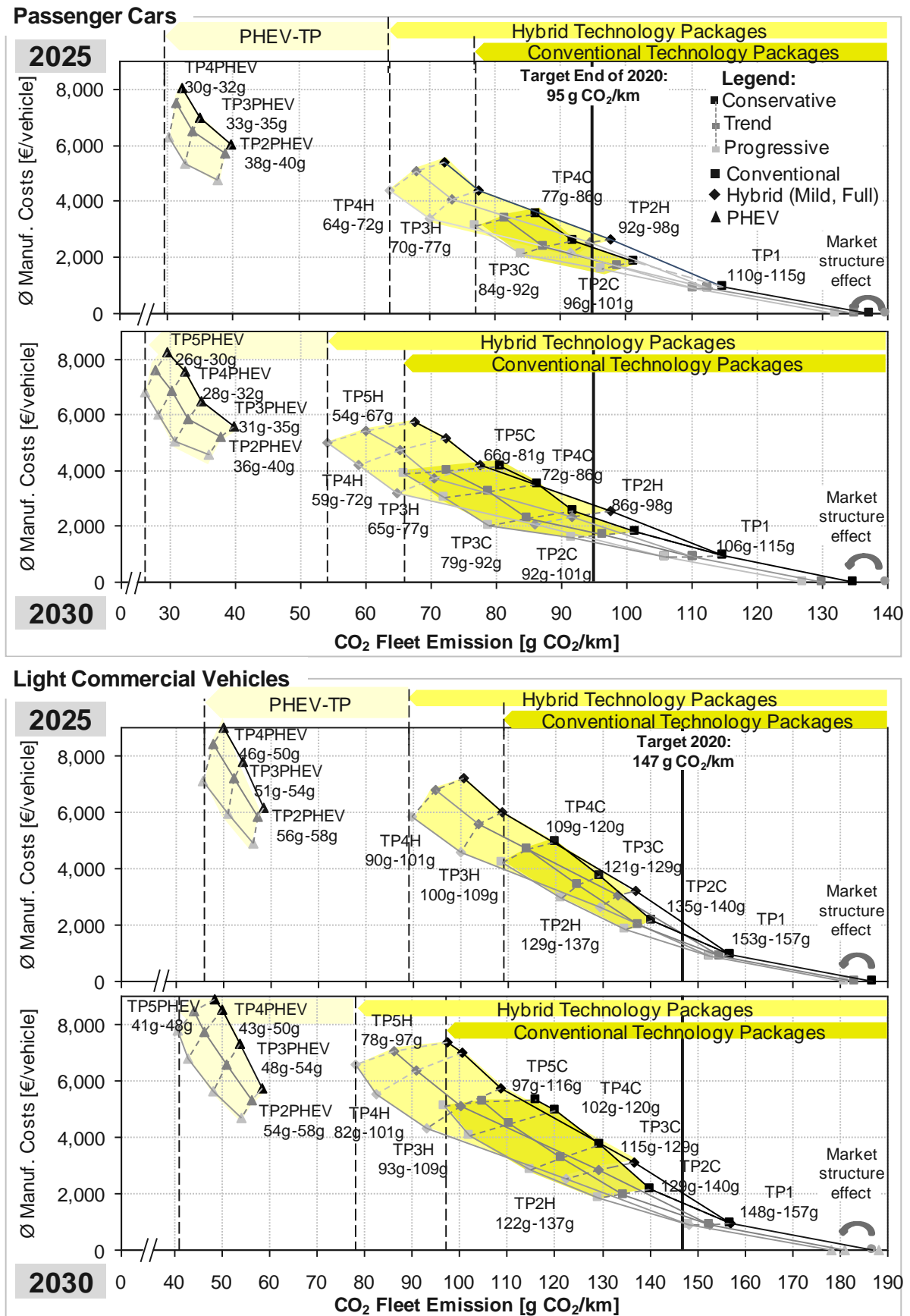


Fig. 4-3: Theoretically resulting fleet emissions for PCs and LCVs

## 5 Economical CO<sub>2</sub> Reduction Potential until 2025 and 2030

From a technological point of view the CO<sub>2</sub> emissions could theoretically be reduced to very challenging levels, if they were introduced in every vehicle. However, the therefore required electrification of the drive train implies high additional production costs for all vehicles. Under the assumption that vehicle manufacturers pass on additional production costs to their customers, an analysis from the end customer's perspective is realized to identify economic viable CO<sub>2</sub> reduction technologies.

The basis for the subsequent calculations is the assumption that additional CO<sub>2</sub> reductions result solely from the economic efficiency considerations given by supply and demand of motor vehicles. The technologically realizable and economically viable CO<sub>2</sub> target values derived in this chapter constitute objective guidelines for the further development of the CO<sub>2</sub> regulation in Europe after 2020/2021.

The results of the economic efficiency calculations significantly depend on the development of fuel and electricity prices until 2030, the demand for mobility, as well as the assumption that a vehicle manufacturer is able to pass on the additional costs on retail price level of the technology packages to the end customer. The modelling of the market demand takes different customer types – highly technology affine individuals to homo oeconomicus – as well as their economic decision behaviour into account. The market demand of each customer group is used to calculate which technology package might be bought for each vehicle segment. Moreover, the fleet emissions at European level are calculated for the considered scenarios.

### 5.1 Economic Reduction Potential for Passenger Cars

Fig. 5-1 shows the resulting demand of technology packages for passenger cars in the entire European market for each segment. Within the trend scenario, the average fleet emission would decrease from 141 g CO<sub>2</sub>/km in the base year 2010 to 96 g CO<sub>2</sub>/km (about -32 %) in 2025 including the market structure effect. Thus, the target value of 95 g CO<sub>2</sub>/km set by the European Union for 2020 would be achieved approx. 5 years later without the implementation of flexibility mechanisms like eco-innovations and super credits. Although hybrid technology packages would pay back for many costumers during the amortization period, conventional technology packages prove to be economically advantageous due to their lower investment costs. A significant market diffusion of hybrid technology packages and PHEV would be expected within the trend scenario by 2030, thus reducing the average fleet emissions to 79 g CO<sub>2</sub>/km (-44 %). Considering the conservative scenario the fleet emissions would decrease merely to 112 g CO<sub>2</sub>/km by 2030. Within the progressive scenario a reduction up to 59 g CO<sub>2</sub>/km might be achieved due to the changed framework parameters. These low values in the progressive scenario would result due to higher fuel prices and lower technology costs, which increase the economic viability of PHEV technology packages for many customer groups. Vehicle manufacturers have a further CO<sub>2</sub> reduction potential by crediting eco-innovations in the height of 7 g CO<sub>2</sub>/km.

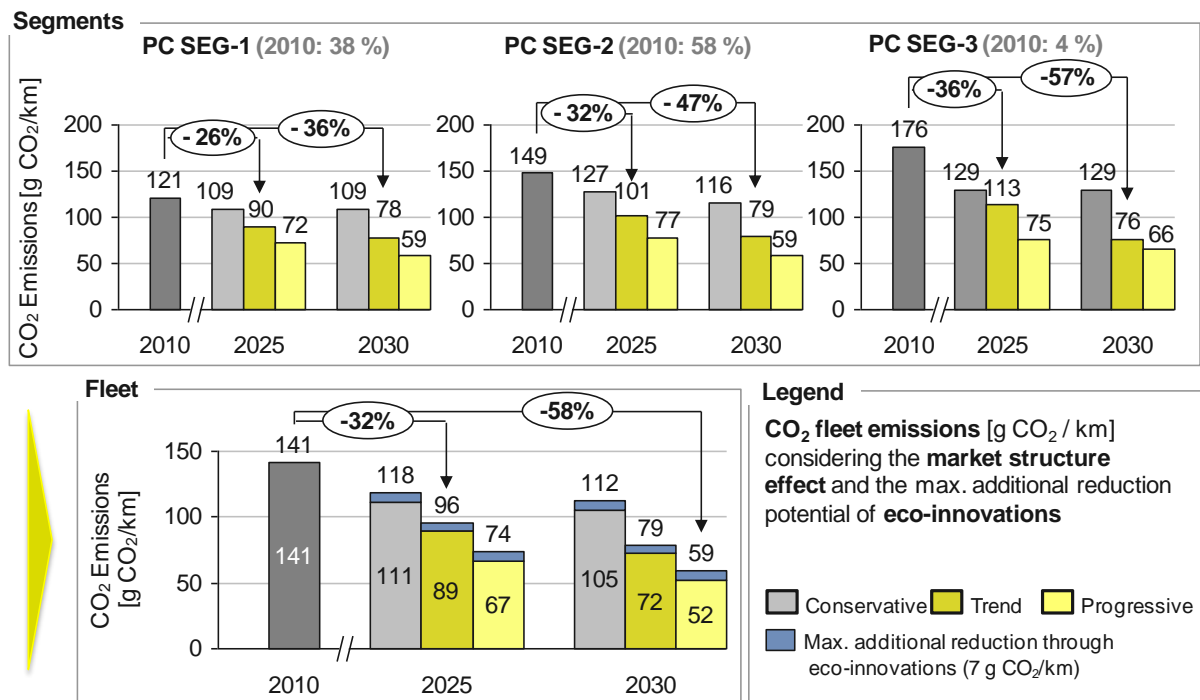


Fig. 5-1: Summary of the fleet emissions in 2025 and 2030 for passenger cars considering the market structure effect and eco-innovations

## 5.2 Economic Reduction Potential for Light Commercial Vehicles

The results for the LCV market are summarized in Fig. 5-2. In the trend scenario, the average fleet emissions of 187 g CO<sub>2</sub>/km in the base year 2011 could be reduced to 140 g CO<sub>2</sub>/km by 2025 including the market structure effect. This corresponds to a reduction of about 25 %. Between 2025 and 2030 the CO<sub>2</sub> fleet emissions would only decrease a further 5 g to 135 g CO<sub>2</sub>/km in the trend scenario. In the progressive scenario however, a significantly greater reduction of 39 g to 97 g CO<sub>2</sub>/km would be observed for this period. Within the context of the different scenario assumptions, the interval of possible CO<sub>2</sub> fleet emissions for LCVs by 2030 extends from 97 g CO<sub>2</sub>/km in the progressive scenario and 159 g CO<sub>2</sub>/km in the conservative scenario. The reason for this uncertainty is the high proportion of class III LCVs in the overall market, which is about 60 %. The development of this vehicle class determines the development of the overall market significantly. Since hybrid technology packages are economically unviable for class III LCVs from an end customer perspective, the CO<sub>2</sub> reduction is low within the trend scenario. Within the progressive scenario the use of hybrid technology packages in class III is economically viable for end customers by 2030. Therefore, a significant reduction of CO<sub>2</sub> fleet emissions is expected in the progressive scenario between 2025 and 2030.



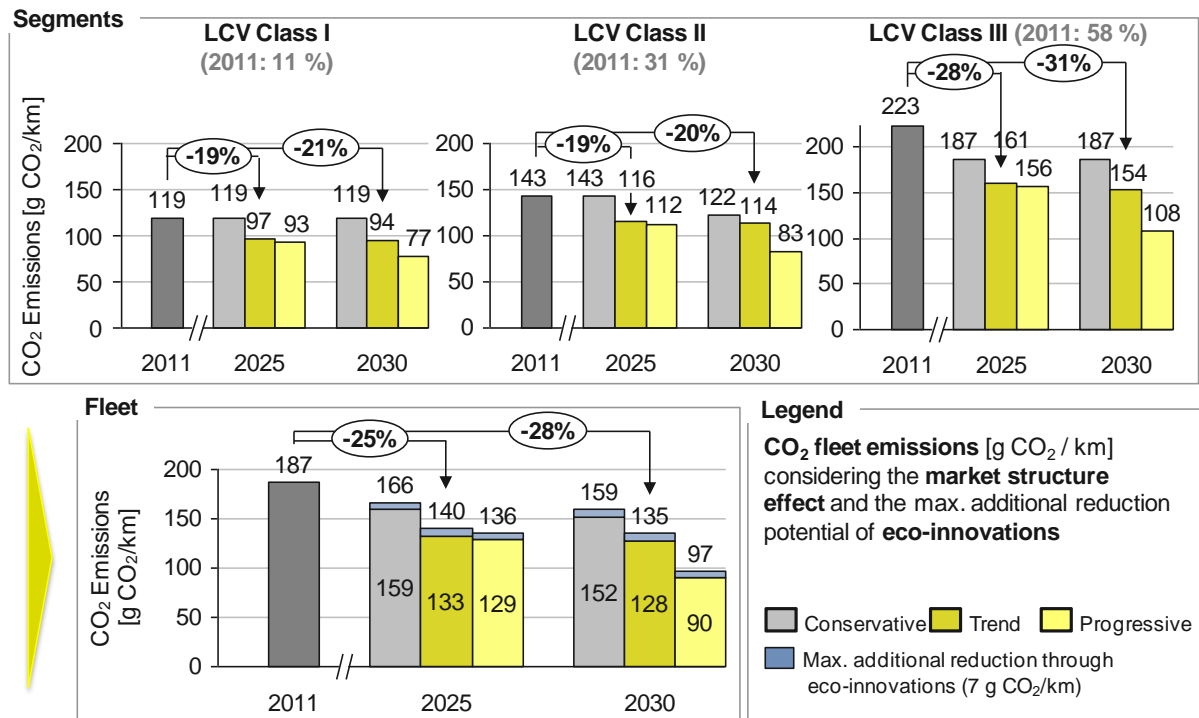


Fig. 5-2: Summary of the fleet emissions in 2025 and 2030 for light commercial vehicles considering the market structure effect and eco-innovations

### 5.3 Analysis of Target Value Proposals for Passenger Cars until 2030

Stricter CO<sub>2</sub> emission targets are being discussed within the EU in order to further reduce passenger car fleet emissions after 2020. However, if the new target values surpass the threshold of economic viability for end customers, high additional costs would arise for vehicle manufacturers in order to reach the goals. Advanced technology packages would be needed for the vehicles in order to achieve the target values and the correlating additional costs could not be passed on to the end customers, as shown in Fig. 5-3.

The retail prices of technology packages for end customers are assumed to be about 60 % higher than the production costs due to value added taxes, distribution and sales as well as guarantee costs, provisions and the profit margin of the manufacturer. Within the trend scenario, end customers are willing to invest in innovative technology packages with an average value of € 1,600 production costs per vehicle, since they can achieve correspondingly high fuel savings during the holding period. Due to further rising fuel prices, the willingness to invest increases to an equivalent of € 2,300 production costs per vehicle by 2030. The actual investment costs for end customers would be 60 % higher in comparison to these production costs. Fig. 5-3 shows the technology costs for vehicle manufacturers in the years 2025 and 2030 within the considered scenarios for the currently discussed target values.

Depending on the scenario, the production costs for the necessary technologies in order to fulfil a target value of 68 g CO<sub>2</sub>/km by 2025 would rise up to € 3,200 – 4,100 per vehicle. End

customers would not be willing to bear these additional costs due to their economic efficiency considerations. The remaining amount of € 500 in the progressive scenario and € 3,300 in the conservative scenario would therefore be borne by the vehicle manufacturers. Depending on the implemented CO<sub>2</sub> emission target value a correspondingly higher or smaller financial burden is to be carried by the manufacturers.

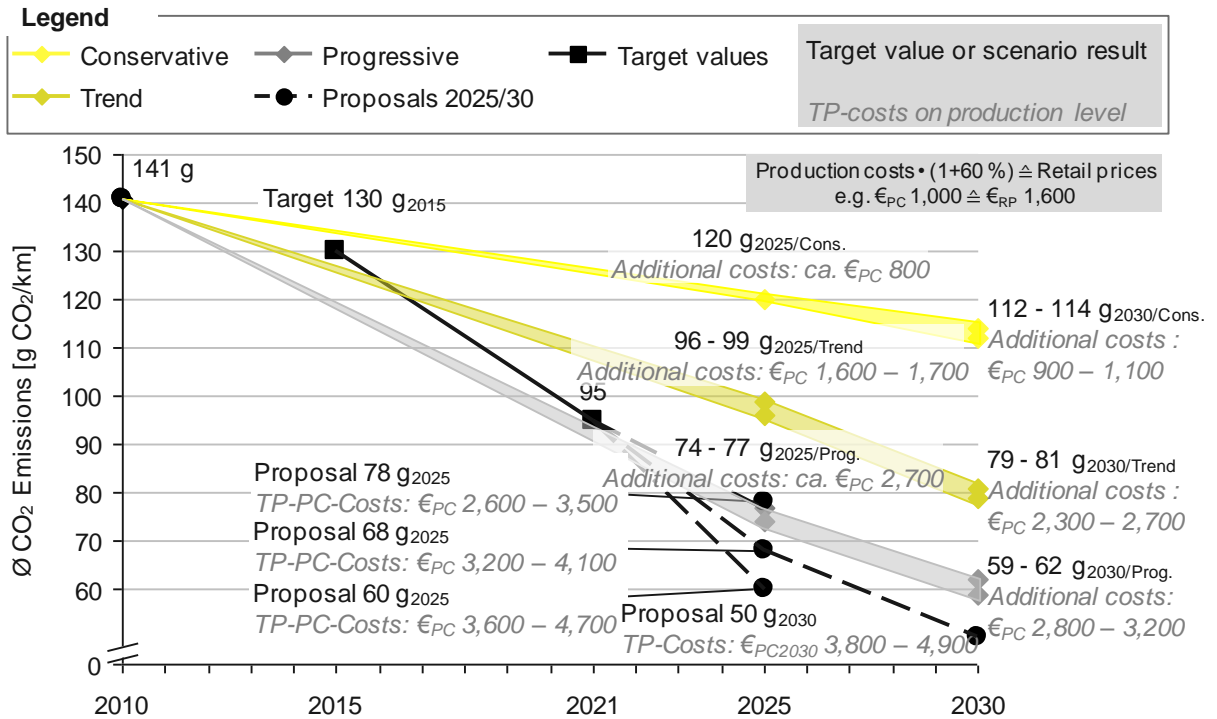


Fig. 5-3: Market scenarios with and without market structure effect and overview of target proposals with resulting technology costs on production level

### 5.4 Sensitivity of the Results

The entire calculation results, both the degree of the achievable CO<sub>2</sub> fleet emissions and the recommendable linear gradient of the curve, depend essentially on whether and to what extent hybrid technologies (mild, full and plug-in hybrids) are economically viable to private and commercial customers. The economic viability is significantly influenced by central modelling assumptions, as shown by the sensitivity analysis. Therefore, there is a strong correlation to the end customers holding period. A one-year extension of this period (standard case: 4 years) increases the economic viability of hybrid technologies for several customer groups by 2025. Similar correlations exist with the retail price of the technology packages. In this context, the calculation results need to be always interpreted in the context of the modelling assumptions.

The calculation results of the CO<sub>2</sub> emissions of PHEV show similarly strong dependences. The current calculation method leads to comparatively low CO<sub>2</sub> emissions for these drive trains, because the usage of CO<sub>2</sub> neutral electricity is assumed. A statistical decreasing de-

pendency of CO<sub>2</sub> emissions and the vehicle mass is reflected by the calculations, which eventually will lead to the definition of almost mass-independent CO<sub>2</sub> target values. Therefore, this result is to be strictly understood as a function of the underlying CO<sub>2</sub> emissions quantification for PHEV. Future changes in the calculation method, for example within the context of the WLTP-introduction, are not considered here.

## 6 Approaches for a Revision of the EU CO<sub>2</sub> Legislation

In the context of possible approaches to revise the EU CO<sub>2</sub> legislation, the variation of reference parameters and improvements to optimize the cost effectiveness of the goal achievement will be discussed.

### 6.1 Variation of Parameters

The reference parameter “mass” is established as a differentiating utility parameter for both passenger cars and light commercial vehicles in the current European CO<sub>2</sub> legislation. The use of different utility parameters is open for a future legislation. Suitable alternatives to the currently utilized reference parameter “mass” should fulfil a number of requirements: correlation, robustness as well as data availability and objectivity.

In the course of the analysis the parameters vehicle mass, footprint, displacement, power, seats, trunk or cargo-volume and the vehicle retail price were compared in terms of the criteria above. The parameter footprint turned out to be the most important alternative due to its utilization in the USA. In general, the vehicle mass shows a better correlation to the CO<sub>2</sub> emission in comparison to the footprint for the European vehicle fleet. However, some segments, such as SUV or sport cars, are not adequately represented. The mass-based utility parameter has proven to be robust against unintended technology developments and thus remains a suitable utility parameter for European CO<sub>2</sub> legislations.

Hence, the maintenance of the vehicle mass can be recommended as a utility parameter for PCs and LCVs. Currently, there is no urgent need to change the parameter. In the future, as an increasing electrification of the drive train is predicted, especially through PHEV, the present correlation between CO<sub>2</sub> emissions and vehicle mass could eventually lose its validity. In this possible future scenario a change of the utility parameter, for example into footprint, could make sense.

### 6.2 Flexibilisation Measures

The current CO<sub>2</sub> regulation combines a manufacturer specific CO<sub>2</sub> target value with accompanying mechanisms such as super credits and eco-innovations. Measures to expand these accompanying mechanisms would increase the cost efficiency of the CO<sub>2</sub> legislation target achievement from the vehicle manufacturer’s point of view. Furthermore, this expansion could have a positive impact on the retail prices for end customers, compare Fig. 6-1.

On the one hand this can be achieved by an objective, temporal or sektoral flexibilisation, for example through eco-innovations, banking borrowing systems or by means of an open or closed CO<sub>2</sub> certificate trading system. These mechanisms have in common, that the overall CO<sub>2</sub> target would be respected and not attenuated within the limits of the regulatory system. The increase in efficiency results from the fact that the scope of manufacturers increases and from the fact, that the target achievement can be optimized in terms of the considered objective, time and sector

In contrast to the above mentioned flexibilisation measures, there are rules that indirectly or directly loosen the targets for vehicle manufacturers and have the potential to reduce the necessary production costs for OEM. These rules include technology funding through CO<sub>2</sub> bonus granting and super credits for low emission vehicles. Technology funding could refer to propulsion technologies or GHG optimized air conditionings. Depending on the amount of CO<sub>2</sub> bonus awarded to these technologies the overall CO<sub>2</sub> target could be slightly weakened in the focussed time frame. The systematically supported market ramp up of these technologies can lead to a cost decrease in production and therefore lead to a fastened and wider market penetration of these technologies in all vehicle segments. With this effect, it is possible to realize lower fleet emission values economically.

Measure	Impact	Attainment of the CO <sub>2</sub> Reduction Targets	Innovation Incentives
<b>CO<sub>2</sub> Certificate Trading</b>	Flexibility of target achievement through integration of other industries	Constant for all economic sectors	-
<b>Credit Trading</b>	Flexibility of target achievement through integration with other OEM	Constant for PCs and LCVs fleet	o
<b>Banking-Borrowing-System</b>	Temporal flexibility of target achievement	Constant over time	(+)
<b>Super Credits</b>	Loosening of the target for particularly low-CO <sub>2</sub> emission vehicles (e.g. BEV, PHEV, FCEV)	Slightly weakened	(+) (funded Technologies)
<b>Funding of Specific Technologies</b>	Loosening of the target for utilization of defined technologies	Slightly weakened	(+) (funded Technologies)
<b>Eco-Innovations</b>	Expansion of technological options to achieve the objectives	Constant for real driving conditions	+
<b>+ Increasing Incentives      o Constant Incentives      - Decreasing Incentives</b>			

Fig. 6-1: Measures to increase the cost efficiency of the target achievement

The potential impacts on CO<sub>2</sub> reduction of the above described measures is often accompanied by opposite effects. Measures, which are aimed directly or indirectly to specific technologies or branches, increase innovation in the addressed areas, whereas innovation in non-funded areas may be reduced. A global valuation of the discussed measures is not possible and depends on specific needs and objectives, e.g. the cost reduction for the vehicle manufacturer, the economic optimization or the need to ensure the competitiveness of the automotive industry. An emission trading limited to the transport sector however, can be emphasized since it can decrease the target achievement costs without attenuating the overall CO<sub>2</sub> targets or exerting direct negative effects on the innovation activities of vehicles manufacturers.

## 7 Recommendations for the European Legislator

The Council and the European Parliament have given the task to the European Commission to review the CO<sub>2</sub> regulation of new passenger cars and light commercial vehicles until the end of 2015 and to submit a report on their findings. This report should include suggestions for amendments as well as the possible setting of realistic and achievable target values for the period up to 2025. According to the analysis carried out in this study, a significant further reduction of CO<sub>2</sub> fleet emissions is technically possible until the year 2030. The range of achievable future CO<sub>2</sub> fleet targets is mainly limited by considerations of costs and economic effectiveness.

To meet the target values for 2015 several economically viable technologies with favourable cost-benefit ratios are being introduced into the market by vehicle manufacturers. The EU fleet target value of 95 g CO<sub>2</sub>/km, which has to be reached by the end of the year 2020, is however, a technological and economical challenge and may only be realized economically under very favourable framework conditions, compare [ERN12] and results of chapter 5. The production costs of additional technologies, which are needed in order to reduce CO<sub>2</sub> progressively increase with stricter CO<sub>2</sub> targets for all vehicles segments. Therefore, more ambitious fleet target values are associated with significant increases in vehicle costs. From the end customer's perspective, stricter fleet target values are only economical, if the higher vehicle costs are can be compensated by resulting fuel savings.

Within the trend scenario, a fleet emission level of 96 – 99 g CO<sub>2</sub>/km (with / without market structure effect) could be achieved by 2025. By the year 2030, a further reduction to 78 – 79 g CO<sub>2</sub>/km may be achieved in the trend scenario. According to the findings in this study, merely in the progressive scenario the upper value – in the height of 78 g CO<sub>2</sub>/km - of the target range set by the European Commission would be viable for 2025. But this viability only applies under the favourable conditions of the progressive scenario, which is mainly influenced by a strong increase of fuel prices. A further reduction in CO<sub>2</sub> fleet emissions implies a significant increase of the additional production costs per vehicle, which would not amortize for the average end customer. Therefore, the additional costs could not be passed on and would be an additional burden for the vehicle manufacturers.

The EU Commission has the opportunity to implement various options to improve the cost and economic effectiveness of the existing regulatory framework. In order to fulfil this purpose, instruments that accelerate the introduction of lower emission vehicles into the market and increase the cost efficiency of the target achievement for vehicle manufacturers need to be mentioned (see chapter 6). Furthermore, an increased recognition of real-life emission reduction technologies should be taken into account, as these do not affect the measured emissions in the standardized driving procedure. In addition, instruments such as banking/borrowing can significantly contribute to improve the cost efficiency of the CO<sub>2</sub> regulation.

Technically, ambitious fleet target values can only be achieved by an increased market introduction of vehicles with innovative technologies, such as electrified drive train in BEV, PHEV

or FCEV. Forecasts regarding the market run-up of electric vehicles are still fraught with uncertainties. The framework has significant influence on the market introduction of electric vehicles, in particular the cost development of battery systems and the expansion of the charging infrastructure. However, vehicle manufacturers have only a limited influence on these aspects. Nevertheless, they are crucial to achieve the fleet emission target values. Therefore, the focus should be directed mainly on the market development as well as the corresponding framework. Meanwhile, supporting measures should be investigated. In analogy to the USA and with regard to the long term nature and the significant dependence on exogenous factors, such as the fuel price development, a regular re-evaluation of the target achievability should be performed in a maximum three years rhythm.

The distribution of the CO<sub>2</sub> reduction pressure between the vehicle manufacturers in the framework of the current legislation can be adjusted substantially by varying the slope of the mass-based target value curve. In the period up to 2030 a further decrease of the correlation between the vehicle mass and the specific CO<sub>2</sub> emission is expected due to the increasing introduction of Plug-in Hybrid Vehicles, which achieve significantly lower CO<sub>2</sub> emission values but have a higher weight due to a larger battery and additional components. In the case of an increased proportion of electric vehicles in higher segments, a flattening of the target curve would be observed on basis of the calculations performed for this study. Especially in the long term it is necessary to examine, to which extent the differentiation of model and manufacturer specific emission target values by a linear slope of a mass-based target value may still be suitable, so that equivalent burdens for vehicle manufacturers with focus on different segments can be defined. The possibility to adjust the slope of the target value curves over time according to the moving average of all fleet emissions should be discussed, in order not to implicitly influence the product portfolio and the fleet design of vehicle manufacturers politically. This would avoid a political engagement in the model policy of the vehicle manufacturers through a predefined flattened target value curve. In general and with a focus on the preservation of the innovation capability of the European automotive industry, an evenly distributed contribution between all vehicle segments to the overall CO<sub>2</sub> reduction is of central importance. This applies especially for the premium segments and its innovation potential, which has shown to enable the development and testing of important innovations which will diffuse over model cycles into the smaller vehicle segments and will contribute there to a CO<sub>2</sub> optimization on a large scale.

With regard to an improvement of the economic CO<sub>2</sub> emission target achievement, further examinations are needed, how and to which extent market based instruments could be added to the European CO<sub>2</sub> regulation. It is being discussed among others to include the transport sector into the European emission trading as an alternative or in addition to the currently implemented system of CO<sub>2</sub> fleet targets. It should be noted, that these and similar measures could have indirect effects on innovation incentives and therefore long-term technological developments. Basically, accompanying measures and framework conditions which have positive long term beneficial effects on vehicle manufacturers and suppliers should be provided.

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