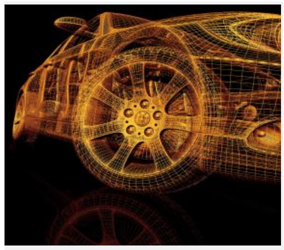
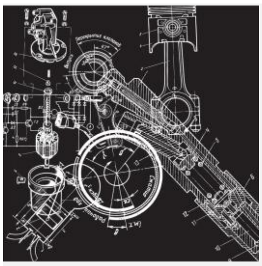
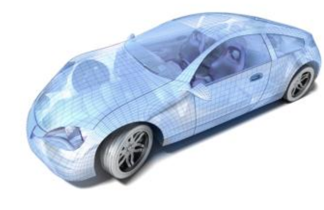
Exploring possible car and van CO_2 emission targets for 2025 in Europe



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1 Introduction

1.1 Policy context

Passenger cars and vans together account for more than half of total greenhouse gas (GHG) emissions from the transport sector in Europe. While GHG emissions from other sectors are generally falling, those from transport have increased by 23% since 1990. In response to that development, the European Union has implemented regulations to reduce emissions from cars and vans.

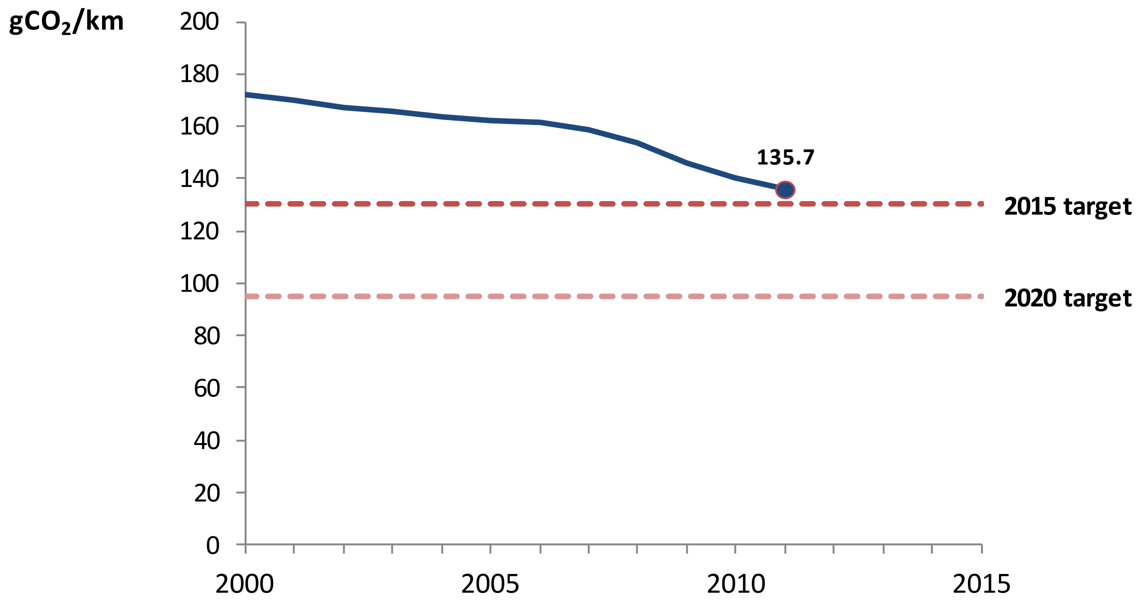
The European Union first introduced mandatory CO_2 standards for new passenger cars in 2009. The regulation sets a target of 130 gCO_2/km for the fleet average of all new cars in 2015 and a further target of 95 gCO_2/km in 2020. A similar regulation for new light-commercial vehicles (vans) was introduced in 2011 with a target of 175 gCO_2/km in 2017 and a further target of 147 gCO_2/km in 2020.

Table 1-1: Summary of light duty vehicles CO_2 emission targets in Europe

Vehicle type	Regulation	CO_2 targets
Passenger Cars	Reg (EC) 443/2009	130 g/km by 2015 and then 95 g/km by 2020
Light Commercial Vehicles (vans)	Reg (EC) 510/2010	175 g/km by 2017 and then 147 g/km by 2020

The regulatory targets have already led to significant reductions in average car CO_2 emissions in Europe, which are already nearing the target level for 2015 with some manufacturers having already met their targets (T&E, 2012).

Figure 1.1: Evolution of European average new car emissions over time



Source: EEA (2012)

Monitoring of van CO_2 emissions was introduced only recently; therefore the data on emissions over time is limited.

In order to provide certainty for manufacturers, longer-term targets are needed. In its proposal to amend existing regulations on CO_2 emissions from light duty vehicles of July 2012, the Commission notes that "*As industry benefits from indications of the regulatory regime that would apply beyond 2020, the proposal includes a further review to take place by, at the latest, 31 December 2014.*"[1]

The European Commission announced in 2010 it will explore a level of 70 gCO_2/km by 2025 and has begun to consult stakeholders on post-2020 emission targets for new cars and vans (EC, 2010).

1.2 Study objectives

This study analysed credible technology pathways to meet 2025 targets for the EU new car and van fleets, with a particular focus on the need for electric vehicles. The following questions are explored:

1. What is the lowest average CO_2 level that can be achieved by 2025 without any electrification, based on conventional internal combustion engines and hybrid technology alone?
2. What might be the minimal level of electrification needed to achieve each average CO_2 level for new passenger cars sold in the EU? What might this mean in terms of the overall powertrain technology mix, as well as the average additional cost per vehicle, in 2015, 2020 and 2025?
    a. For a 60 gCO_2/km target objective;
    b. For a 70 gCO_2/km target objective.
3. How do these levels of electrification compare with electric vehicle deployment targets set by EU governments and potential targets set by the EU?
4. What would be equivalent targets for vans by 2025 assuming a similar rate of new technology deployment as for the cars sector?

[1] COM (2012) 393. Proposal for a Regulation amending Regulation (EC) No 443/2009 to define the modalities for teaching the 2020 target to reduce CO_2 emissions from new passenger cars. Available online at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0393:FIN:EN:PDF

2 Analysis of possible trajectories to meet 2025 targets for cars

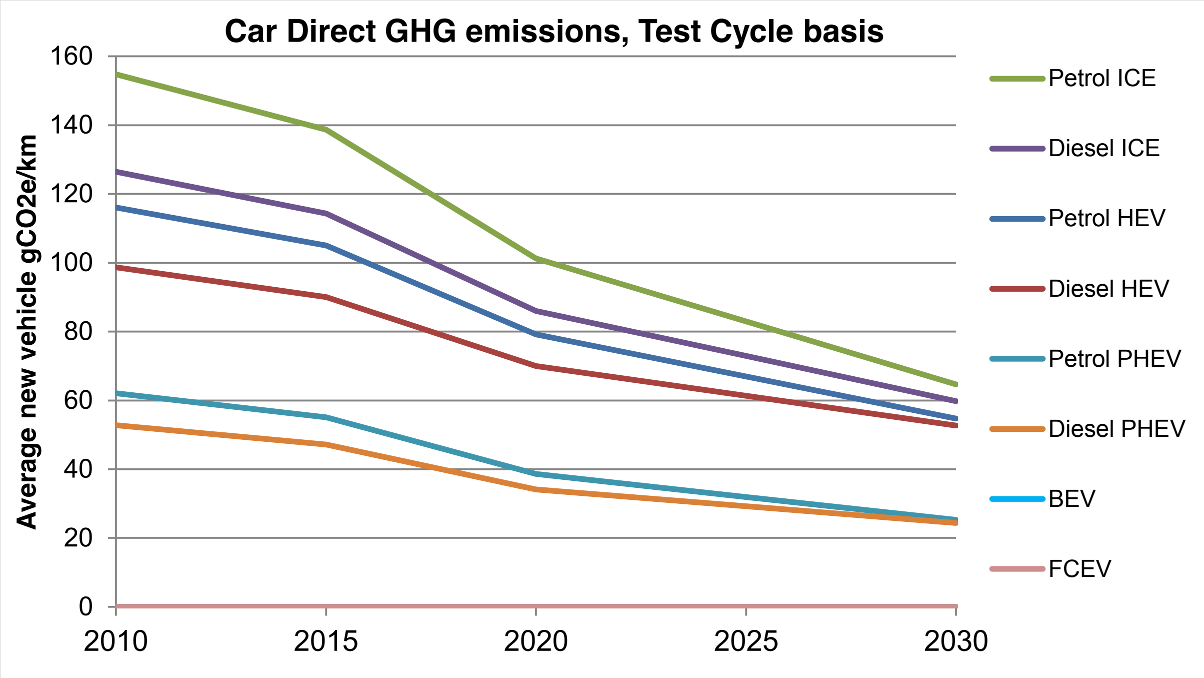
2.1 Study approach

The analysis in this report is based on Ricardo-AEA's Road Vehicle Cost and Efficiency Calculation Framework. The methodology and assumptions from this framework were also used in the previous work by AEA Technology plc for the UK Committee on Climate Change (AEA, 2012). The datasets have since been updated with further literature for the purposes of this analysis. A summary of the methodological basis, assumptions and datasets is provided in Appendix 1. The powertrain types covered by the framework include:

- **ICEs**: Internal combustion engines, as used in conventional vehicles powered by petrol, diesel, LPG and CNG.
- **HEVs**: Hybrid electric vehicles. Powered by both a conventional engine and an electric battery, which is charged when the engine is used. The difference between HEVs and other types of EV is that there is no change in the fuelling of the vehicle (i.e. no need to plug in to a recharging point or switch to hydrogen); therefore consumers are minimally affected in terms of refuelling. The degree of hybridization is assumed to be mild or full – i.e. with an electric engine able to provide motive power assistance to the ICE.
- **Advanced electric vehicles (EVs):**
    - **PHEVs (including REEVs)**: Plug-in hybrid electric vehicles. Powered by both a conventional engine and an electric battery, which can be charged from the electricity grid. The battery is larger than that in an **HEV**, but usually significantly smaller than that in a battery electric vehicle (**BEV**). These vehicles can be designed with the ICE and electric motor in parallel configurations, or in series (where they are often referred to as range-extended electric vehicles, **REEVs**). For this study, the electric range was considered to be 30km for PHEVs and 60km for REEVs in 2010 (rising by 5km/10km per decade for PHEV/REEV respectively). Efficiency improvements are calculated as combined average efficiencies based on relative % distance travelled in ICE mode – 69% in ICE mode for PHEVs and 38% for REEVs in 2010, with these shares decreasing in future years as the electric range is increased. Estimates for PHEVs are calculated based on an average of the two alternative (i.e. parallel and series) configurations.
    - **BEVs**: Battery electric vehicles, also referred to as a pure electric vehicle. Runs on electricity only and does not have a conventional engine. The electric range for BEVs increases as battery technology improved over time, starting at 160km in 2010 and increasing by 40km per decade (i.e. to 240km by 2030).
    - **FCEVs**: Fuel cell electric vehicle. A vehicle powered by a fuel cell, which uses hydrogen as an energy carrier. These vehicles are included because they are capable of travelling much longer distances compared to BEVs – 500km for the hydrogen FCEV – which is considered necessary for meeting longer-term targets.

Figure 2.1 provides an illustration of the trajectory in relative performance of the different powertrains (in gCO_2/km) to 2025. All powertrain types are assumed to improve their emissions performance over time. A summary of the methodological basis, assumptions and datasets used to derive these figures is provided in Appendix 1.

Figure 2.1: Car direct CO_2 emissions (g/km) by powertrain type, test cycle basis



Notes: Direct CO_2 emissions are measured on the NEDC test cycle and do not include accounting rules such as super credits. Direct emissions from battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV) are zero.

2.2 Scenario analysis

2.2.1 Overview

Four scenarios for cars were developed for this study to investigate the potential CO_2 reductions that could be achieved with and without advanced EVs (PHEVs, BEVs and FCEVs). The scenario development included both defining the deployment of individual technological options to improve vehicle efficiency (such as engine and transmission improvements, weight reduction, etc), as well as defining the overall powertrain technology deployment scenarios (i.e. future market shares of different powertrain types). In all scenarios, deployment of individual efficiency improvement technologies is rapid and ambitious (i.e. almost all known options should be applied close to their maximum levels by 2030). Further details of efficiency options utilised in the calculation framework methodology employed for the analysis are provided in Appendix 1. Deployment of HEVs and advanced EVs in future years is ambitious but credible when compared to other targets, forecasts or scenarios (see Section 2.3). The overall split between petrol and diesel fuelled powertrains is also assumed not to change significantly in the future from current levels.

- **Scenario A:** explores a CO_2 emission reduction target of 75g/km that could be achieved using conventional ICE and HEV technology only (i.e. no PHEVs, BEVs or FCEVs).
- **Scenario B**: explores the new fleet penetration of hybrid vehicles required to meet a target of 70g/km in 2025. This scenario uses conventional ICE and HEV technology only (i.e. no PHEVs, BEVs or FCEVs).
- **Scenario C**: introduces the possibility of including advanced EVs (PHEVs, BEVs or FCEVs) to meet a target of 70g/km in 2025. The share of HEVs, PHEVs, BEVs and FCEVs used to meet the target are based on credible new fleet penetration rates and a realistic/balanced mix of technologies.

- **Scenario D:** also includes advanced EVs and explores the technology mix that could be used to meet a target of 60g/km in 2025. The share of HEVs, PHEVs, BEVs and FCEVs used to meet the target are based on credible, but more optimistic, new fleet penetration rates and a realistic/balanced mix of technologies.

The ratio of technologies within the advanced EV category is based on relative deployment shares that are consistent with existing literature. The ratio of PHEVs to BEVs within the literature shows a wide range. Examples have been found of 10:1 (in favour of PHEVs) to 1:1 depending on the assumptions used (see for example IEA, 2011; CE Delft, 2011; JRC, 2010 amongst others). It is usual to find projections in the literature with a higher proportion of PHEVs due to the higher cost and more limited range of BEVs (and also potential near-term constraints on recharging infrastructure availability). A responsible ratio appears to be in the range of 2:1 and 4:1. The projections in Scenarios C and D maintain ratios in this range. Uptake of FCEVs is included in modest amounts, as these technologies are currently being actively researched and developed, and many stakeholders consider them necessary to achieve longer-term CO_2 reduction targets.

Table 2-1 provides an overview of the scenarios, along with the average direct CO_2 emissions achieved in 2025.

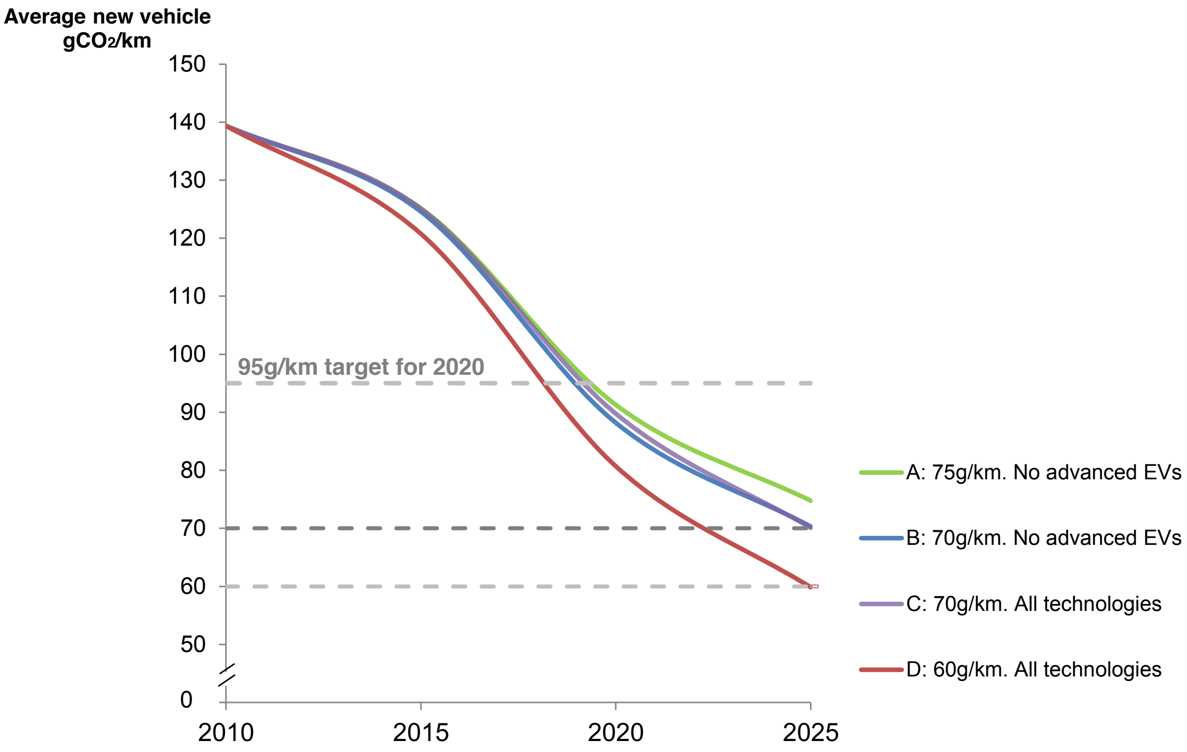
Table 2-1: Scenarios based on achieving target levels for average car direct CO_2 emissions (g/km) in 2025, test cycle basis

	Target in 2025		
	75g/km	70g/km	60g/km
No advanced EVs	A	B	
All technologies		C	D

Figure 2.2 illustrates the CO_2 trajectory over 2015-2025. All of the scenarios exceed the EC Reg (EC) 443/2009 requirement of 130g/km in 2015, as is generally expected given the current progress to date (see Figure 1.1). In addition, all of the scenarios exceed the EC Reg (EC) 443/2009 requirement of 95g/km in 2020. This is because the roll-out of powertrain technologies to meet deeper cuts in 2025 would need to start earlier than 2020; it would be more challenging to jump from 95g/km in 2020 to the lower emission targets in five years.

Of note is the trajectory for Scenario A (75g/km, no advanced EVs), which shows the 95g/km target in 2020 could potentially be met without the use of advanced EVs if efficiency improvements in ICE technology are introduced. This is consistent with the analysis from TNO et al (2011) and ICCT (2012) which shows that the 95g/km target can be met without any advanced ICEs. This must be interpreted within the limitations of the study - for consistency between marginal capital cost and fuel consumption assumptions, different powertrains are modelled based on the **average car**. In reality there are a range of characteristics and relative shares of different powertrain/fuel combinations for different vehicle sizes and market segments. The calculation framework is based on the average sized car in the EU and does not include downsizing, which is another potential source of cost-effective CO_2 reductions available that could be utilised in addition or as an alternative to technological improvement, depending on utility requirements.

Figure 2.2: Car direct CO_2 emissions (g/km), test cycle basis



Notes: direct CO_2 emissions refer to the test cycle emissions and do not include accounting rules such as super credits.

2.2.2 Technology mix

Table 2-2 shows the technology mix projected in each scenario as a percentage of the new vehicle fleet in 2015, 2020 and 2025. Currently, conventional ICEs make up the vast majority of the fleet and may be expected to maintain their market share of new vehicles in 2015 to a large extent, making up at least 95% of sales in all scenarios.

- In Scenario A (75g/km, no advanced EVs), conventional ICEs continue to dominate, accounting for more than three-quarters of new sales in 2025. This scenario shows a relatively low overall level of fleet transformation.
- In Scenario B (70g/km, no advanced EVs), the 70g/km target might be achieved with roughly equal shares of conventional ICE and HEV new sales; therefore, advanced EVs may not be required to meet a 70g/km target in 2025, although the uptake of HEVs is high (54%) and would require a step change in the rate of deployment of HEV technology.
- In Scenario C (70g/km, all technologies), PHEVs, BEVs and FCEVs are introduced. The higher emission savings of advanced EVs mean that lower levels of HEVs are required, so that overall the share of ICEs remains high (71%). A minor share of FCEVs (0.5%) is introduced to cater for long-distance travel, as these vehicles are not constrained by range in the same way as battery-powered EVs.
- In Scenario D (60g/km, all technologies), there are roughly equal shares of ICE cars and all other technologies together in 2025. Penetration of HEVs is around 24% and penetration of advanced EVs is 24%. Uptake of FCEVs is introduced at a slightly higher rate as in Scenario C (up to 2% by 2025). It is not possible to reach the 60g/km using ICEs and HEVs alone; therefore some introduction of EVs is needed.

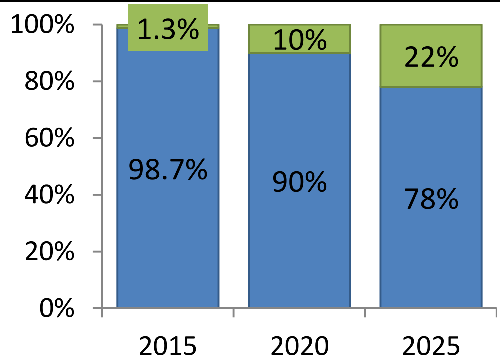
These scenarios have been developed for the purposes of illustrative comparisons, and additional support measures would be needed in particular for the introduction of advanced EVs (such as the development of recharging and hydrogen refuelling infrastructure). Within each scenario, the share of different technologies could vary while still meeting the same target. The relative shares here have been calculated based on achieving a credible trajectory and a realistic share of powertrains (see Section 2.2), for example in comparison with other studies, governmental and industry announcements (see Section 2.3).

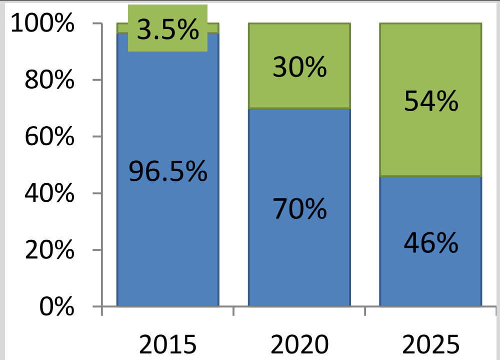
FCEV technology is still in development, and projections of its commercialization are highly uncertain. However, it is generally accepted that in order to meet the demands for long-range travel, hydrogen technology is a better option than a BEV, and typically has a better long-term GHG reduction potential than PHEVs (depending on the GHG intensity of hydrogen and electricity supply). In the IEA BLUE Map scenario, FCEVs are assumed to become commercially available by around 2020 (IEA, 2010). However, manufacturers indicate they are expecting commercial introduction as early as 2015. Including FCEVs in the scenarios with all technologies (C and D) causes a modest increase in average cost per vehicle (€30-40) compared to an alternative situation in which the targets are met using other advanced EVs.

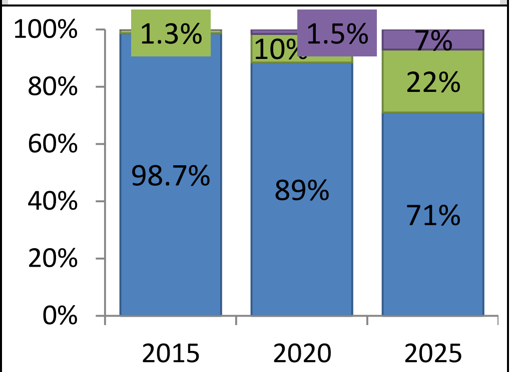
Table 2-2: Detailed figures. Technology mix as % of new cars

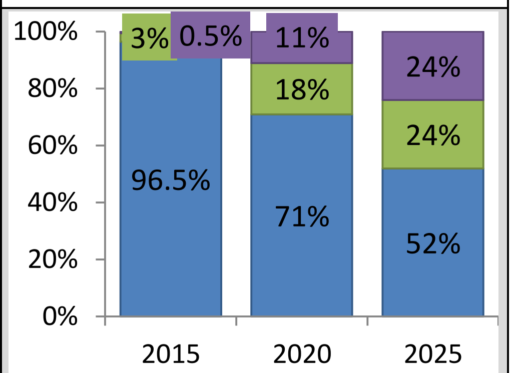
Key: ICE HEV Advanced EVs (PHEV, BEV & FCEV)

Scenario	Powertrain	2015	2020	2025
A: 75g/km No advanced EVs	ICE	98.7%	90%	78%
	HEV	1.3%	10%	22%
B: 70g/km No advanced EVs	ICE	96.5%	70%	46%
	HEV	3.5%	30%	54%
C: 70g/km All techs	ICE	98.7%	89%	71%
	HEV	1.3%	10%	22%
	PHEV	0%	1%	4.5%
	BEV	0%	0.5%	2%
	FCEV	0%	0%	0.5%
D: 60g/km All techs	ICE	96.5%	71%	52%
	HEV	3%	18%	24%
	PHEV	0.4%	7.5%	15%
	BEV	0.1%	3%	7%
	FCEV	0%	0.5%	2%









2.2.3 Average marginal costs per vehicle

The average marginal costs per vehicle to meet the targets in each of the scenarios are shown in Table 2-3 below. The marginal costs are compared to the current situation as a reference case – i.e. ICE vehicles with no further additional technology/improvements in CO_2 emissions compared to current levels. Due to the mandatory introduction of more stringent Euro standards for air pollution, there are additional costs for ICE vehicle even without improving CO_2 emissions; however, these are excluded from the accounting for clarity. Without further improvement/additional technology added to vehicles, and excluding other changes in specifications vehicles become cheaper to manufacture over time. For the purposes of the analysis the cost of the vehicle excluding the ICE powertrain (engine and transmission) is assumed to remain approximately constant, whilst the powertrain is assumed to reduce in cost by 0.5% p.a.

The average marginal costs per vehicle (compared to no further improvement) for meeting a target of 70g/km in 2025 are around €1,615 (scenarios B and C). The difference between costs in scenarios B and C is small because the lower uptake of HEVs in scenario C is compensated for by the higher price of advanced EVs that are taken up. To meet a target in 2025 of 60g/km in scenario D, average marginal costs per vehicle are estimated to increase to €2,370.

Table 2-3: Headline figures. Average marginal costs per vehicle in 2025 compared to 2010 (central), €

	Target in 2025		
	75g/km	70g/km	60g/km
No advanced EVs	A € 1,300	B € 1,600	
All technologies		C € 1,630	D € 2,370

Table 2-4 shows the average additional costs per vehicle in 2015, 2020 and 2025, as well as the central, high and low cases. These costs refer to the average across vehicles, whereas individual costs may vary. The basis of the central, high and low case estimates is summarised in Appendix 1.

Table 2-4: Detailed figures. Average additional costs per vehicle compared to 2010, €

Scenario	Costs	2015	2020	2025
A: 75g/km, no advanced EVs	**Central**	**370**	**810**	**1,300**
	High	510	1,110	1,790
	Low	280	600	970
B: 70g/km, no advanced EVs	**Central**	**410**	**1,010**	**1,600**
	High	550	1,370	2,170
	Low	310	730	1,210
C: 70g/km, all techs	**Central**	**370**	**910**	**1,630**
	High	510	1,230	2,210
	Low	280	670	1,210
D: 60g/km, all techs	**Central**	**560**	**1,590**	**2,370**
	High	700	2,090	3,190
	Low	470	1,150	1,730

Notes: Costs have been rounded and refer to the average across vehicles, whereas individual costs may vary significantly.

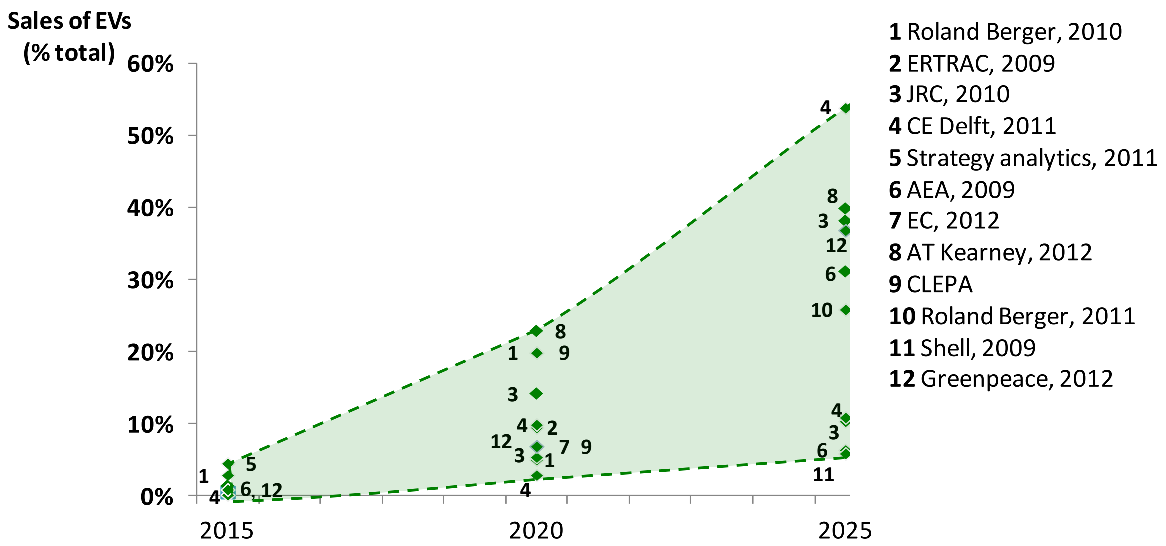
In this study we have only considered the additional cost of manufacturing, but not the total cost of ownership (TCO), including fuel costs and maintenance/other operational costs as well as the upfront cost of the vehicle. The TCO will depend on a number of factors which are difficult to assess at this point in time, including the purchase price of vehicles as well as prices for petrol, diesel and electricity.

2.3 Analysis of advanced EV uptake compared to other studies

The scenarios developed for this study are based on credible assumptions and consistent with other studies in this area. Experts generally agree that electric vehicles will be a key technology in the future, although predictions of market share vary widely depending on the assumptions underlying the estimates. In general, the lower estimates assume that the battery costs do not reduce in line with expectations; that government incentives for advanced EVs are limited and that further development of ICEs leads to significant additional efficiency gains. The high projections assume breakthroughs in battery costs and performance as well as significant government support in terms of incentives and infrastructure development. The most likely scenarios lie somewhere within this range.

Figure 2.3 compares predicted annual sales of electric vehicles in Europe from several studies, which include both market forecasts and scenarios. Market forecasts are produced by industry analysts and are used by companies to help them plan and manage their product portfolio and predict the market sales principally rely on projecting existing trends into the future in combination with some expertise or detailed understanding of the existing market place. Scenarios are generally based on various more specific assumptions on future technical development (e.g. battery cost and performance improvements) and other key influencing factors (e.g. future oil prices). In some cases back-casting approaches are also used: i.e. starting from a desired future position and working backwards towards the current situation in order to establish what would need to happen in order for this to be achieved – these are most commonly used by governments and policy makers.

Figure 2.3: Comparison of annual sales projections for electric vehicles (PHEV, BEV and FCEV) in Europe



Notes: where literature sources provide figures in terms of percentages, we have converted them to absolute figures using the new fleet volumes estimated based on extrapolation from 2010 sales provided in ICCT (2011). Estimates from Greenpeace (2012) are based on the weighted average of projections for the small, medium and large market segments.

The highest estimates in 2020 are from Roland Berger (2010) in “the future drives electric" scenario, which see the market share for EVs and PHEVs reaching 20% in Western Europe by 2020, and from AT Kearney (2012) with a corresponding share of 23%. The estimate from Roland Berger (2010) is an optimistic scenario where uptake of EVs is driven by higher oil prices, accelerated battery cost reduction, stronger government support and a broader EV product range in the next five to ten years. The results from AT Kearney (2012) are based on interviews with Original Equipment Manufacturers (OEMs), suppliers and governments, supported by calculations of the Total Cost of Ownership (TCO). These come from their "moderate" scenario, which represents their estimate of the most likely development. The highest estimate in 2025 is from CE Delft (2011) in the "EV Breakthrough" scenario. This assumes that from 2015 onwards R&D leads to a rapid reduction of battery cost and increase in battery lifetime, whereas ICE development is roughly in line with expectations from the car CO_2 regulations (i.e. based on expectations resulting from the cost-curves developed in TNO, 2011). The total cost of ownership for advanced EVs is assumed to become competitive with conventional vehicles in certain market segments. Government incentives are assumed to be high at first but rapidly reduce from 2015 onward. The second-highest estimate in 2025 (40%) is from AT Kearney (2012), which is based on their "most likely" predictions.

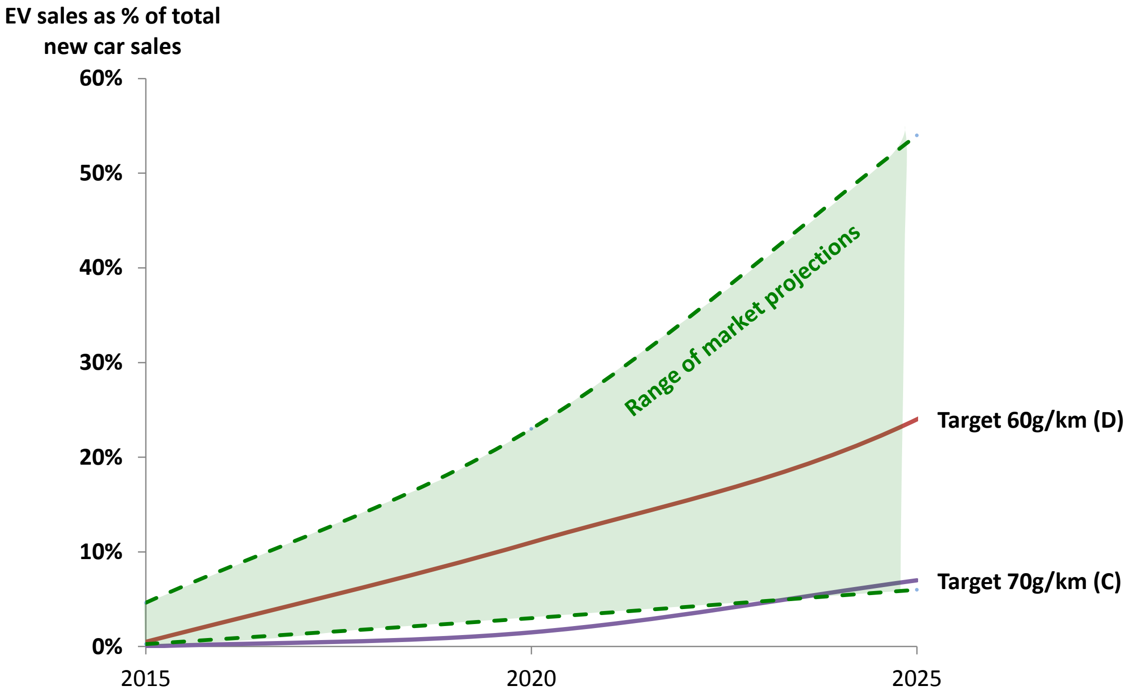
In addition, the collective national targets from eight European countries[2] together amount to cumulative sales of 6.7 million by 2020 (JRC, 2010). These targets have not been included in Figure 2.3 because the uptake trajectory for these sales is not indicated and only eight European countries are represented. There is some indication that these targets may be revised downward. Despite this, Member States are still investing in significant support for uptake of electric vehicles.

The estimates sourced from the literature have been compared to the level of advanced EVs in the projections for this study. Figure 2.4 shows the range of market projections, along with the uptake trajectories for advanced EVs in scenario C (target 70g/km) and scenario D (target 60g/km). In 2020, the target of 70g/km without further measures to stimulate the uptake of electric vehicles is expected to reach only minimal levels of such vehicles, and sales will fall well below even the most conservative market projections. The level of uptake to meet the target of 70g/km in 2025 (scenario C) is near the bottom of the range of the market projections. This is because the high emission savings of advanced EVs mean that only a small proportion is needed; as seen in Scenario B, it could be possible to meet the same target without EVs (although uptake of HEVs would need to be substantially higher). The level of uptake in 2025 for the target of 60g/km, in combination with measures outside vehicle standards, falls comfortably within the range of market projections for advanced EVs.

In terms of cumulative sales of EVs, these targets imply overall EV fleet numbers of around 0.7 million and 5.5 million vehicles by 2020, respectively for the 70g/km and 60g/km objectives for 2025. These compare favourably with other estimates of 6.6 million and 5 million electric vehicles by 2020, from JRC (2010) and ETRAC (2012) respectively.

[2] Denmark, France, Germany, Ireland, Netherlands, Spain, Sweden, UK

Figure 2.4: Projected EV sales (PHEVs, BEVs and FCEVs) to meet 70g/km and 60g/km in the scenarios with all technologies



Note: Includes PHEVs, BEVs and FCEVs

As advanced EVs are disruptive technologies that are still in development, predictions of market penetration are highly uncertain. Factors that will affect uptake are wide-ranging, including:

- Governmental policies to support electric vehicles across different countries;
- The speed of innovation, particularly in battery performance and cost;
- The deployment of the necessary infrastructure to create consumer confidence;
- OEM decisions regarding production (and the availability of key components);
- Fuel prices;
- Consumer preferences.

Support in Europe has aimed to stimulate the market by addressing the above factors through a range of policy instruments.

2.4 Equivalent targets for vans by 2025

In terms of developing equivalent targets for vans by 2025, it was considered that scenarios based on similar levels of efficiency improvement technology and alternative powertrain technology uptake would be appropriate for comparison. Therefore exactly the same percentage deployment levels of the individual efficiency improvement technologies that are summarised in Appendix 1 (Table 5-3) for cars are also applied to vans (i.e. technical options like stop-start, engine downsizing and boost, weight reduction, etc). In addition, the same percentage deployment levels for individual powertrain types (i.e. ICE, HEV, PHEV, BEV and FCEV) summarised in earlier Table 2-2 for cars are also applied in the vans analysis.

This approach is distinct from the analysis based on using cost curves as devised by TNO (2012), which consider improvements to ICE vehicles but do not analyse the potential for use of different technology deployment.

Based on the equivalent analysis for vans, the summary results show that the equivalent target for 70g/km for cars in 2025 could be around 99-100g/km for vans, and the equivalent target for 60g/km for cars in 2025 could be around 85g/km for vans.

Figure 2.5: Van direct CO_2 emissions (g/km), test cycle basis

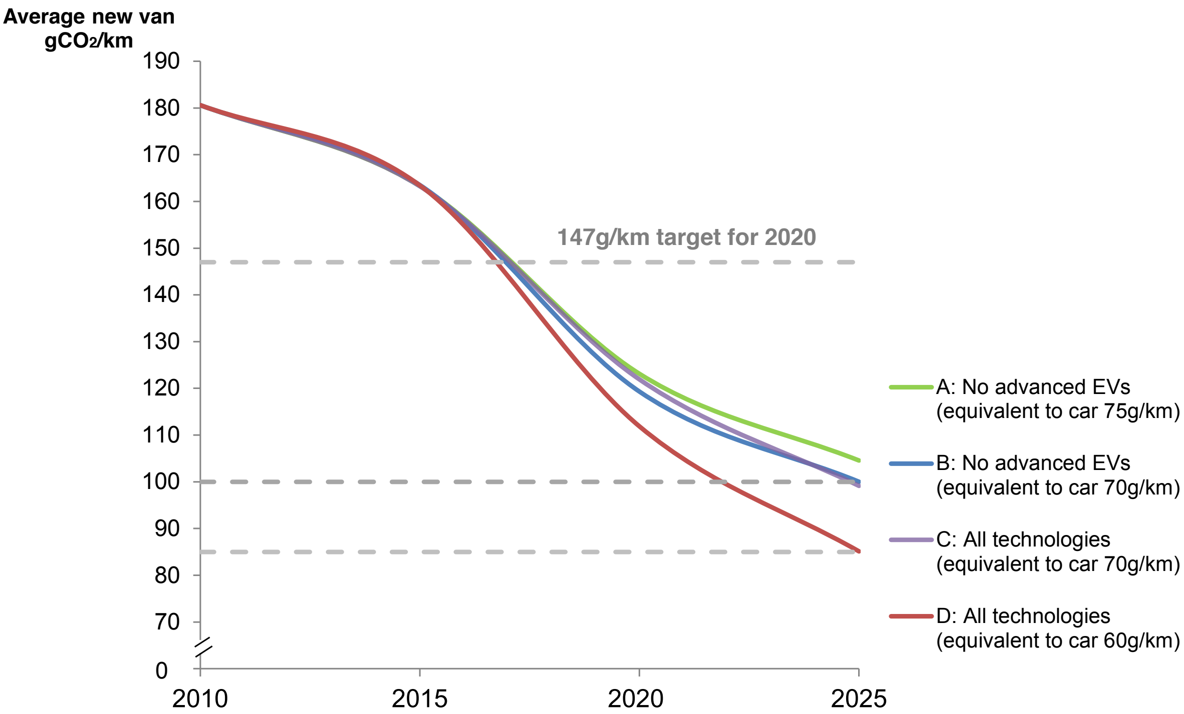


Table 2-5: Summary figures for cars and vans in 2025

Scenario	Technology mix		gCO2/km		Marginal cost	
			Cars	Vans	Cars	Vans
A: 75g/km, no advanced EVs	ICE	78%	75	105	€ 1,300	€ 1,560
	HEV	22%				
B: 70g/km, no advanced EVs	ICE	46%	70	100	€ 1,600	€ 1,830
	HEV	54%				
C: 70g/km, all techs	ICE	71%	70	99	€ 1,630	€ 1,830
	HEV	22%				
	Advanced EVs	7%				
D: 60g/km, all techs	ICE	52%	60	85	€ 2,370	€ 2,500
	HEV	24%				
	Advanced EVs	24%				

Notes: Technology mix is presented as a percentage of new vehicles; gCO_2/km corresponds to direct test cycle emissions; Marginal cost is the average additional cost per vehicle

The marginal costs of achieving the same level of technology uptake are broadly similar, but slightly higher for vans (partly due to a lower-level starting basis in terms of 2010 deployment of some of the improvement technologies). Currently the uptake of other technological measure for improving vans lags somewhat behind the car sector in part due to more conservatism in this sector, but also the less challenging near-term CO_2 reduction targets.

3 Summary and Conclusions

This study analysed credible technology pathways to meet 2025 targets for the EU new car and van fleets. The following key conclusions may be drawn from the analysis performed:

- A CO_2 target of 70g/km in 2025 for new cars might potentially be achieved with no advanced EV powertrains (PHEV, REEV, BEV and FCEV), if the just over half the new car fleet was made up of HEV powertrains. A modest penetration of advanced EV powertrains (at the bottom end of the range of 2025 market share projections and scenarios) would allow for a larger proportion (around 71%) of conventional ICEs and smaller proportion of HEV powertrains.
- A CO_2 target of 60g/km in 2025 for new cars would require a significant level of uptake of advanced EV powertrains – up to 24% of new vehicles. However, this level of uptake is still at the middle of the range of credible market projections and scenarios for uptake of advanced EV powertrains. The 60g/km target also requires accelerated progress improving the efficiency of ICE vehicles including a quarter of new cars being hybrid
- The potential additional manufacturing costs for meeting a direct CO_2 target level of 70g/km for cars in 2025 could be around €1,615 (with a range from €1,210-€2,210). Equivalent costs for a 60g/km target could be €2,370 (with a range of €1,730-€3,190). Cost are compared to current vehicles;
- Through deploying similar levels of technology into vans as for cars, the results show that the equivalent CO_2 targets for 70g/km and 60g/km levels for cars in 2025 could be around 100g/km and 85g/km respectively for vans. Manufacturing costs for these levels could be expected to be €100-200 higher than for achieving the car targets.

In summary, the analysis has demonstrated that new car CO_2 emission targets as low as 60g/km for 2025 could be achieved using existing, known technological options and a mix of advance EV powertrains that is well within the range of credible market projections and scenarios. The analysis has also shown that comparable technological improvements and deployment of alternative powertrains could result in an equivalent target for vans being as low as 87g/km. However, this could only be achieved with a step-change in the rate of technological improvement of vans, which is currently driven by relatively unambitious CO_2 targets for 2017 and 2020 (i.e. compared to those for cars). For both cars and vans the average anticipated additional vehicle manufacturing costs are not prohibitive.

This study has focused on the additional manufacturing cost, excluding manufacturer/dealer margins and taxes and has not considered the total cost of ownership (TCO), including fuel costs and maintenance/other operational costs in addition to the upfront cost of the vehicle. Factoring in lifetime fuel cost and operational savings can significantly improve the relative attractiveness of more efficient technological options.

For the car sector at least, the up-front average additional manufacturing costs could also potentially be further reduced through a degree of vehicle down-sizing (not explored here).

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5 Appendix 1 - Summary of key assumptions on technology performance and capital costs used in the analysis

5.1 Introduction and Methodological Basis

The analysis in this report is based on Ricardo-AEA's Road Vehicle Cost and Efficiency Calculation Framework. The methodology and assumptions from this framework were also used for previous work by AEA Technology plc for the UK Committee on Climate Change (AEA, 2012)[3]. These have their sources in a range of major UK and European studies and have been previously tested with experts from industry and academia. Full details of the methodology, datasets and key information sources are provided in project report, available from CCC's website[3].

Since this calculation framework was developed for the CCC, Ricardo-AEA has further updated key datasets and assumptions based on additional literature evidence. This appendix provides a summary of the key amendments, summarised as follows:

- Development of a 'technology packages' methodology;
- Addition of indicative high and low cost estimates for individual technological options;
- Revisions to key technology data assumptions, in particular those for the costs and performance of weight reduction, batteries and fuel cells;
- Revisions to other elements of the methodology and calculations, including:
  - Introduction of a 1% p.a. cost reduction due to learning over time for new technologies, to supplement existing volume related learning /cost reduction calculations;
  - The core/current technology ICE powertrain (engine + transmission) manufacturing is also assumed to reduce in cost at a rate of 0.5% p.a. (i.e. excluding technological improvements).
  - Assumptions on battery sizing for different powertrain types, including useable SOC (state of charge) reserve and range in electric-only mode.
- Introduction of indicative additional long-term (2030-2050) technology options.

5.2 Updated Technology Datasets

Eight indicative 'technology packages' were developed in order help better conceptualise technology deployment and consistently build individual technology deployment assumptions in a more consistent and systematic way. The technology packages were developed to achieve nominal efficiency improvement objectives in 5-year increments from 2010 to 2040 and at 2050, assuming a challenging, but achievable rate of roll-out of the technologies (based on their relative cost-effectiveness). The overall deployment of individual

[3] AEA (2012), A review of the efficiency and cost assumptions for road transport vehicles to 2050, a report by AEA Technology plc for the UK Committee on Climate Change, April 2012. Currently available from CCC's website at the following location: http://www.theccc.org.uk/reports/international-aviation-a-shipping/supporting-research

technologies in different periods was subsequently estimated based on indicative shares of deployment of these packages under the different scenarios. The assumed package deployment shares under the three scenarios is summarised in Table 5-1 below.

Table 5-1: Summary of the key technology assumptions related to technology package deployment

Package		2010	2015	2020	2030
1	2010 ICE	100%	40%	5%	
2	~2015 ICE: -15% on 2010 (~halfway to 2020 target)		50%	10%	
3	~2020 ICE: -30% on 2010 (~95gCO_2/km target)		10%	70%	5%
4	~2025 ICE: -45% on 2010 gCO_2/km			10%	20%
5	~2030 ICE: Close to max for known technology (-55%)			5%	60%
6	~2035 ICE: Everything currently known at max deployment				10%
7	~2040 ICE: All current + unknown 2040 technology, 35% LW				5%
8	~2050 ICE: All current + unknown 2040, 2050 technology, 40% LW				

Notes: LW = total lightweighting/weight reduction

- Table 5-2 shows the allocation of technologies into each of the technology packages summarised above
- The resulting deployment levels of individual technologies for each technology package is presented in Table 5-3.

The final range of technologies and the assumptions on their costs and performance is presented in Table 5-2 for cars. The majority of the central technology costs and efficiency improvement potentials are used in the original calculation framework dataset, which were based on the basic case dataset presented in TNO et al (2011) [4]. This dataset was provided by ACEA and the automotive suppliers body CLEPA for the TNO et al (2011) analysis. However, there were a number of modifications and additions made, as mentioned in the previous section. In particular, the central weight reduction costs and potentials are based on data from the EPA[5], also presented in Annex D of TNO et al (2011).

This weight reduction dataset was based on a highly detailed study by Lotus (2010)[6] for ICCT, and complimentary follow-on research commissioned by the EPA and carried out by FEV (2011)[7], which had similar findings. These studies have found that whilst weight reduction to light duty vehicle's body in white (BIW) using alternative materials adds significant cost to the overall vehicle, this is offset to a degree by zero, or even cost negative weight reduction potential in other parts of the vehicle (e.g. through smart design and reduction in materials), as well as complimentary secondary weight reduction and savings through down-sizing of key vehicle components that is enabled due to the primary weight reduction (e.g. smaller/less expensive brakes for lighter vehicles).

High and low cost estimates for the individual technology options presented in Table 5-2 were developed assuming a similar differential between the TNO et al (2011) base case, scenario 'a' and scenario 'a+b' cost curve estimates. This was equivalent to a 25% reduction on the central costs for the low case, and a corresponding 37% increase for the high case.

[4] TNO et al (2011), available at: http://ec.europa.eu/clima/policies/transport/vehicles/cars/docs/study_car_2011_en.pdf
[5] EPA (2010). Interim Joint Technical Assessment Report: Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025, a report by the US EPA's Office of Transportation and Air Quality, September 2010. Available at: http://www.epa.gov/otaq/climate/regulations/ldv-ghg-tar.pdf
[6] Lotus (2010). An Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program, a study by Lotus Engineering Inc. for the International Council on Clean Transportation (ICCT), March 2010. Available from: http://www.theicct.org/sites/default/files/publications/Mass_reduction_final_2010.pdf
[7] FEV (2012).Light-Duty Vehicle Mass Reduction and Cost Analysis - Midsize Crossover Utility Vehicle, prepared by FEV for the US EPA's Office of Transportation and Air Quality, August 2012. Available at: http://www.epa.gov/otaq/climate/documents/420r12026.pdf

Table 5-2: Summary of the technology package definition, efficiency improvement and cost assumptions for cars (X = technology applied at 100% level)

Sub-component	Type	T#	% Change in Energy Cons.	2010 Cost	Technology Package							
					1	2	3	4	5	6	7	8
Petrol - low friction design and materials	PtrainE	1	-2.0%	€35	10%	X	X	X	X	X	X	X
Petrol - gas-wall heat transfer reduction	PtrainE	2	-3.0%	€50	10%		X	X	X	X	X	X
Petrol - direct injection (homogeneous)	PtrainE	3	-5.3%	€180	15%	X	X					
Petrol - direct injection (stratified charge)	PtrainE	4	-9.3%	€550	0%			X				
Petrol - thermodynamic cycle improvements (e.g. HCCI)	PtrainE	5	-14.5%	€488	0%				X	X	X	X
Petrol - cam-phasing	PtrainE	6	-4.0%	€80	10%	X	X					
Petrol - variable valve actuation and lift	PtrainE	7	-10.5%	€280	5%			X	X	X	X	X
Diesel - variable valve actuation and lift	PtrainE	8	-1.0%	€280	0%			X	X	X	X	X
Diesel - combustion improvements	PtrainE	9	-6.0%	€50	10%	50%	X	X	X	X	X	X
Mild downsizing (15% cylinder content reduction)	PtrainE	10	-5.5%	€275	20%	X						
Medium downsizing (30% cylinder content reduction)	PtrainE	11	-8.5%	€473	5%		X	X				
Strong downsizing (>=45% cylinder content reduction)	PtrainE	12	-17.5%	€650	0%				X	X	X	X
Reduced driveline friction	PtrainE	13	-1.0%	€50	5%		X	X	X	X	X	X
Optimising gearbox ratios / downspeeding	PtrainE	14	-4.0%	€60	10%		X	X	X	X	X	X
Automated manual transmission	PtrainE	15	-5.0%	€300	0%			X	X			
Dual clutch transmission	PtrainE	16	-6.0%	€725	0%					X	X	X
Start-stop hybridisation	PtrainE	17	-5.0%	€213	5%		X	X				
Start-stop + regenerative braking (smart alternator)	PtrainE	18	-10.0%	€400	0%				X	X	X	X
Non-specific general improvement	PtrainE	19	-10.0%	€-	10%	20%	40%	60%	80%	X	X	X
Aerodynamics improvement	Aero	1	-1.8%	€55	5%		X	X	X	X	X	X
Low rolling resistance tyres	Rres	1	-3.0%	€38	20%	X	X	X	X	X	X	X
Mild weight reduction (~10% total)	Weight	1	-6.7%	€35	10%	X						
Medium weight reduction (~20% total)	Weight	2	-13.5%	€220	3%		X	X	X			
Strong weight reduction (~30% total)	Weight	3	-20.2%	€810	0%					X		
Very strong weight reduction (~35% total)	Weight	4	-23.5%	€1,800	0%						X	
Extreme weight reduction (~40% total)	Weight	5	-26.8%	€3,000	0%							X
Thermo-electric waste heat recovery	Other	1	-2.0%	€1,000	0%					X	X	X
Secondary heat recovery cycle	Other	2	-2.0%	€250	0%				X	X	X	X
Auxiliary systems efficiency improvement	Other	3	-12.0%	€450	15%			X	X	X	X	X
Thermal management	Other	4	-2.5%	€150	10%			X	X	X	X	X
Long term ICE improvements (stage 1)	Other	5	-7.5%	€400	0%						X	X
Long term ICE improvements (stage 2)	Other	6	-5.0%	€1,000	0%							X

The resulting deployment levels of individual technologies for each technology package is presented in Table 5-3.

Table 5-3: Summary of the efficiency improvement, cost assumptions and deployment levels resulting from the technology package methodology for cars

Sub-component	Type	T#	% Change in Energy Cons.	2010 Cost	Technology Package 2010	2015	2020	2030	2040	2050
Petrol - low friction design and materials	PtrainE	1	-2.0%	€35	10%	60%	95%	100%	100%	100%
Petrol - gas-wall heat transfer reduction	PtrainE	2	-3.0%	€50	10%	10%	85%	100%	100%	100%
Petrol - direct injection (homogeneous)	PtrainE	3	-5.3%	€180	15%	60%	80%	5%	0%	0%
Petrol - direct injection (stratified charge)	PtrainE	4	-9.3%	€550	0%	0%	10%	20%	0%	0%
Petrol - thermodynamic cycle improvements (e.g. HCCI)	PtrainE	5	-14.5%	€488	0%	0%	5%	75%	100%	100%
Petrol - cam-phasing	PtrainE	6	-4.0%	€80	10%	60%	80%	5%	0%	0%
Petrol - variable valve actuation and lift	PtrainE	7	-10.5%	€280	5%	0%	15%	95%	100%	100%
Diesel - variable valve actuation and lift	PtrainE	8	-1.0%	€280	0%	0%	15%	95%	100%	100%
Diesel - combustion improvements	PtrainE	9	-6.0%	€50	10%	50%	100%	100%	100%	100%
Mild downsizing (15% cylinder content reduction)	PtrainE	10	-5.5%	€275	20%	50%	10%	0%	0%	0%
Medium downsizing (30% cylinder content reduction)	PtrainE	11	-8.5%	€473	5%	10%	80%	25%	0%	0%
Strong downsizing (>=45% cylinder content reduction)	PtrainE	12	-17.5%	€650	0%	0%	5%	75%	100%	100%
Reduced driveline friction	PtrainE	13	-1.0%	€50	5%	10%	85%	100%	100%	100%
Optimising gearbox ratios / downspeeding	PtrainE	14	-4.0%	€60	10%	10%	85%	100%	100%	100%
Automated manual transmission	PtrainE	15	-5.0%	€300	0%	0%	15%	80%	5%	0%
Dual clutch transmission	PtrainE	16	-6.0%	€725	0%	0%	0%	15%	95%	100%
Start-stop hybridisation	PtrainE	17	-5.0%	€213	5%	10%	80%	25%	0%	0%
Start-stop + regenerative braking (smart alternator)	PtrainE	18	-10.0%	€400	0%	0%	5%	75%	100%	100%
Non-specific general improvement	PtrainE	19	-10.0%	€-	10%	0%	5%	75%	100%	100%
Aerodynamics improvement	Aero	1	-1.8%	€55	5%	18%	41%	77%	99%	100%
Low rolling resistance tyres	Rres	1	-3.0%	€38	20%	3%	35%	90%	100%	100%
Mild weight reduction (~10% total)	Weight	1	-6.7%	€35	10%	3%	35%	90%	100%	100%
Medium weight reduction (~20% total)	Weight	2	-13.5%	€220	3%	3%	35%	90%	100%	100%
Strong weight reduction (~30% total)	Weight	3	-20.2%	€810	0%	10%	85%	100%	100%	100%
Very strong weight reduction (~35% total)	Weight	4	-23.5%	€1,800	0%	60%	95%	100%	100%	100%
Extreme weight reduction (~40% total)	Weight	5	-26.8%	€3,000	0%	50%	10%	0%	0%	0%
Thermo-electric waste heat recovery	Other	1	-2.0%	€1,000	0%	10%	85%	85%	5%	0%
Secondary heat recovery cycle	Other	2	-2.0%	€250	0%	0%	0%	10%	20%	0%
Auxiliary systems efficiency improvement	Other	3	-12.0%	€450	15%	0%	0%	5%	65%	10%
Thermal management	Other	4	-2.5%	€150	10%	0%	0%	0%	10%	90%
Long term ICE improvements (stage 1)	Other	5	-7.5%	€400	0%	0%	0%	15%	95%	100%
Long term ICE improvements (stage 2)	Other	6	-5.0%	€1,000	0%	0%	5%	75%	100%	100%

Similar deployment levels were also developed for vans. Currently there is a lag in uptake in the van sector, somewhat behind the car sector in part due to more conservatism in this sector, but also the less challenging near-term CO_2 reduction targets. For the purposes of the analysis of the full potential for reductions in the van sector, it has been assumed technologies are deployed at the same rate as for cars.

In addition to the information presented in the previous tables, the following separate key assumptions relevant to the cost calculations for hybrid and electric vehicles, presented in Table 5-4, were also updated from those used previously in AEA (2012).

Table 5-4: Summary of the key technology assumptions related to hybrid and electric vehicles

Area	Category	Unit	2010	2020	2030
BEV battery system (cars) (1)	Central cost	€/kWh	558	245	163
	Low cost	€/kWh	558	165	125
	High cost	€/kWh	558	307	201
BEV battery system (vans) (1)	Central cost	€/kWh	504	221	147
	Low cost	€/kWh	504	149	113
	High cost	€/kWh	504	277	181
Battery system cost increase over BEV (2)	HEV	%	100%	100%	100%
	PHEV	%	50%	50%	50%
	REEV	%	25%	25%	25%
	BEV	%	0%	0%	0%
	FCEV (H2FC)	%	100%	100%	100%
Battery usable SOC for electric range (3) (4)	HEV	%	50%	55%	60%
	PHEV	%	60%	65%	70%
	REEV	%	70%	75%	80%
	BEV	%	80%	80%	85%
	FCEV (H2FC)	%	50%	55%	60%
All-electric range (5) (6)	HEV	km	2	2	2
	PHEV	km	30	35	40
	REEV	km	60	70	80
	BEV	km	120	160	200
	FCEV (H2FC)	km	5	4	3
Electric motor system	Central cost	€/kW	41	22	14
	Low cost	€/kW	41	14	13
	High cost	€/kW	41	31	22
Electric powertrain (HEV) (7)	Additional cost (excl. battery, motor)	€	1014	890	800
Electric powertrain (Others) (7)	Additional cost (excl. battery, motor)	€	1282	1031	930

Notes:

(1) Updated primarily based on finalised report for CCC on battery costs (Element Energy, 2012)[8]. Converted from $ to € using a 1.3 $/€ exchange rate.

(2) Assumptions on battery costs for HEV, PHEV and REEV have been separated out based on ANL (2010)[9] and discussions with industry experts. In particular, as a result the battery cost assumptions for PHEV and REEV are significantly lower than those used in the earlier study for CCC (AEA, 2012).

(3) In hybrid and electric vehicles it is necessary to provide a reserve state of charge (SOC) 'header' to ensure (a) there is sufficient power for efficient basic operation, (b) to protect the battery from excessively deep discharges which can be significantly reduce battery lifetimes. It is anticipated that this header will reduce in the future as battery technology performance and durability improves.

(4) Separate SOC assumptions have been utilised for different powertrains on the basis of ANL (2010)[9] and discussions with industry experts.

(5) Ranges are for real-world performance; equivalent range will be 20-25% higher on a test-cycle basis. Range assumptions for BEVs have been reduced vs AEA (2012) to better reflect the current real-world ranges of BEVs.

(6) Ranges for PHEV and REEV are estimated to increase at slightly lower rate than those for BEVs (previously no increase in range over 2010 levels was assumed for PHEV and REEV).

(7) Excludes battery system and motor system costs. Advanced EVs need larger/more complex electric heating/cooling systems compared to HEVs, since they are not able to draw upon significant waste heat generated by an ICE in very cold conditions.

[8] Element Energy (2012), Cost and performance of EV batteries, Final report by Element Energy for the UK Committee on Climate Change, March 2012. Currently available from the following location: http://www.theccc.org.uk/reports/international-aviation-a-shipping/supporting-research
[9] ANL (2010). Modeling of Manufacturing Costs of Lithium-Ion Batteries for H EVs, PHEVs, and EVs, a report by Santini et al of Argonne National Laboratory. Presented at The 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exhibition (EVS25), China, Nov 5-9, 2010.

Additional updated assumptions relating to fuel cell vehicles (FCEV) and 2010 conventional internal combustion engines (ICE) are also presented in Table 5-5 and Table 5-6. For ICEs, future costs were estimated based on a reduction of 1% p.a. from 2010 levels.

Table 5-5: Summary of the additional technology assumptions for fuel cell electric vehicles (FCEVs)

Area	Category	Unit	2010	2020	2030
Fuel cell system cost	Central cost	€/kW	880	100	55
	Low cost	€/kW	880	80	45
	High cost	€/kW	880	150	80
H2 storage cost	Central cost	€/kWh	59	16	10
	Low cost	€/kWh	59	13	6
	High cost	€/kWh	59	20	13

Table 5-6: Updated assumptions for the base costs of 2010 conventional internal combustion engines (ICE), before the addition of further technological improvements

Area	Category	Unit	2010	2020	2030
Petrol ICE	Central cost	€/kW	26	25	24
	Low cost	€/kW	22	21	20
	High cost	€/kW	28	27	26
Diesel ICE	Central cost	€/kW	34	32	31
	Low cost	€/kW	33	31	30
	High cost	€/kW	37	35	34

5.3 Limitations

The costs and performance of different technology options are based on information sourced from the literature and from expert consultation, which have been combined in a consistent way using Ricardo-AEA's calculation framework. However, it is only possible to factor in technology interactions (overlaps, synergies and dis-synergies) in an approximate way, as this is not a full vehicle simulation tool. There is also considerable future uncertainty over these parameters, which is a limitation common to all projections.

The potential for future cost reduction in individual technologies will be influenced by a wide range of factors including rates of technology deployment (i.e. economies of scale), breakthroughs in fundamental research, future prices of key materials and components. High and low cost sensitivities have been developed to analyse this uncertainty.

Certain elements have been fixed for the purposes of this analysis because (a) it will enable a clearer understanding of the specific impacts of technological development independent of other factors, and (b) the characteristics and effects of such considerations are highly uncertain.

For consistency between marginal capital cost and fuel consumption assumptions, different powertrains are modelled based on the average car or van. In reality there are a range of characteristics and relative shares of different powertrain/fuel combinations for different vehicle sizes and market segments. In the future there may be a shift to smaller (for passenger cars) or larger (for vans) vehicle sizes/segments due to various drivers. In addition, the very characteristics of future vehicles and how they are used is likely to change (particularly in the longer term) – to an extent that is highly uncertain.

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