

**elementenergy**

***Towards a European  
Market for  
Electro-Mobility***

Final report

for

**Transport &  
Environment**

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## Abbreviations

AT PZEV	Advanced technology partial zero emission vehicle
BEV	Battery electric vehicle
EC	European Commission
ECCo	Electric Car Consumer model
ETS	Emissions Trading Scheme
EU	European Union
HEV	(Full) Hybrid electric vehicle
ICCT	The International Council on Clean Transportation
ICE	Internal combustion engine
LDV	Light duty vehicle
NEDC	New European Driving Cycle
NEV	Neighbourhood electric vehicle
NMOG	Non-methane organic gases
OEM	Original equipment manufacturer
PHEV	Plug-in hybrid electric vehicle
PZEV	Partial zero emission vehicle
RW	Real world
SMMT	The Society of Motor Manufacturers & Traders (UK)
UF	Utility factor (proportion of kilometres driven under electric power)
ULCV	Ultra-low carbon vehicle
WLTC	Worldwide harmonised Light vehicles Test Cycle
WLTP	Worldwide harmonised Light vehicles Test Procedure
ZEV	Zero-emission vehicle

## 1 Executive Summary

The EU has set a target to reduce non-Emissions Trading Scheme CO<sub>2</sub> emissions by 30% from 2005 levels by 2030, as part of the EU's 2030 Climate and Energy Package. Transport currently represents 35% of this, and so deep emissions reductions from this sector will be required if the overall target is to be met. The European Commission has previously set legally binding average CO<sub>2</sub> emissions standards for new vehicles. However, no targets are yet in place beyond the 95 gCO<sub>2</sub>/km for new cars in 2021 and 147 gCO<sub>2</sub>/km for new vans in 2020. The EU has laid out its intention to continue setting lower targets in the 2020s, with car and van targets for 2025 and 2030 likely to be announced in 2017. The European Commission has consistently set targets 8 years in advance of the date of enforcement to align with vehicle manufacturers' normal 5-7 year design cycles.

While the required decarbonisation pathway in the short term can still be achieved with incremental improvements to the efficiency of conventional internal combustion engines, the Commission has recognised that long term emissions goals, such as reducing overall emissions by 80% between 1990 and 2050, will require the widespread introduction of ultra-low carbon vehicle (ULCV) technology, for example plug-in vehicles and hydrogen fuel cells. Early deployment of ULCVs is therefore seen as the most cost-effective long term decarbonisation strategy, as this ensures that the powertrain technologies are sufficiently advanced and available at low cost when required to meet ever more ambitious CO<sub>2</sub> reductions in the decades to come. This creates a tension with policies based only on fleet average emissions, because the lowest cost improvements to CO<sub>2</sub> emissions in the short term (improving internal combustion engine efficiency) may lead to delayed investment in ultra-low carbon vehicles that are required in the medium to long term. To encourage ULCV development, the EU has employed a system of Super-credits, which allows vehicle manufacturers to count vehicles with emissions less than 50 gCO<sub>2</sub>/km (NEDC) multiple times in their calculation of average new vehicle emissions to comply with CO<sub>2</sub> standards. The first Super-credit scheme ran from 2012 to 2015 and an additional period of Super-credits will be in place between 2020 and 2022. However, the system has been criticised for effectively allowing average emissions to be higher than specified by the target, and its impact has been questionable, with ULCVs making up just 1.24% of all European car sales in 2015.

A ULCV mandate, where OEMs are required to sell a minimum proportion of ULCVs in their overall sales, has been proposed as an alternative policy to bring about widespread ULCV adoption. Such a system has been in place in California since 1990, although it has gone through several revisions and has been criticised for being too weak, despite 45% of the USA's plug-in vehicle sales between 2011 and 2015 taking place in California.

In this study, policies to bring about higher ULCV adoption in the 2020s have been assessed for their effectiveness. The future emissions of new vehicles are forecast from Element Energy's Vehicle Cost and Performance Model, which employs the efficiency gains and deployment schedule of 46 efficiency technologies featured in the Commission's latest cost curve study. This covers conventional petrol and diesel ICEs, full hybrids (HEVs), plug-in hybrids (PHEVs) and battery electric vehicles (BEVs) across nine car segments and five van segments. An EU stock model for cars and vans, based on transport demand forecasts from the TREMOVE model, is used to estimate stock emissions out to 2030.

This study first identifies 2025 and 2030 CO<sub>2</sub> targets for new cars and vans that result in emissions falling by 25, 30, 35 and 40 percent between 2005 and 2030 for both the car and van stock. A 30% reduction for both vehicle types is estimated to require WLTP emissions of 75 gCO<sub>2</sub>/km in 2025 and 50 gCO<sub>2</sub>/km in 2030 for cars, and 82 gCO<sub>2</sub>/km in 2025 and 33

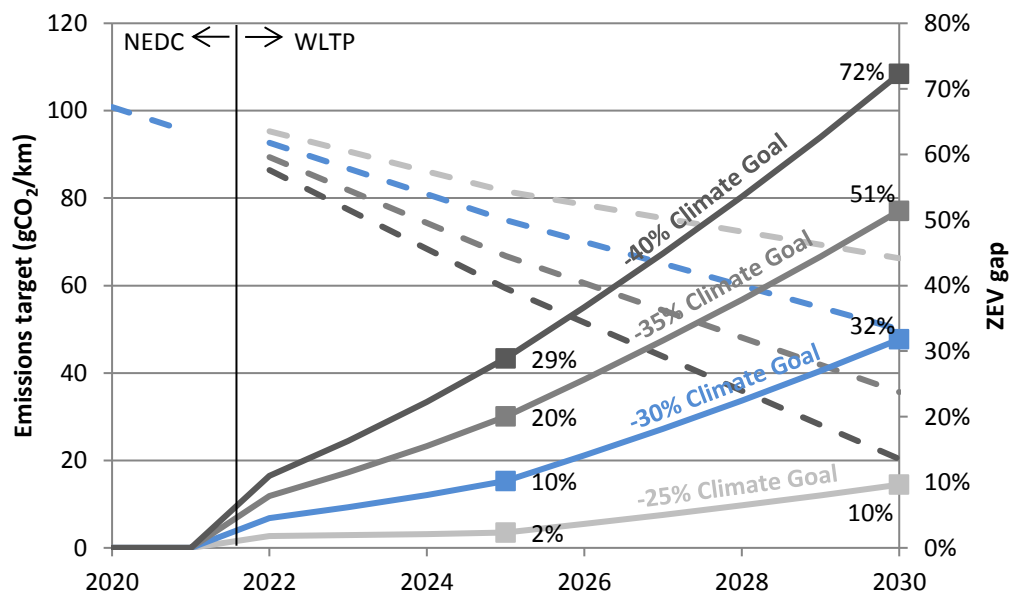
gCO<sub>2</sub>/km in 2030 for vans. New vans are required to undergo considerable decarbonisation largely to compensate for the forecasted increase in van transport demand. However, as they currently make up only 17% of the light duty vehicle (LDV) emissions, it was found that a 1 gCO<sub>2</sub>/km tightening of the 2030 car target permits a ~6 gCO<sub>2</sub>/km rise in the 2030 van target for the same overall emissions.

The Super-credits system is assessed by extending the current 2020-2022 scheme out to 2030. If ULCVs with emissions less than 50 gCO<sub>2</sub>/km (NEDC) are counted as 1.33 vehicles in 2023-2030, this has the potential to weaken the stock emission reduction of cars in 2030 by 1.3 percentage points, equivalent to an additional 8 Mt of CO<sub>2</sub> per year in 2030, even if the CO<sub>2</sub> standards are met on paper. It was also observed that at low CO<sub>2</sub> target levels, where ULCVs are actually needed to meet the target, the market share of ULCVs was lower than without the Super-credit extension. For example, considering only BEVs, it is seen that without Super-credits a 32% market share is needed in 2030, compared with 26% with 1.33 Super-credits per BEV. The effect of the continued use of Super-credits is therefore to effectively reduce the supply of electric vehicles, which is the opposite of their intention.

The effectiveness of a ULCV mandate, introduced in place of a new vehicle CO<sub>2</sub> target, is investigated assuming this would replace a fleet average CO<sub>2</sub> standard and therefore result in a slowing or halt in conventional vehicle emissions reductions from 2021. In order to reduce emissions by 30% between 2005 and 2030, it is suggested that a zero-emission vehicle (ZEV) mandate should grow linearly in the 2020s to 45% in 2030. However, the major disadvantage of this policy is that it provides no guarantee of decarbonisation, since it does not preclude conventional vehicle emissions rising back up to their historic values as OEMs focus on better performance, cheaper manufacturing costs or larger vehicles.

Consequently, a ULCV mandate combined with a set of CO<sub>2</sub> targets is also explored. The intention is to encourage OEMs to meet increasingly low CO<sub>2</sub> targets with more ULCVs, without disrupting the planned deployment schedule of efficiency technology in conventional ICEs and hybrid electric vehicles. The number of ZEVs required to bridge the forecasted average emissions of ICEs and HEVs to the target level is quantified as the ZEV Gap. For cars, this rises to 10% ZEVs in 2025 in order to meet 75 gCO<sub>2</sub>/km, and 32% in 2030 to meet 50 gCO<sub>2</sub>/km.

**The ZEV Gap (solid lines) for the WLTP targets (dotted lines) needed to reduce car emissions by 25%, 30%, 35% and 40% between 2005-30 (Climate Goals)**



The ZEV Gap provides recommended values for a ZEV mandate in the 2020s. The ZEV Gap, emissions of conventional ICEs/HEVs, and the CO<sub>2</sub> target are three inter-dependent variables. Defining two of these indirectly sets the third. This provides a mechanism to control not only the overall emissions level, and the market share of ZEVs, but also the emissions of conventional vehicles. The latter should fall at the rate currently planned by the automotive industry to avoid wasted development costs and improve vehicle efficiency for drivers whom ULCVs are unsuitable.

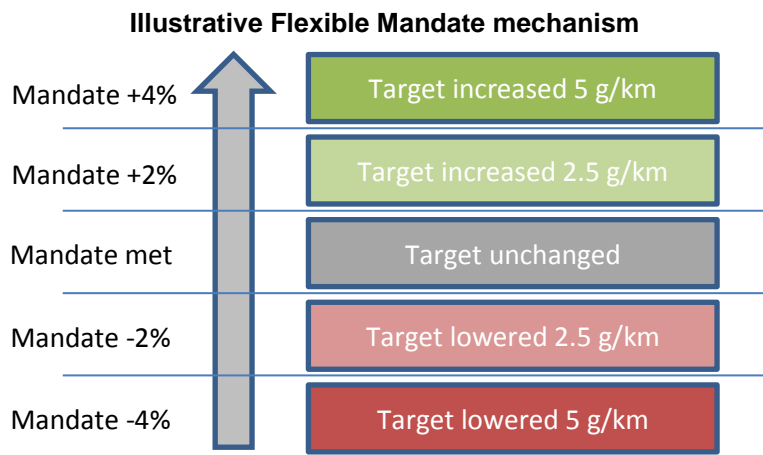
PHEVs can be included in the mandate through a credit system, whereby PHEVs are credited towards meeting the mandate based on their emissions:

$$credit\ value = 1 - \frac{E_{ULCV}}{\bar{E}_{ICE}}$$

← Emissions of ULCV  
 ← Average emissions of ICEs/HEVs

ZEVs are worth 1 credit, and PHEVs would be worth between 0 and 1 credit. A ULCV mandate would require a certain number of credits to be accumulated based on the ZEV Gap. This credit valuation scheme discourages the introduction of low range, high emission PHEVs as they receive few credits and a high market share would be required to meet the mandate. For example, PHEVs with a 10 km electric range are unable to meet the recommended 2030 mandate (32%) even with a market share of 100%. This system means that any mixture of ULCVs that accumulates the mandated number of credits will result in the CO<sub>2</sub> target being met, as long as the average emissions of conventional vehicles follow the intended path. The mechanism is broadly successful in achieving a 30% emissions reduction between 2005 and 2030, while steering OEMs towards ULCV deployment. However, at high PHEV share overall emissions reduction is marginally lower as the WLTP test may overestimate the extent to which the cars utilise their batteries in real world driving.

A ULCV mandate can be further incorporated into the CO<sub>2</sub> standards regulation through a proposed Flexible Mandate. Here, an OEM's Specific CO<sub>2</sub> Target is adjusted based on their performance against the ULCV Mandate. An OEM that exceeds the mandate would be rewarded by having their CO<sub>2</sub> target relaxed by an amount relative to their exceedance, and vice versa:



Without a mandate, OEMs that sell a high share of ULCVs are naturally rewarded in terms of their fleet CO<sub>2</sub> target, as the low emissions of ULCVs allow them to sell higher emission conventional vehicles while still meeting their target. OEMs that sell very few ULCVs are correspondingly required to make their conventional vehicles more efficient. However, the latter is currently viewed by OEMs as more cost-effective in the short term. The Flexible Mandate leverages this benefit/disadvantage relationship to make the ULCV option more

attractive. However, it suffers from the drawback that if the market as a whole exceeds the mandate (i.e. higher than expected ULCV sales), the CO<sub>2</sub> standards are diluted which could compromise the overall decarbonisation goal. For example, if the target is increased by 2 gCO<sub>2</sub>/km for every 1 percentage point that the mandate is exceeded, then consistently exceeding the mandate by 5 percentage points would result in emissions reduction 2005-2030 of 25.9%. This is considerably lower than the 30% required, and equivalent to an additional 24.6 Mt of CO<sub>2</sub> per year in 2030. Care must be taken in designing the Flexible Mandate to ensure the risk of excess emissions is correctly assessed and managed.

This study has also attempted to assess the possibility of incorporating electric quadricycles, such as the Renault Twizy, into a ULCV mandate. These typically have a range of less than 100 km, a limited top speed, and can carry one or two passengers. They are well suited to short, low speed trips and thus have the potential to electrify a high proportion of city driving, where zero emissions solutions are particularly important for improving air quality. Analysis of electric quadricycle mileage data and normal passenger car trip statistics suggest they are suitable for electrifying 50-70% of current drivers' trips. However, due to their unsuitability for highway driving, they are not capable of fully decarbonising light duty transport and this must be accounted for in any credit valuation. Our analysis suggests that if electric quadricycles are included in a future ULCV mandate, they should receive 0.35-0.45 credits compared to 1 credit for a full size BEV, reflecting the lower potential to fully displace a conventional car. Further work is required to understand the usage patterns and modal shifts of quadricycle owners, as they should receive fewer credits if it is shown that they primarily replace public transport or 2-wheelers rather than full size cars.

Finally, this study investigates the viability of including a credit trading and banking system in a ULCV mandate. The mandate requires a liquid credit trading system in order to work efficiently. This allows the market to be treated as a single entity, ensuring the mandate does not have to target specific OEMs. Banking of credits enables surplus credits to be used towards compliance with the mandate in future years. An issue observed in the California ZEV Mandate is the existence of a credit glut, which has occurred due to the market consistently exceeding the relatively low mandate levels. The risk of this for the ULCV mandate proposed in this study is small, as the suggested growth in the mandate level will quickly absorb any surplus credits. A credit glut would only occur if very high ULCV uptake occurred, by which point the mandate would be redundant as the shift to ultra-low carbon transportation will be occurring faster than needed. However, it is still recommended that credits expire after a fixed term to avoid any chance of a shift back to conventional fossil-fuel based technology.

The main conclusions from this study are as follows conclusions:

- Achieving a 30% reduction in car and van emissions through vehicle regulation between 2005 and 2030 would require a WLTP target of 75 gCO<sub>2</sub>/km for new cars in 2025 and 50 gCO<sub>2</sub>/km in 2030. The equivalent for new vans is 82 gCO<sub>2</sub>/km in 2025 and 33 gCO<sub>2</sub>/km in 2030. Furthermore, a 1 gCO<sub>2</sub>/km tightening of the 2030 car target permits a ~6 gCO<sub>2</sub>/km rise in the 2030 van target, in order to maintain an overall 30% reduction in emissions 2005-30.
- Ultra-low carbon vehicle technology is crucial to achieving long term decarbonisation goals in the light duty vehicle sector. OEMs should be encouraged to meet CO<sub>2</sub> targets with ULCVs, rather than focus exclusively on the incremental improvement of conventional vehicle efficiency, which will not be sufficient to meet long term climate goals.
- Super-credits are no longer suitable to encourage ULCV uptake at low CO<sub>2</sub> targets and may result in emissions being higher than the set targets.



- A ULCV mandate could result in higher ULCV uptake if it replaces continued CO<sub>2</sub> targets. However, if it places no limitation on the emissions of non-mandated vehicles it would not guarantee emissions reductions. Instead, a ULCV mandate should be combined with CO<sub>2</sub> targets.
- A mandate of 10% ZEVs in 2025 and 32% in 2030 for cars, and 30% in 2025 and 68% in 2030 for vans, is necessary in order to achieve a 30% emissions reduction from 2005-30 for both light duty vehicles sectors through regulation. PHEVs can be included in this mandate by crediting them against their emissions relative to the emissions of conventional vehicles, taking into account the expected emissions improvements of the latter.
- A Flexible Mandate can be employed to leverage the benefit of meeting CO<sub>2</sub> targets with more ULCVs, rewarding OEMs exceeding mandated ULCV volumes with a less stringent target for their conventional vehicles and penalising underachievement in ULCV sales. However, care is needed to avoid diluting the overall CO<sub>2</sub> target and compromising emissions reductions by 2030.
- Electric quadricycles could be included in a mandate and/or CO<sub>2</sub> target, but their contribution should be weighted by a recommended credit value of 0.35-0.45 (compared to 1 credit for a full size BEV)
- Credit banking from overachievement in earlier years should be permitted, although an expiration date should be attached to credits to avoid the risk of a credit glut. Credit trading between OEMs should also be permitted to allow maximum flexibility in how to meet future obligations.

## 2 Introduction

The EU is committed to reducing carbon emissions across all sectors to meet long term climate goals. This includes the road transport sector, which contributes one-fifth of the EU's total carbon dioxide (CO<sub>2</sub>) emissions and is now the largest individual sector. As part of its 2030 Climate and Energy Package the EU has set a target to reduce emissions in the non-Emissions Trading Scheme (ETS) sectors by 30% from 2005 levels (the -30% Climate Goal). The transport sector represents 35% of all non-ETS sector emissions and therefore low carbon, fuel efficient vehicles offer an obvious route to achieving this reduction. However, this is dependent upon the use of suitable policies and regulations to drive continued falls in new vehicle emissions.

In an attempt to reduce road transport emissions, the EU has set legally binding targets for CO<sub>2</sub> emissions of both new cars and vans. In Regulation (EC) No 443/2009 a target of 130 gCO<sub>2</sub>/km was introduced for the average type approval emissions of all new passenger cars sold in 2015, followed by a target of 95 gCO<sub>2</sub>/km in 2021. An equivalent ruling for vans, Regulation (EU) No 510/2011, set targets of 175 gCO<sub>2</sub>/km in 2017 and 147 gCO<sub>2</sub>/km in 2020. Despite initial opposition from vehicle manufacturers, in which a proposed 2012 target of 130 gCO<sub>2</sub>/km was relaxed with a phase in period of 2012 to 2015, both the 2015 car target and 2017 van target were achieved early in 2013. Most vehicle manufacturers are on track to comfortably meet the 2020/21 targets as well.

In a recent communication, the European Commission (EC) stated that “*Emissions from conventional combustion engines will need to further decrease after 2020. Zero- and low emission vehicles will need to be deployed and gain significant market share by 2030.*”<sup>1</sup> The EC has signalled its intention to set post-2020 CO<sub>2</sub> standards for both cars and vans. which will likely be mandatory for 2025 and initially indicative for 2030. In addition, the EC will investigate ways to incentivise low and zero-emissions vehicle technology, such as electrified powertrains and hydrogen fuel cells.

In the longer term, the EU aims to cut emissions by 80% in 2050 from 1990 levels<sup>2</sup> and a strong decarbonisation pathway for surface transport is viewed as a key component. Achieving this in a cost effective manner is critical and it is important that policies are designed with this long term goal in mind. Although incrementally improving the efficiency of conventional ICE technology will meet the required emissions trajectory in the short term, the marginal increase in cost of efficiency gains and technical constraints limit the extent to which this strategy alone can yield the emissions reduction required. Consequently, early investment in ULCV development offers a more cost effective method of decarbonisation in the long term, when deployment will shift from being discretionary to essential, and allows for deeper emissions reductions.

The present EU policy mechanism to encourage uptake of ultra-low carbon vehicle (ULCVs) is a system of Super-credits, which allows manufacturers to count vehicles with a type-approval rating of less than 50 gCO<sub>2</sub>/km as multiple vehicles in their calculation of average new vehicle emissions. This has gone some way to bringing about the development of ULCVs, with 39 models now available in Europe across the main car segments.<sup>3</sup> Despite

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<sup>1</sup> Brussels, 20.7.2016, COM(2016) 501 final, A European Strategy for Low-Emission Mobility

<sup>2</sup> Brussels, 8.3.2011, COM(2011) 112 final: A Roadmap for moving to a competitive low carbon economy in 2050

<sup>3</sup> European Alternative Fuels Observatory ([www.eafo.eu](http://www.eafo.eu))

this, ULCVs are yet to gain significant market penetration, making up just 1.24% of all European car sales in 2015.<sup>4</sup>

However, the Super-credits system has been criticised for effectively weakening the regulation by multiple counting of low emission cars, potentially compromising the purpose of the decarbonisation policy. For cars, the first Super-credits scheme ran from 2012 to 2015, with cars with emissions lower than 50 gCO<sub>2</sub>/km counting as 3.5 cars in 2012, decreasing stepwise to a single car in 2016. The impact has been small with only Nissan and Renault removing more than 2g from their emissions targets through the scheme in 2014. Even if Super-credits were ignored, all manufacturers still met their Specific CO<sub>2</sub> Targets.<sup>5,6</sup> This suggests that the scheme does not offer a large enough incentive to develop ultra-low carbon vehicles when the targets can comfortably be met with conventional vehicles regardless.

In 2014, an additional period of Super-credits was introduced which treats cars with type approval emissions less than 50 gCO<sub>2</sub>/km as 2 cars in 2020, 1.67 in 2021 and 1.33 in 2022. Since the market share of ULCVs is expected to continue to rise, this has the potential to cause a larger gap between the actual average emissions and that submitted for compliance with the target. This may compromise the effectiveness of further targets in the 2020s, and ultimately the -30% Climate Goal for which these targets should be designed to meet. To attempt to manage this risk the total permissible use of Super-credits over this period is limited to 7.5g/km.

## 2.1 ULCV Mandates

A vehicle mandate, where manufacturers are required to produce and sell a certain number of a particular powertrain, offers an alternative mechanism to encourage deployment of ULCVs. Such a scheme was introduced in California in 1990 with the adoption of the Zero Emission Vehicle (ZEV) Regulation as part of the Low Emissions Vehicle Programme, which sought to reduce smog-forming emissions within the State. Originally this required 2% of vehicles for sale in California in 1998, and 10% in 2003, to have zero emissions, however, the policy has gone through several revisions to account for longer than expected lead times and technical challenges to deliver the powertrains required. Most notably, a credit system was introduced which expanded the scope of the mandate to hybrid powertrains.

The system in place now is complex. The number of credits awarded to each vehicle is dependent on its specifications, such as range and refuelling speed. Each low emission powertrain type is placed into different “tranches” and the credits awarded retain their tranche value. Manufacturers are required to submit a mandated level of credits from each tranche, which provides a level of control to favour certain powertrains over others. Manufacturers can use higher tranche credits, e.g. awarded to ZEVs, to satisfy the requirements of lower tranches but not vice versa. Surplus credits may be banked for use in future years or sold to manufacturers that have not fulfilled their requirement and would otherwise be liable to pay a penalty.

The mandated credit level has been gradually increased over time, with a modest target of 100s of ULCVs in 2005-2012 and 1000s in 2012-17. From 2018 onwards, the mandated credit level is set to undergo significant ramp up from 4.5% in 2018 to 22% in 2025, 16% of which must be from ZEVs. As a result of the mandate, California leads the way with US plug-

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<sup>4</sup> Sales data from [ev-volumes.com](http://ev-volumes.com)

<sup>5</sup> European Environment Agency (2014) Monitoring CO<sub>2</sub> emissions from new passenger cars and vans in 2014

<sup>6</sup> The actual CO<sub>2</sub> target is adjusted for each OEM depending on the average mass of vehicles they produce. This is known as the “Specific CO<sub>2</sub> Target”

in car sales, accounting for 184,657 of the 407,378 plug-in electric cars sold in the United States between January 2011 and January 2016. Its success in this respect has resulted in it being rolled out to nine other States.

However, the policy has faced criticism for its system of credit allocation. Credits are awarded for registering a vehicle for sale, rather than actually selling it, which has led to some OEMs developing low specification compliance vehicles. Others, such as Toyota and Honda currently receive 9 credits for each of their H<sub>2</sub> fuel cell vehicles and so very few are needed to satisfy the mandate. OEMs can therefore comply with the mandate without necessarily intending to develop vehicles for mass market adoption. The relatively low mandate levels combined with generous credit allocations has led to a glut in the number of credits in circulation. A system of credit trading has therefore allowed some OEMs to delay developing ULCVs altogether, and simply purchase the requisite number of credits from another OEM. Tesla has benefitted significantly from this, generating \$600m in credit sales to date. Credit trading does not diminish the number of ULCVs on the road, and is a crucial source of funding for the likes of Tesla who are currently incurring significant development costs. However, this has allowed OEMs to postpone their own ULCV programmes resulting in little choice for a prospective ULCV buyer. Amendments to the criteria for credit allocation and the ramp up in mandate level from 2018 are intended to correct the regulation's shortcomings, however, the Natural Resources Defense Council estimate that the current credit glut will result in ZEVs needing to make up only 6% of sales in 2025.<sup>7</sup>

## 2.2 Description of this study

The timetable for the EU's post-2020 strategy on low carbon road transport remains in the assessment phase; however, previous targets have been set approximately 8 years before the enforcement date in order to accommodate vehicle manufacturers' usual 5-7 year model cycles. If the trend of setting targets at 5 year intervals is to continue, a 2025 target must soon be decided upon. The European Commission has shown an intention to continue setting CO<sub>2</sub> standards, and in addition will "*analyse the impact of different ways to incentivise low- and zero-emission vehicles in a technology neutral way, such as setting specific targets for them.*"<sup>1</sup> This suggests that a ULCV mandate is being considered alongside other options.

It is recommended that the discussion of a 2025 target level should incorporate future target levels, as well as this supplementary policy to encourage ULCV development, to ensure compatibility. This will provide long-term clarity to vehicle manufacturers. To aid the discussion for post-2020 decarbonisation policies, this study explores the potential for policy mechanisms to further incentivise the uptake of ULCVs, which can work alongside the structure of existing CO<sub>2</sub> standards regulation. The policies investigated are tasked with two primary aims:

- To reduce total light duty vehicle (cars and vans) emissions by 30% between 2005 and 2030
- To prioritize the uptake of ultra-low carbon vehicle technology, such as electrified powertrains and low carbon fuels, over excessive improvements to conventional fossil-based technology

Section 3 briefly outline the assumptions used in the study modelling framework. This includes the dataset for future emissions of cars and vans, the relative market shares of the different powertrains, and an EU wide stock model to show the impact on stock emissions between 2005 and 2030. A detailed review of each of these is provided in the Appendix.

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<sup>7</sup> Reuters: *California's zero-emission vehicle program is stuck in neutral*, 01/09/2016

Section 4 defines recommended new vehicle CO<sub>2</sub> targets that would result in the -30% Climate Goal being met.

Sections 5, 6 and 7 assess various alternative and supplementary policies which could be employed to incentivise the uptake of low carbon vehicles, such as Super-credits and a ULCV mandate, both on its own and incorporated into CO<sub>2</sub> standards.

Section 8 explores the sensitivity of results to the Climate Goal, PHEV range, growth in smaller and larger car segments, and proportion of PHEV driving with electric power

Sections 9 and 10 explore the additional characteristics of a possible ULCV mandate, for example, the inclusion of electric quadricycles and credit trading.

### 3 Modelling Assumptions

#### 3.1 Cost and Performance Model

To provide a baseline against which the impact of decarbonisation policy can be assessed, it is necessary to project out to 2030 the likely emissions for cars and vans in the EU. For this study, a dataset provided by Element Energy’s Vehicle Cost and Performance Model was used. This covers nine car segments based on the UK SMMT Classification, which is similar to other classification schemes such as that used in the ICCT Pocketbook.

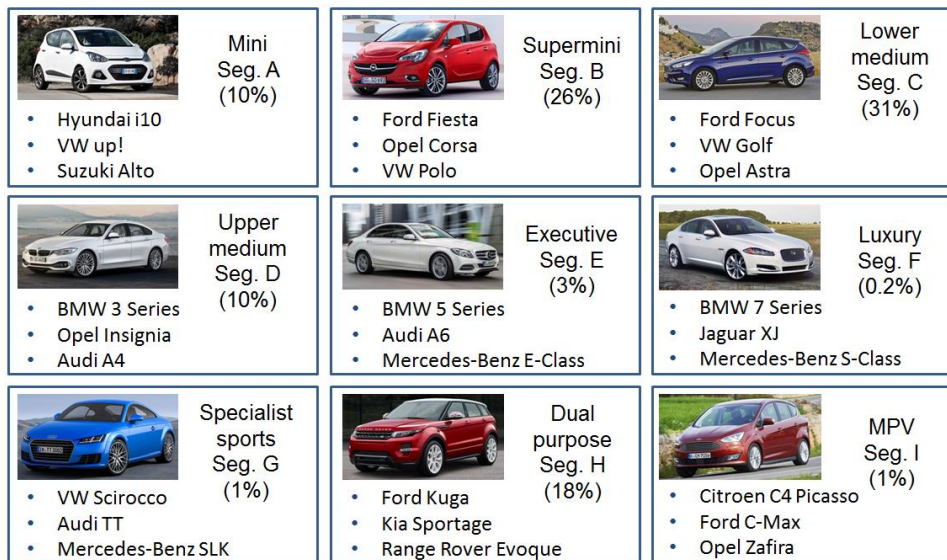


Figure 1: Segmentation of cars in EE’s Cost and Performance Model and example vehicles. Approximate market shares shown in brackets<sup>8</sup>

An equivalent model also exists covering the five van segments, grouped by size and weight.



Figure 2: Segmentation of vans in EE’s Cost and Performance Model. Segmentation based on payload mass and volume

The model is baselined to average 2015 petrol and diesel ICEs. To forecast changes to vehicle efficiency over time, the deployment schedule and efficiency gains of the 46 on-cycle efficiency technologies included in Ricardo-AEA’s 2015 Cost Curve study<sup>9</sup> are employed. This study forms the basis of the European Commission’s own cost curve work. The

<sup>8</sup> ICCT Pocketbook 2014

<sup>9</sup> Ricardo-AEA (2015) Improving understanding of technology and costs for CO2 reductions from cars and LCVs in the period to 2030 and development of cost curves

methodology and assumptions behind the Cost and Performance Model are outlined in detail in the Appendix (Section 12.1).

The model was used to generate emissions forecasts for both petrol and diesel conventional ICEs, full hybrids (HEVs), plug-in hybrids (PHEVs) in the period 2015-30. Emissions forecasts are provided in terms of NEDC and WLTP type-approval and real world driving. The average 2015 petrol and diesel ICEs used as the baseline starting point were derived in terms of NEDC. Their performance values are converted to WLTP through conversion factors from ADAC EcoTest laboratory results<sup>10</sup>, and an assumed loss in currently available test cycle flexibilities. A study into the real world emissions gap by Element Energy and ICCT<sup>11</sup> concluded that for cars in 2014, test cycle flexibilities contributed on average 24 percentage points of the 35% gap from NEDC to real world energy consumption. It is proposed that when transitioning to WLTP this will fall to just 8 percentage points. For vans, the use of flexibilities is less severe and is estimated to currently contribute 20 percentage points, which also falls to 8 percentage points under the WLTP.

It is assumed that no changes in employed flexibilities occur in the WLTP until 2020, after which the gap due to flexibilities opens up again from 8 percentage points in 2020 to 17 percentage points in 2025 due to manufacturer optimisation of the new test procedure. No additional optimisation is assumed beyond 2025, as Real Driving Emission testing begins to be introduced. The resulting trend in NEDC and WLTP type-approval emissions for a range of petrol and diesel ICEs is shown in Figure 3. The increase in emissions when switching to WLTP is due primarily to the loss of allowed test cycle flexibilities.

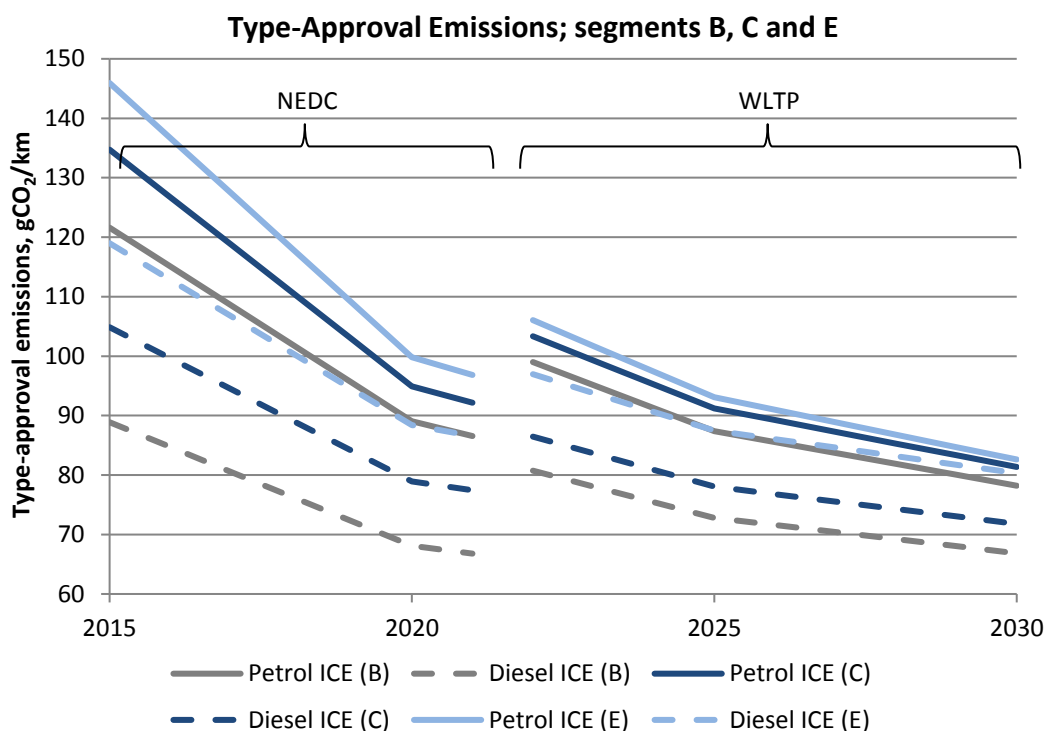


Figure 3: A selection of forecast emissions from the Cost and Performance Model, expressed in terms of NEDC and WLTP type approval

<sup>10</sup> ICCT (2014) The WLTP: How a new test procedure for cars will affect fuel consumption values in the EU

<sup>11</sup> Element Energy and ICCT for the Committee on Climate Change (2015) Quantifying the impact of real-world driving on total CO<sub>2</sub> emissions from UK cars and vans

Similarly, conversion to real world performance is calculated using the real world emissions gap identified in Element Energy and ICCT real world emissions study. See Appendix 12.1.2 for further details.

### 3.1.1 The Utility Factor

For PHEVs, it is necessary to factor in the proportion of driving under electric power in order to give an overall fuel consumption figure. Both NEDC and WLTP test procedures base this upon the PHEV’s electric range and fuel consumption when driving in charge depleting (electric) and charge sustaining (fuel-powered) modes. It is assumed in this model that fuel consumption is zero in the former and equivalent to a pure hybrid vehicle in the latter.

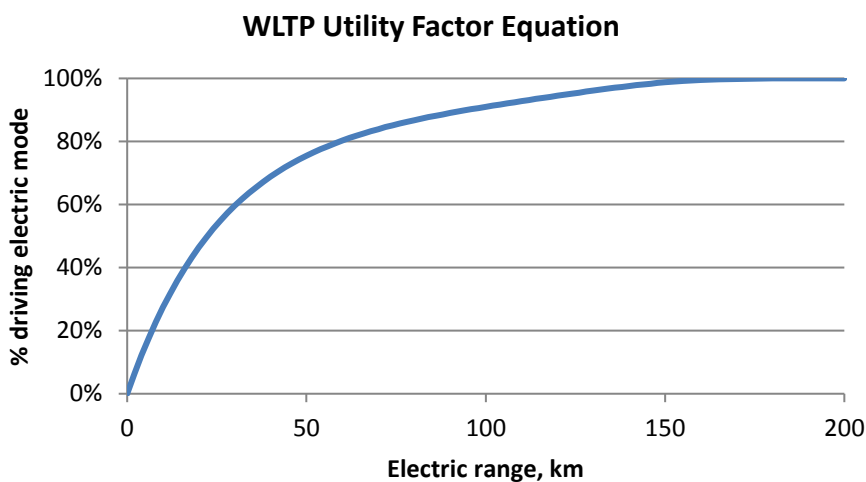
In both test procedures, a utility factor describes the proportion of driving carried out in electric mode. For NEDC, if it is assumed that electricity consumption is zero in fuel-powered mode, the utility factor is expressed as:<sup>12</sup>

$$Utility\ Factor = \frac{D_e}{D_e + D_{av}}$$

$D_e$  = vehicle’s electric range (expressed in NEDC)

$D_{av}$  = 25 km (assumed average distance between battery depletion and recharge)

In the WLTP, the utility factor is calculated using a function derived from real world trip statistics, which relates electric range to the proportion of driving in electric mode:<sup>13</sup>



**Figure 4: Relationship between plug-in hybrid electric range and proportion of driving in electric mode, as used in the WLTP**

In the baseline, all PHEVs are assumed to have a 50km range (NEDC) in all years 2015-30, based on currently available models and the latest OEM announcements. The basis of this assumption is that OEMs have settled on 50 km as this provides an optimal proportion of electric driving. Given the current high purchase price of PHEVs, it is assumed that in future OEMs will choose to take advantage of falling battery costs by reducing vehicle cost

<sup>12</sup> E/ECE/324/Rev.2/Add.100/Rev.3–E/ECE/TRANS/505/Rev.2/Add.100/Rev.3

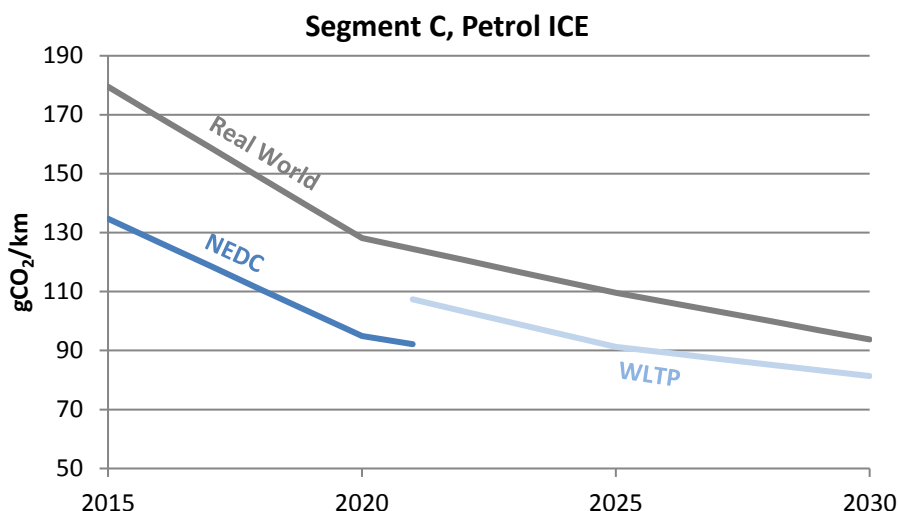
<sup>13</sup> ECE/TRANS/WP.29/GRPE/2016/3, Annex 8, Appendix 5



rather than increasing range while keeping cost the same. The impact of PHEV ranges increasing is explored in Section 8.4.

Derivation of utility factor function presented in Figure 4 is outlined in the WLTP Technical Report<sup>14</sup>. It uses actual trip statistics from two datasets: The European WLTP database which was used to develop the WLTC speed profile, and a database provided by Fiat. It is stated that neither dataset is representative of the European vehicle fleet with respect to segment and mileage distributions. Consequently, the data was re-weighted to better reflect European driving behaviour but it is noted that additional data will need to be collected before 2020 to improve the robustness of the utility factor function. Since it is based on actual trip data it has also been used to derive a real world utility factor, but due to the recognised shortcomings of the source data, the sensitivity of results to the utility factor is tested in Section 8.5. Real world electric range can be calculated from the WLTP range by accounting for the higher electricity consumption under real world conditions. Analysis of real world electricity consumption data from Spritmonitor.de, Europe’s largest database for real world fuel consumption, shows that current electricity consumption is about 25% higher than NEDC for cars, and 50% for vans. Taking into account the difference in efficiency improvement with future technology packages on both the NEDC and real world drive cycles suggests this gap will decrease by a few percentage points between 2015 and 2030.

Figure 5 shows the emissions of Segment C petrol vehicles under the three different driving cycles. It can be seen that using the NEDC utility factor results in close agreement between the model output for Petrol PHEV and what is currently available on the market. For example, the model predicts 37 gCO<sub>2</sub>/km in 2015, equal to the similarly specified Segment C Audi A3 e-tron Sportback released in the same year. It can be seen that, unlike the ICE and HEV, the Petrol PHEV shows very similar WLTP and NEDC type-approval values in 2020. This is because the increase in fuel consumption under the WLTP is offset by the higher proportion of driving in electric mode (70% vs 66% for the NEDC test). This alone corresponds to a 12% decrease in fuel consumption on the WLTP relative to NEDC.



<sup>14</sup> UN/ECE/WP.29/GRPE/WLTP-IG: Technical Report on the development of a Worldwide Worldwide harmonised Light duty driving Test Procedure (WLTP), Appendix 1

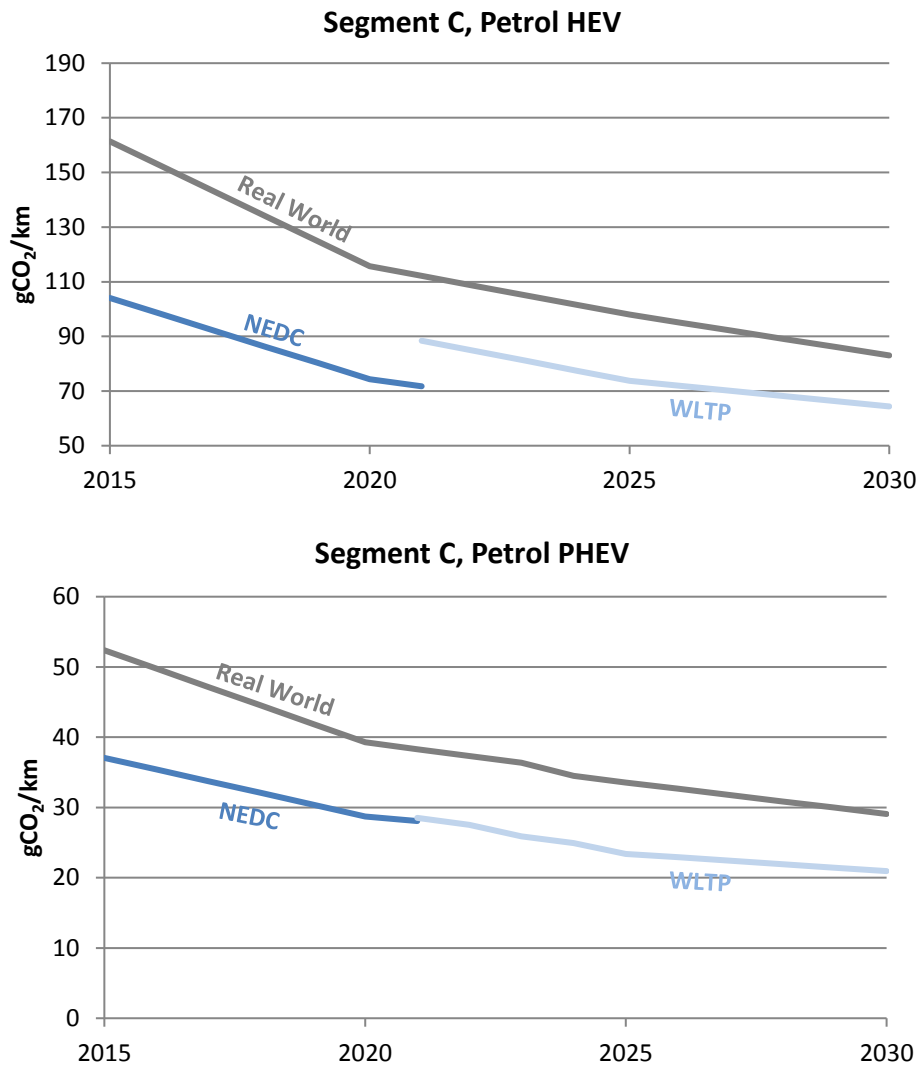


Figure 5: Forecasted trend in emissions ratings of Petrol ICEs, HEVs and PHEVs Segment C cars, expressed in terms of NEDC, WLTP and real world driving.

### 3.2 Future powertrain uptake: The ECCo European Scenario

The EU CO<sub>2</sub> target is concerned with average new car emissions levels across all powertrains and segments, and so knowing the predicted emissions of each individual powertrain is not enough to test future compliance with hypothetical target scenarios. In addition, a realistic view of the market share of each powertrain in the period 2015-30 is also required. For the investigation of potential ULCV mandates in this study, a realistic baseline scenario for the relative market penetration of HEVs versus ICEs, and petrol versus diesel within each segment was devised.

Element Energy’s Electric Car Consumer (ECCo) tool is an uptake model which was used to predict the changes in the petrol/diesel share and uptake of full hybrids within each segment. These results were then applied to the current composition of the European vehicle market, providing a projection for the ratios of conventional powertrains (i.e. petrol and diesel ICEs and HEVs) in the period 2015-30 (see Figure 6).

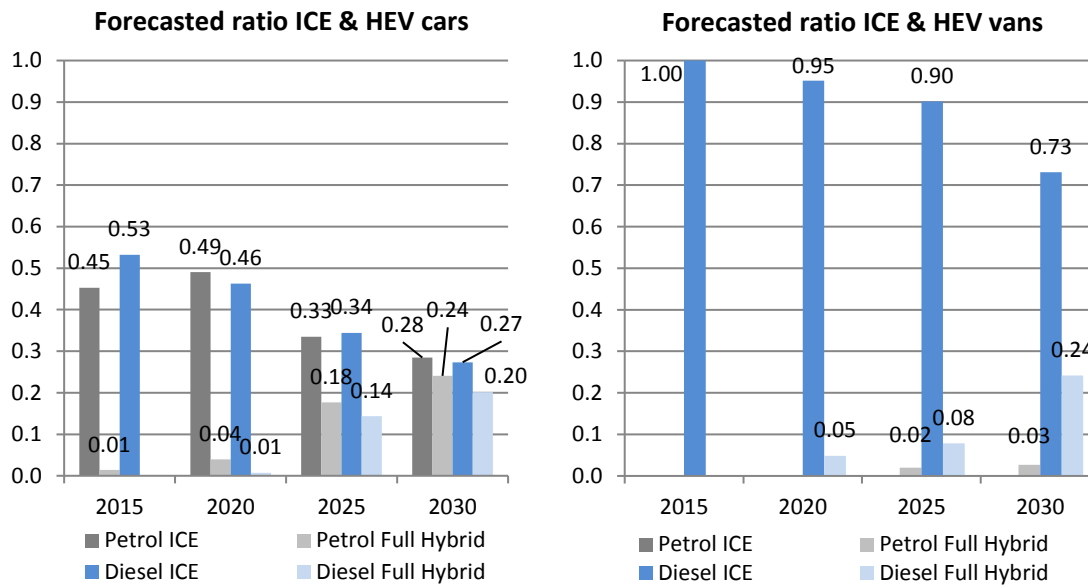


Figure 6: Overall ratios of petrol/diesel ICEs/HEVs cars and vans forecast in the ECCo European Scenario. Market shares of ULCVs introduced as a variable input.

It is assumed that segment shares remain at 2015 levels i.e. that there is no systematic trend toward bigger or smaller cars, although this assumption is tested as a sensitivity in Section 8.3.

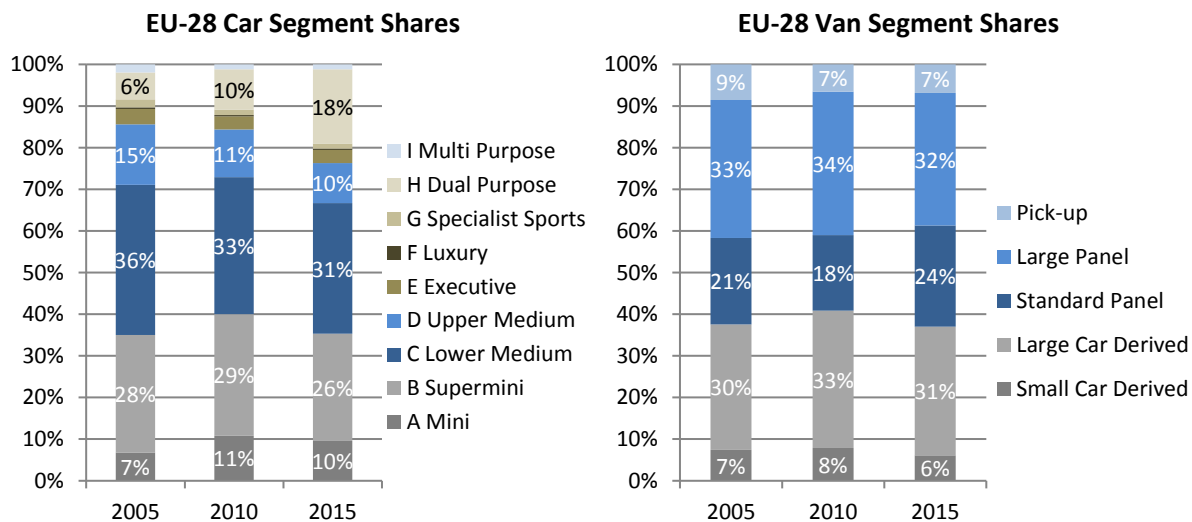


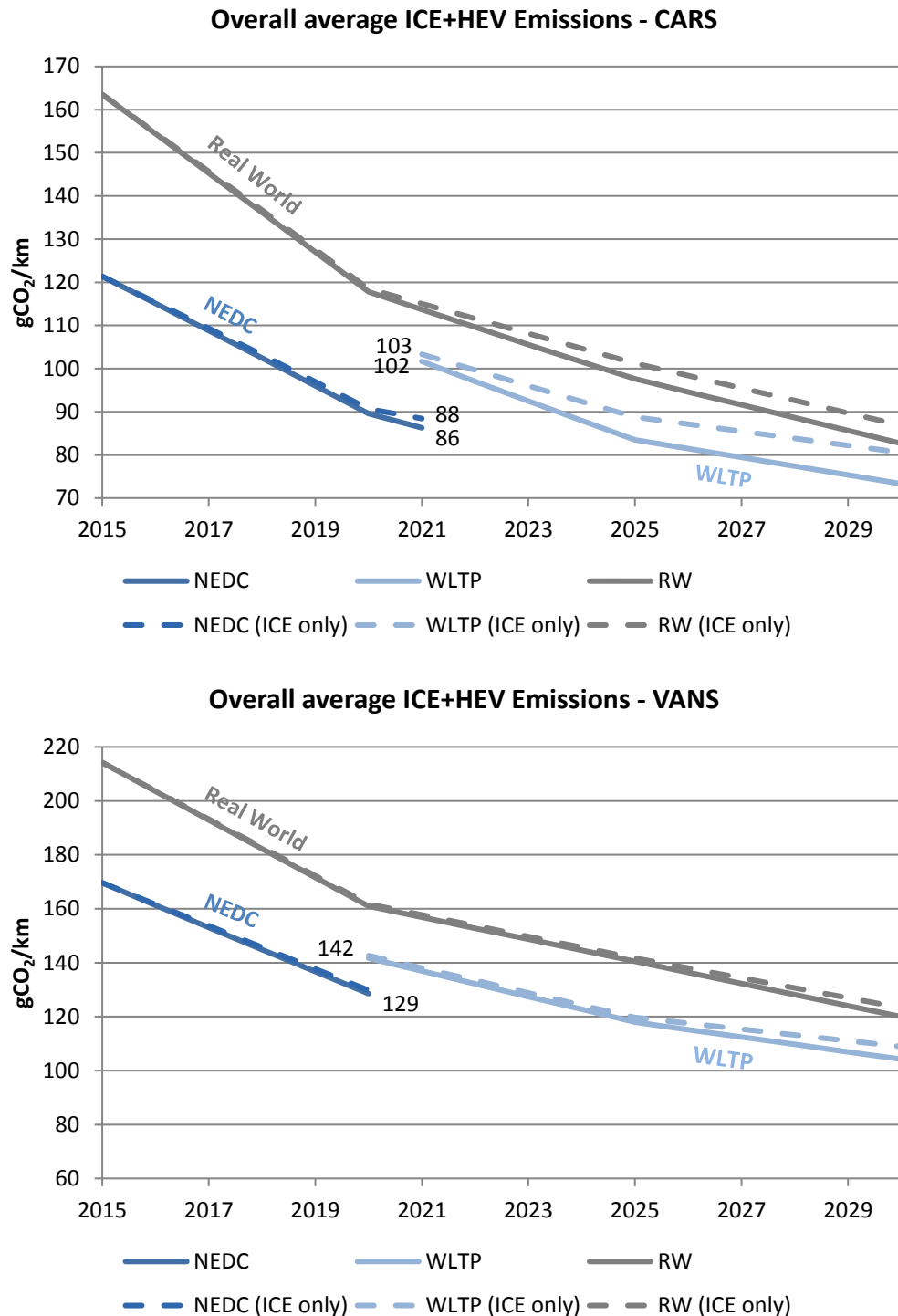
Figure 7: Historical segment shares in the EU-28 for cars<sup>15</sup> and vans<sup>16</sup>

Figure 8 shows the average emissions of new conventional powertrains as estimated by the outputs of the Cost and Performance Model and the relative market shares from the ECCo European Scenario. The 95 gCO<sub>2</sub>/km car target and 147 gCO<sub>2</sub>/km van target are predicted to be met comfortably, even without any growth in full hybrid sales. It is possible that OEMs will slow deployment on efficiency technology in order to avoid surplus efficiency gains, however, it should be noted that the 2015 car target of 130 gCO<sub>2</sub>/km was achieved two years earlier than required, and the 2017 van target of 175 gCO<sub>2</sub>/km four years early. A review of currently available models suggests that it is plausible that this will happen again.

<sup>15</sup> Segment shares provided by ICCT

<sup>16</sup> Raw dataset provided IHS Automotive

For example, the 2016 Opel Astra 1.6 CDTi 110 PS ecoFlex with stop-start (diesel, C-segment) is already rated at 88 gCO<sub>2</sub>/km (NEDC), while the larger 2016 Mercedes E-Class 220 diesel (E-segment) achieves 102 gCO<sub>2</sub>/km (NEDC). If a post-2020/21 target is set, then it is likely that this pattern of achieving the target several years beforehand will continue, as OEMs shift focus to the subsequent target once the current one has been met.



**Figure 8: Predicted average emissions of ICEs and HEVs incorporating the emissions ratings of each powertrain and the relative market shares of the ECCo European Scenario**

To test the impact of introducing BEVs and PHEVs, the ratio of the conventional powertrains presented in Figure 6 remain unchanged. PHEVs are distributed between petrol and diesel within a segment according to that segment’s petrol to diesel ratio. It is assumed that low uptake of EVs occurs up to 2020 as EVs are not predicted to be necessary in order to meet the 95 gCO<sub>2</sub>/km car target in 2021, and 147 gCO<sub>2</sub>/km van target in 2020. Without an additional policy mechanism, OEMs have little incentive to introduce them in large volumes into Europe. Therefore, both BEVs and PHEVs are each assigned a nominal 1% share in 2020, to represent negligible growth in the electric vehicle sector. This is supported by a low ULCV market shares predicted by ECCo.

With regards to meeting an emissions reduction goal in 2030, the impact of the assumed ULCV market share in 2020 is in fact small. By 2030, 23% of cars purchased in 2020 have been scrapped and the trend in decreasing mileage with age means they contribute only 40% of the total kilometres travelled relative to new cars. For example, if instead it is assumed that the BEV market share in 2020 is 5%, and grows linearly to what is required to meet this study’s baseline 2025 CO<sub>2</sub> target (see Section 7.1), then the total emissions of the car stock in 2030 are only 0.4% lower, compared with a 1% market share in 2020.

### 3.3 EU Stock Model to estimate overall LDV emissions

In order to define realistic CO<sub>2</sub> targets in the 2020s, an EU-28 stock model was developed for both cars and vans. Stock, sales and mileage data by vehicle age for the period 2005-2010 were provided by the TRACCS database, and a historical scrappage rate was derived by regression analysis. A correction factor was applied to take into account the recent trend in increasing vehicle age in Europe. This resulted in car and van stock models that closely match historical stock and sales figures.

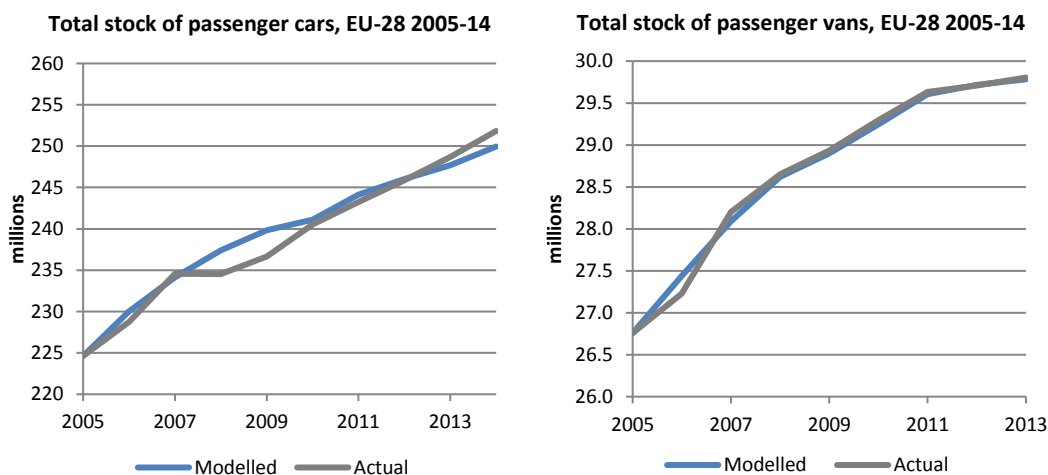


Figure 9: Comparison of actual EU-28 car and van stock with modelled

Future stock and total vehicle kilometres travelled were estimated using the forecasted percentage increases from the TREMOVE model. The methodology used to develop the stocks models are outlined in the Appendix (Section 12.3).

Annual real world emissions levels for new cars can then be fed into each year of the stock model to calculate overall CO<sub>2</sub> emissions for that year. The historical trend in the emissions gap<sup>17</sup> was applied to the average type-approval emissions published by the European Environment Agency<sup>5</sup>, to provide total emissions in the period 2005-2015. The trend in future

<sup>17</sup> From analysis by ICCT/Element Energy (2015)

real world emissions can therefore be defined in order to achieve the requisite 30% reduction in total emissions 2005-30 (the -30% Climate Goal).

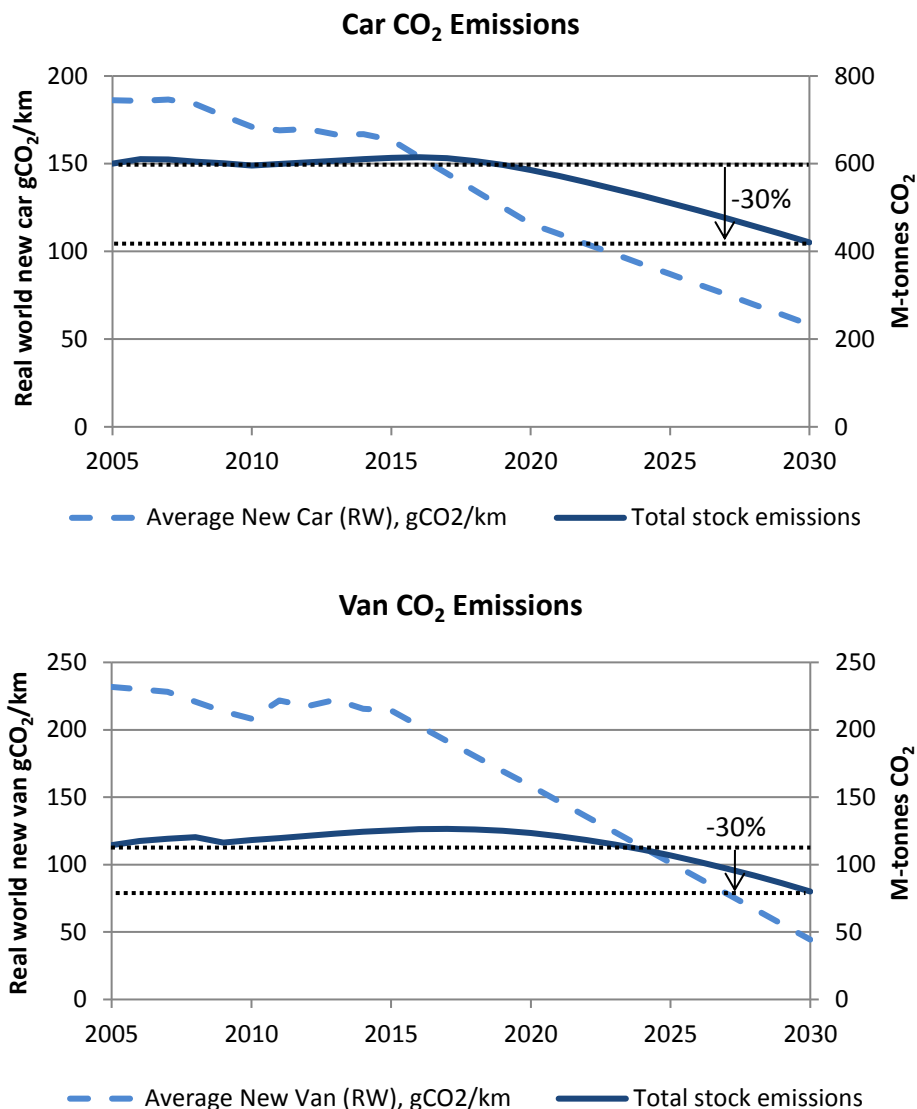


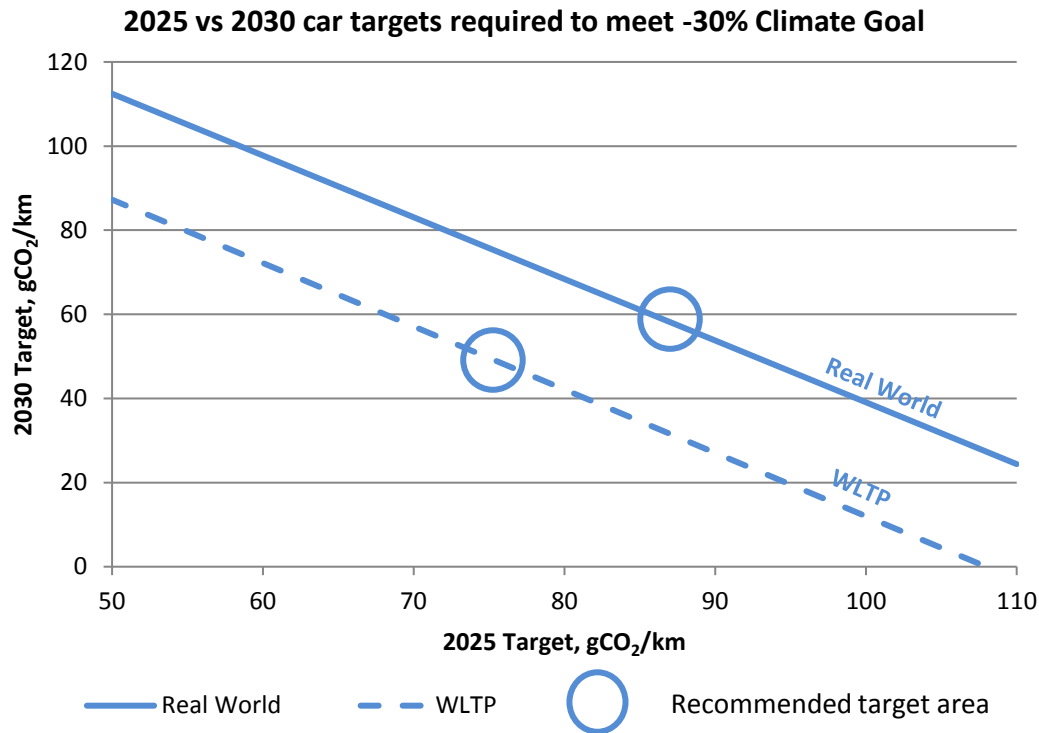
Figure 10: Example trends in real world emissions that results in a 30% reduction in total car and total van emissions 2005-30

## 4 Defining Future Emissions Targets

### 4.1 Cars

The European Commission’s recent communication on the decarbonisation roadmap<sup>1</sup> suggests that fleet emissions targets will continue to be used beyond 2020 to drive further reductions in type-approval and real world emissions. In this study, it is proposed that targets should be set in 2025 and 2030 to reduce emissions by 30% between 2005 and 2030. Figure 11 shows the combination of real world emissions of new cars in 2025 and 2030 that are estimated to achieve this by the stock model, assuming a linear trajectory between new car emissions predicted in 2020 and the 2025 and 2030 targets. Emissions to 2020 remain fixed in this analysis, based on the average ICE and HEV emissions forecast in Figure 8, and

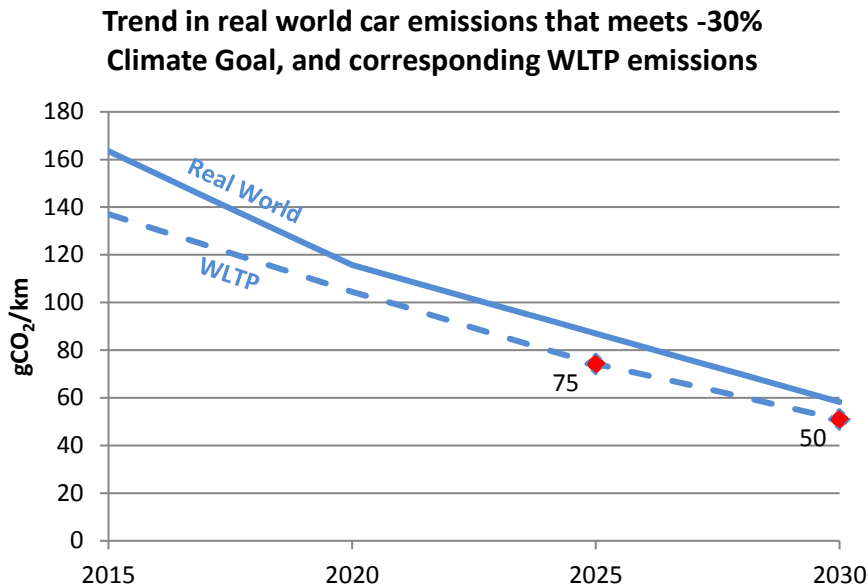
assumed 1% share each for PHEVs and BEVs in 2020, to reflect the fact that a 2020/21 target is already in place and future targets will not affect this.



**Figure 11: Relationship between 2025 and 2030 car targets that meet the -30% Climate Goal**

An illustrative trend in the average real world gap can be used to convert these real world targets to WLTP values. The real world emissions gap is sensitive to the powertrain mix, particularly the proportion of PHEVs. To estimate an average gap in both 2025 and 2030, the share of a 1:1 ratio of BEVs and PHEVs that reduces predicted real world ICE/HEV emissions to the target levels was identified. The resulting average WLTP emissions define the target in terms of WLTP. Figure 11 illustrates the existence of a linear relationship between 2025 and 2030 targets which meet the -30% Climate Goal i.e. a higher 2025 target requires a lower 2030 target and vice versa.

The recommended real world target area in Figure 11 results in a smooth continuous downward trend in the period 2020-30, plotted in Figure 12. The corresponding targets expressed in terms of WLTP are 75 gCO<sub>2</sub>/km in 2025 and 50 gCO<sub>2</sub>/km in 2030. In this work, these are designated the baseline targets against which the effectiveness of various policy mechanisms is tested. Note that this does not include consideration of the limit value curve, which adjusts each OEM's Specific CO<sub>2</sub> Target based on the average mass of their vehicles. This analysis looks to treat the vehicle market as a single entity, and consequently does not require a mass adjustment factor which is designed to scale relative to the market average mass. It is also unclear whether mass will continue to be used as the adjustment parameter, or replaced by vehicle footprint as is the case in the US.



**Figure 12: Smooth downward trend in real world car emissions required to meet the -30% Climate Goal, and the corresponding WLTP emissions assuming a 1:1 ratio of BEVs to PHEVs**

A key assumption in setting these targets is the performance of the market against the 95 gCO<sub>2</sub>/km target in 2021. In the baseline, it is proposed that this is met in 2019, continuing the trend of meeting a target several years in advance. This reflects the deployment schedule featured in R-AEA’s latest cost curve study<sup>9</sup>, upon which the Commission will base its own estimates. However, if efficiency technology deployment occurs slower than currently expected, and the target is instead achieved in exactly 2021, then this will result in higher stock emissions in the 2020s. In this scenario, but where the 2025 and 2030 targets have still been set at 75 gCO<sub>2</sub>/km and 50 gCO<sub>2</sub>/km (WLTP), emissions reduction between 2005 and 2030 is estimated to be only 27.5%. In this case, the baseline targets will have failed to achieve the -30% Climate Goal. A thorough understanding of planned technology deployment by OEMs up to 2021 must therefore be in place when setting CO<sub>2</sub> targets for the 2020s.

## 4.2 Vans

An identical approach can be taken to derive the required van targets. Due to the strong growth forecast for the van stock, a more aggressive decrease in real world emissions on a per vehicle basis is required in order to reduce stock emissions to the -30% Climate Goal between 2005-2030. Figure 13 shows the recommended target area which gives a smooth downward trend in real world emissions, corresponding to 101 gCO<sub>2</sub>/km (RW) in 2025 and 82 gCO<sub>2</sub>/km (RW) in 2030. These represent a 53% and 79% decrease, respectively, in real world emissions of new vans from 2015. The accompanying WLTP targets, based on a real world gap which assumes a 1:1 ratio of BEVs to PHEVs, are 82 gCO<sub>2</sub>/km in 2025 and 33 gCO<sub>2</sub>/km in 2030.



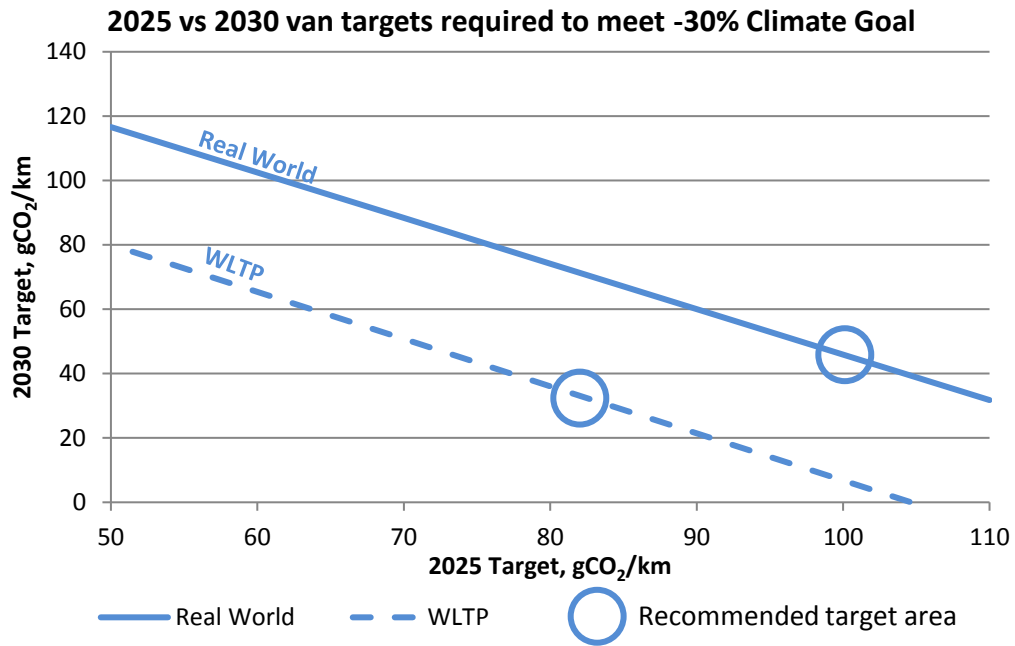


Figure 13: Relationship between 2025 and 2030 van targets that meet the -30% Climate Goal

Due to the strong forecasted growth in the van stock, the sector requires deeper reductions in emissions compared with cars in order to meet the -30% Climate Goal, and hence very low CO<sub>2</sub> targets are needed. Figure 14 shows the recommended emissions trajectory.

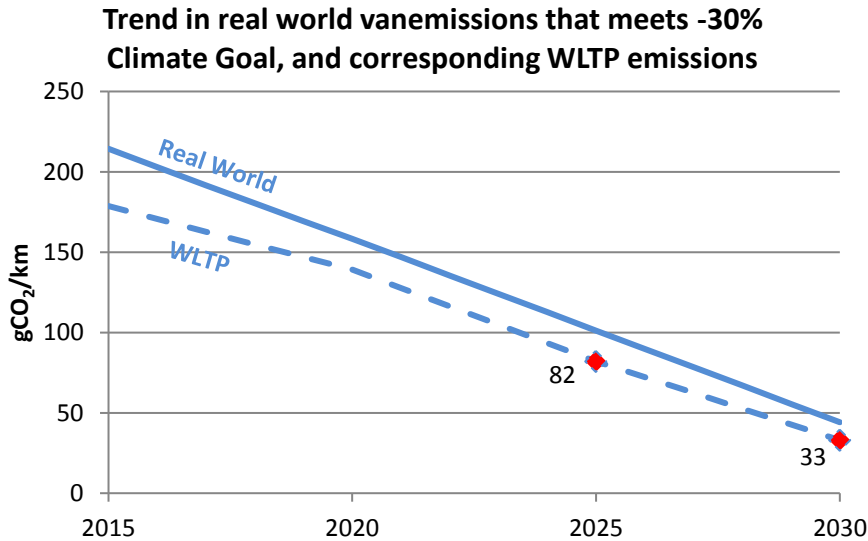


Figure 14: Smooth downward trend in real world van emissions to meet 30% Climate Goal, and corresponding WLTP emissions assuming a 1:1 ratio of BEVs to PHEVs

However, this assumes that both the car and van sectors would each be required to reduce emissions by 30% from 2005 levels. Currently the overall van stock is estimated to account for only 17% of light duty vehicle emissions, and so a more relaxed emissions reduction pathway for vans would require only a small tightening of the car targets to compensate. The relationship between tighter car targets and weaker van targets that result in a combined 30% reduction in emissions 2005-30 is explored in Section 8, but for the purpose of this analysis the car and van stocks will be treated separately.

## 5 Super-credits

Super-credits entitle OEMs to count vehicles with low type-approval emissions as more than one vehicle in their calculation of average emissions for compliance with the CO<sub>2</sub> target. The European Commission has announced the following Super-credits will be in place in the period 2020-22 for cars emitting less than 50 gCO<sub>2</sub>/km (NEDC - the super-credits threshold will not be transitioned to WLTP<sup>18</sup> and vehicles will continue to be tested using the NEDC system):

- 2 credits in 2020
- 1.67 credits in 2021
- 1.33 credits in 2022

As average car emissions are predicted to be significantly lower than the 95 gCO<sub>2</sub>/km target in 2021 it is unlikely that OEMs will take advantage this super-credits regime to any great extent. However, if the 2025 and 2030 targets were set at the proposed baseline levels of 75 gCO<sub>2</sub>/km and 50 gCO<sub>2</sub>/km then OEMs would likely have to produce ULCVs in order to comply. In this case, a super-credit scheme would be of significant advantage to OEMs in order to reduce their average vehicle emissions to the required levels.

To test the impact of such a scheme, the proposed 2020-22 super-credit period is extended, with 1.33 super-credits offered to every vehicle with emissions lower than 50 gCO<sub>2</sub>/km (NEDC) from 2022-30. The impact on meeting the -30% Climate Goal for various BEV to PHEV ratios is evaluated against a scenario with no super-credits offered from 2023-30. In each case the BEV/PHEV market share is set such that the average WLTP emissions (incl. super-credits) in each year meet the target trajectory. The target trajectory is the linear interpolation between 104 gCO<sub>2</sub>/km in 2020 (the predicted WLTP emissions of new cars in 2020), and the 75 gCO<sub>2</sub>/km target in 2025 and the 50 gCO<sub>2</sub>/km target in 2030.

**Table 1: Impact of extending the Super-credits regime in 2023-30 on ULCV market share and meeting the -30% Climate Goal**

BEV:PHEV ratio	Super-credits 2023-30	2025			2030			Emissions Reduction 2005-30
		ULCV Market Share	Actual gCO <sub>2</sub> /km		ULCV Market Share	Actual gCO <sub>2</sub> /km		
			WLTP	RW		WLTP	RW	
1:0		10.2%	75.0	87.5	31.8%	50.0	56.2	-29.9%
1:1	-	11.6%	75.0	87.9	36.4%	50.0	57.2	-29.6%
0:1	-	13.5%	75.0	88.5	42.7%	50.0	58.6	-29.2%
1:0	1.33	7.9%	76.9	89.7	26.4%	54.0	60.7	-28.5%
1:1	1.33	9.1%	76.9	90.0	30.6%	53.7	61.3	-28.3%
0:1	1.33	10.6%	76.8	90.4	36.4%	53.4	62.1	-28.1%

The results in Table 1 reveal that extending super-credits to 2030 could result in the actual average WLTP emissions being 2 gCO<sub>2</sub>/km higher than the 2025 targets, and 3-4 gCO<sub>2</sub>/km

<sup>18</sup> Commission Expert Group for Policy Development and Implementation of CO<sub>2</sub> from Road Vehicles, 7<sup>th</sup> May 2015, Summary Minutes

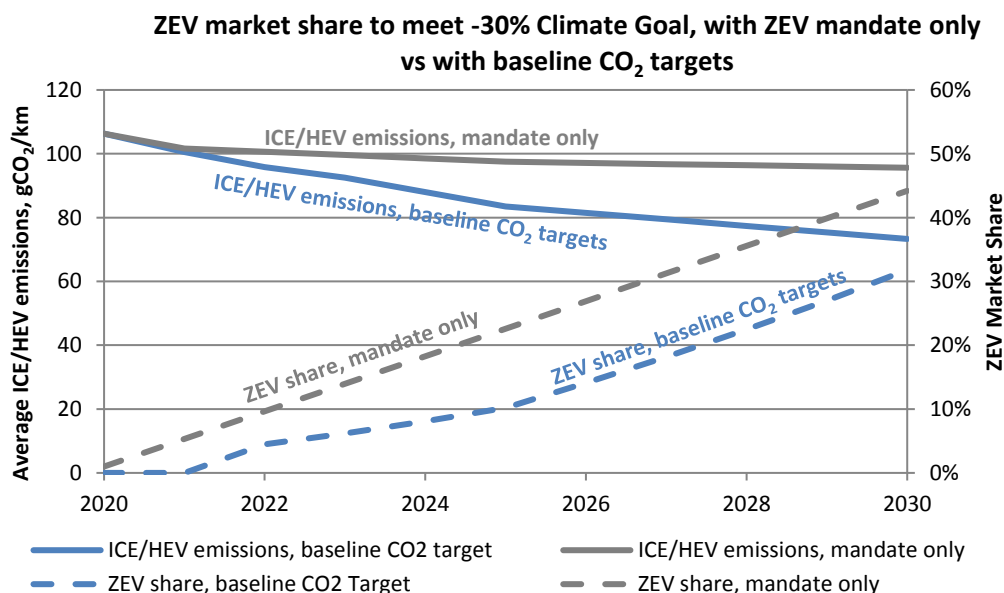
higher than the 2030 target. For example, a 1:1 BEV to PHEV ratio would allow average WLTP emissions to be 53.7 gCO<sub>2</sub>/km in 2030, compared with a target of 50 gCO<sub>2</sub>/km. This is well inside the proposed 7.5 gCO<sub>2</sub>/km cap, but weakens the stock emissions reduction 2005-30 by approximately 1.3 percentage points. The EU Stock Model estimates that this is equivalent to an additional 8 Mt of CO<sub>2</sub> in 2030, and 31 Mt cumulatively from 2020 to 30.

However, of greater concern is that super-credits during the 2020s can discourage rather than encourage deployment of ULCVs. Before 2020, where fleet emissions targets can be met without ULCVs (i.e. using improvements in conventional vehicles), super-credits encourage deployment of ULCVs because the multiple counting allows the sale of less efficient conventional cars while still meeting the target. However, when ULCVs are actually required to meet low CO<sub>2</sub> targets, super-credits discourage their supply as fewer ULCVs are needed due to the multiple counting. For example, in 2030 it is estimated that BEVs/PHEVs would require a market share of 32-43% to meet a 50 gCO<sub>2</sub>/km target, depending on the BEV to PHEV ratio. However, if 1.33 Super-credits are available per ULCV in 2030, then a BEV/PHEV market share of only 26-36% is required. Hence super-credits do not facilitate the long term goal of electrified and zero-emission transport, and in fact reduce the need to deploy ULCVs to meet a given target while increasing overall stock emissions.

## 6 ULCV Mandate

An alternative approach to setting CO<sub>2</sub> targets in the 2020s could be to simply mandate OEMs to sell a certain share of ULCVs (or provide a choice between the two policies as proposed by the UK Government<sup>19</sup>). This provides certainty that ULCVs will make up a significant portion of the LDV stock in the long term, while yielding some flexibility to OEMs in how they develop their conventional powertrains. However, the impact of such a policy on emissions becomes largely dependent on the strategy OEMs adopt with their non-mandated powertrains. They may choose to continue to improve their efficiency to make them more competitive, or instead focus all their attention on developing ULCVs. Reversing efficiency technology deployment in conventional vehicles would waste the development cost up to that point, but OEMs may decide to do this to reduce capital cost or improve performance. Alternatively, or in addition, they may increase engine power or increase vehicle sizes (for example with new cross-over models) resulting in higher emissions.

Consequently, setting a mandate level with an emissions reduction goal in mind is challenging. For the purpose of this analysis, a complete stall in additional technology deployment for conventional vehicles is assumed post-2021, and conventional vehicle emissions ratings remain at their 2021 levels, but this does not necessarily represent future OEM strategy under a ULCV mandate. Figure 15 shows the ZEV market share that would be required to meet the -30% Climate Goal under such a scenario. The ZEV market share was simply increased linearly from 2020 until the -30% Climate Goal was met. It is assumed that the HEV and petrol/diesel markets grow at the rate predicted by the ECCo European Scenario, hence the slight downward shift in average ICE/HEV emissions. This is a assumption with high uncertainty as changes in the relative market shares of these powertrains are dependent on the relative changes in their efficiencies and therefore costs. Also presented is the equivalent ZEV share required were the targets suggested in Section 4.1 (75 gCO<sub>2</sub>/km in 2025, and 50 gCO<sub>2</sub>/km in 2030) imposed and emissions of conventional vehicles followed the trajectory predicted in the Cost and Performance Model.



**Figure 15: The required ZEV market share to meet the -30% Climate Goal for cars if conventional vehicle emissions stall under a ZEV mandate, compared with the baseline CO<sub>2</sub> target scenario where efficiency continues to improve**

<sup>19</sup> Proposal suggested during communication with Transport & Environment

Unsurprisingly, a higher market share of ZEVs is required when conventional vehicle emissions are static after 2021, requiring a 45% market share in 2030 and strong growth from the beginning of the decade. The advantage of this approach is that the ZEV market grows quickly, and this may bring forward the capability of the market to deliver overall zero-emission transportation. OEMs have limited funds for development, and for this reason there are long term advantages to focussing their efforts on ULCV technologies early. If it is expected that eventually conventional powertrain technology will be dropped entirely due to ever stricter climate goals, then any policy that encourages its improvement instead of other more long-term options is potentially wasteful.

However, removing the CO<sub>2</sub> target removes a lever through which the vehicle market can be influenced. Having a mandate on its own relies heavily on the presumption that the emissions levels of conventional cars at worst remain the same. It is plausible that, if the policy allows it, OEMs may choose to roll back the improvements made in vehicle efficiency for the sake of performance gains or vehicle price reduction, the net result being significantly higher average emissions. A ULCV mandate on its own provides no upper bound on how high emissions can go, and so it is recommended that any policy should stipulate OEMs cannot make vehicle emissions higher. This in itself is the same as setting a CO<sub>2</sub> standard. What is more, it is not an inevitability that conventional fossil-fuel based internal combustion technology will have no place in a future transportation make-up. If zero-emission technology remains unsuitable for certain applications, or the technology can be decarbonised with advanced biofuels, then discouraging its development is short-sighted.

## 7 Combined ULCV Mandate and CO<sub>2</sub> Target

Devising a mandate and CO<sub>2</sub> target in tandem can achieve both the desired level of ULCV uptake and improvement in conventional technology, while guaranteeing an overall level of decarbonisation. Early investment in ULCV technology offers the most cost effective option to achieve the emissions levels required in the 2040s and 2050s, and so OEMs should be encouraged to focus efforts on the lowest emission powertrains. The overarching aim of a ULCV mandate should be to complement a CO<sub>2</sub> target, encouraging OEMs to meet future CO<sub>2</sub> obligations through increasing their deployment of electrified and zero emission technology. However, given that the majority of vehicles in the 2020s are expected to contain internal combustion engines (including plug-in hybrids), some continued efficiency improvement remains desirable, particularly in areas which benefit future electrified vehicles such as mass reduction, aerodynamics, and hybridisation. Ideally, policy should aim not to disrupt the expected technology deployment schedule for conventional vehicles, which is incorporated into the outputs of the Cost and Performance Model.

Our modelling suggests that the planned efficiency improvements of conventional vehicles are insufficient to meet the -30% Climate Goal in 2030. For example, average ICE/HEV emissions are forecast to be 84 gCO<sub>2</sub>/km (WLTP) in 2025, above the required target of 75 gCO<sub>2</sub>/km. Short-term cost-optimisation may result in OEMs bridging this gap by accelerating deployment of efficiency technology in their conventional powertrains. This is inadvisable given that this strategy becomes more expensive and technically unfeasible as targets are tightened. Instead, this gap should be bridged by increasing the market share of ULCVs. This can be quantified through the ZEV Gap concept:

### 7.1 The ZEV Gap

The rate of improvement in conventional ICE/HEV efficiency is based on a technology deployment schedule currently expected by automotive sector experts. If CO<sub>2</sub> targets are reduced at a rate faster than the improvements in average ICE/HEV efficiency, there reaches a point where ULCVs are needed to avoid disrupting this deployment schedule of efficiency technology for conventional ICEs/HEVs. The ULCV requirement to meet a target can be quantified as the *ZEV Gap*, defined as the market share of zero-emission vehicles needed in order to reduce the average emissions of conventional vehicles ( $\bar{E}_{ICE}$ ) to fulfil an overall CO<sub>2</sub> target level ( $E_{target}$ ).

$$required\ ZEV\ \% \ share = \frac{\bar{E}_{ICE} - E_{target}}{\bar{E}_{ICE}}$$

This concept is presented in the World Energy Council's World Energy Perspectives: E-mobility 2016. The World Energy Council study features a relatively conservative forecast for the emissions of conventional cars, based on the average annual improvement from 2004-2014. However, this gives an underestimation of the current rate of emission reduction, which became faster post-2008 when the CO<sub>2</sub> standards were introduced. New car emissions fell at an average rate of 1.5% p.a. 2004-2008, and 3.6% p.a. 2009-2014. The result is a predicted ZEV gap for cars of 16% by 2020 in The World Energy Council study.

The emissions reduction of conventional vehicles in this study are considerably more rapid, but take a more comprehensive view of the deployment of individual vehicle technology, and also assume growth of the HEV market. This enables the 2020/1 car and van targets to be met without ZEVs. For cars, ZEVs are not predicted to be necessary to meet the 95 gCO<sub>2</sub> (NEDC) target in 2021, however will be necessary from 2022 to achieve the trajectory in WLTP emissions required to meet the -30% Climate Goal. To meet the 75 gCO<sub>2</sub>/km target

in 2025 and 50 gCO<sub>2</sub>/km in 2030, ZEV market shares of 10% and 32% will be needed respectively.

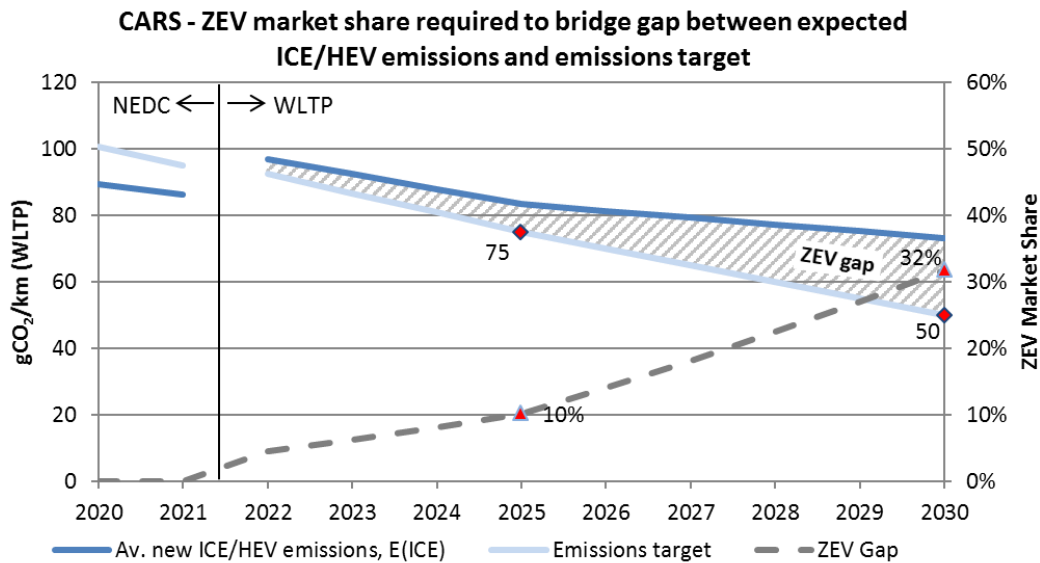


Figure 16: Illustration of the car ZEV gap between the forecasted emissions of conventional vehicles and targets of 75gCO<sub>2</sub>/km in 2025 and 50 gCO<sub>2</sub>/km in 2030

For vans, the low target levels and lack of significant ULCV uptake predicted before 2020, result in a much larger ZEV Gap opening up from 2021, and reaching 30% in 2025 and 68% in 2030. The high market shares of ZEVs required also reflects anticipated strong growth in the number of vehicles in circulation from the van sector, which requires deeper reductions to meet the -30% Climate Goal in 2030.

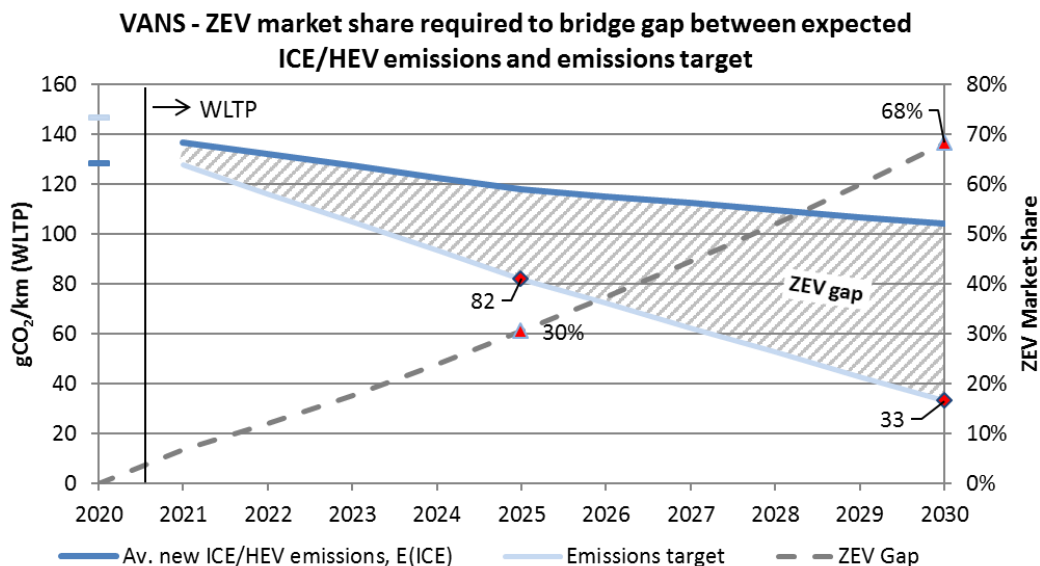


Figure 17: Illustration of the van ZEV gap between the forecasted emissions of conventional vehicles and targets of 82gCO<sub>2</sub>/km in 2025 and 33 gCO<sub>2</sub>/km in 2030

The ZEV gap, average emissions target, and average emissions of conventional vehicles are three inter-dependent variables, i.e. defining two automatically fixes the value of the third. Consequently, setting a CO<sub>2</sub> target and ZEV mandate would indirectly set the required average emissions of conventional vehicles ( $\bar{E}_{ICE}$ ).

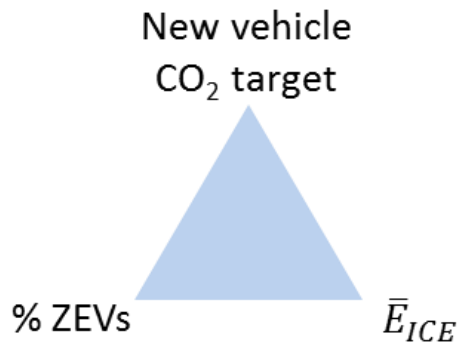


Figure 18: Representation of the inter-dependent relationship of the new vehicle CO<sub>2</sub> target, ZEV gap and emissions of conventional vehicles ( $\bar{E}_{ICE}$ )

Setting a ZEV mandate at the ZEV Gap presented here, and the CO<sub>2</sub> targets suggested in Section 4, would allow the emissions of conventional vehicles to follow that expected by the current deployment schedule. The policy would therefore fulfil its aim of steering OEMs towards ULCVs led decarbonisation without interrupting the currently expected cycles of conventional efficiency technology.

### 7.2 Incorporating PHEVs with a credit mandate

Setting a ULCV mandate to the ZEV Gap is limited as it does not take into consideration the presence of PHEVs in the sales mix. PHEVs are not zero-emission vehicles on a tailpipe basis, and so contribute less to reducing average emissions than BEVs. Figure 19 shows the combinations of BEV and PHEV market shares that reduce average emissions from  $\bar{E}_{ICE}$  to the baseline WLTP targets. If only PHEVs with 50km electric ranges were available then a 43% market share would be needed in 2030, compared with 32% for BEVs only. This creates uncertainty over where to set the mandate level as it requires an assumption on the likely relative market shares of BEVs and PHEVs, as well as any changes to the electric range of PHEVs. If this assumption turns out to be inaccurate, then the average emissions of conventional vehicles would have to fall more quickly than in the expected  $\bar{E}_{ICE}$  trajectory, even if the mandated number of ULCVs were sold. This would contravene the mandate's purpose.

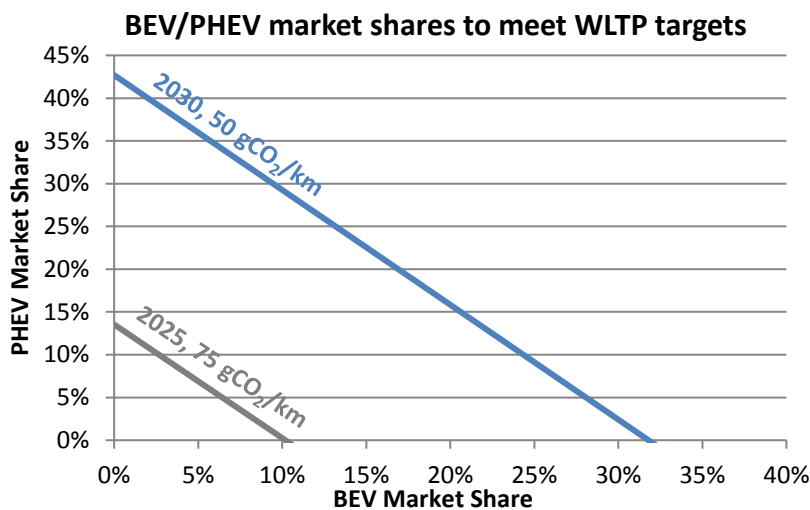


Figure 19: Combinations of PHEV/BEV car market shares that close the gap from  $\bar{E}_{ICE}$  to WLTP target levels



Instead, therefore, a system of credits can be introduced such that PHEVs contribute less towards mandate compliance than BEVs. Rather than mandating a certain market share of ULCVs, OEMs could be required to accumulate a certain number of credits. This requirement could be expressed as a percentage over total vehicles sold:

$$credit \% = \frac{total\ credits}{total\ vehicles\ sold} > mandate\ \%$$

If ZEVs are worth 1 credit, then the credit % is the same as mandate level suggested by the ZEV Gap.

### 7.2.1 PHEV Credit Evaluation

The intention of the mandate proposed in this study is to direct OEMs towards using ULCV technology to comply with increasingly strict CO<sub>2</sub> targets, rather relying on continued improvements to conventional vehicles. It is therefore closely linked to the decarbonisation potential of ULCVs and it appears appropriate to base credit value on their emissions. A simple approach could be to assign the same fixed credit value to all PHEVs based on the average PHEV emissions relative to ICEs/HEVs.

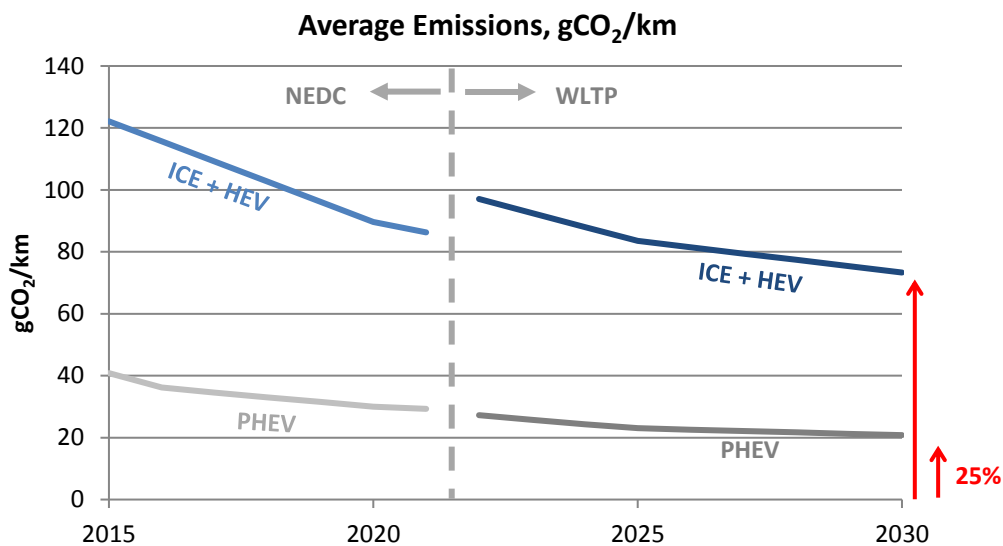
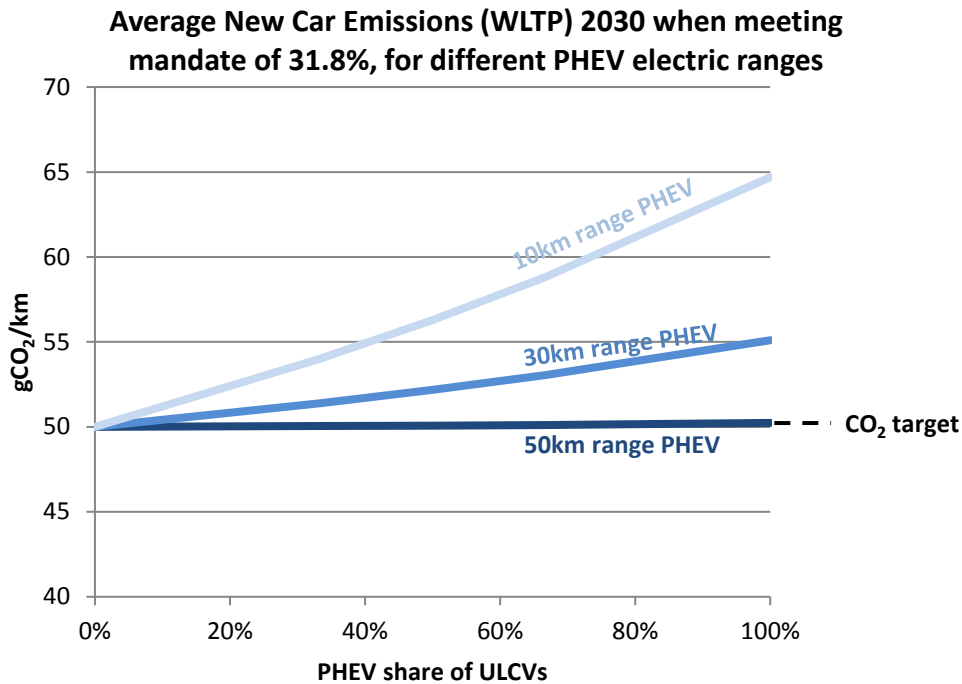


Figure 20: Average emissions of ICE/HEVs and PHEVs in the ECCo European Scenario

Figure 20 shows that the average emissions of PHEVs in the ECCo European Scenario are approximately 25-30% of average ICE/HEV emissions over 2022-30. The average PHEV therefore offers ~75% of the emission reduction potential of a ZEV, and hence a credit value of 0.70-0.75 for PHEVs appears appropriate.

However, fixing the credit value creates the risk of misevaluating PHEVs’ potential to reduce average emissions. Figure 21 shows the impact on average emissions of reducing PHEV ranges in a scenario where PHEVs receive 0.75 credits and the mandate is met. This would occur if OEMs choose to develop low range ‘compliance’ PHEVs which receive credits but do not contribute significantly to emissions reduction.



**Figure 21: Impact of different PHEV ranges on average new car emissions, with different BEV/PHEV ratios that meet the 31.8% mandate in 2030. PHEVs receive 0.75 credits per vehicle**

It can be seen that average emissions rise well above the target with high PHEV uptake, despite compliance with the mandate. The consequence of such a scenario is that OEMs would have to improve the efficiency of their conventional ICEs/HEVs in order to meet the CO<sub>2</sub> target. The mechanism would therefore fail in its purpose to guide OEMs towards ULCV development and away from focussing on aggressively improving their ICEs.

If the mandate policy leaves open the possibility of “compliance” vehicles, evidence from California suggests that at least some OEMs will favour this option. Fiat Chrysler, for example, openly admits that it only produces its Fiat 500e BEV for the purpose of the California ZEV Mandate and looks to lease the bare minimum to consumers. Fiat Chrysler CEO, Sergio Marchionne is quoted as saying “*I hope you don’t buy it, because every time I sell one, it costs me \$14,000.*” Ford, Honda and Toyota also produce very limited numbers of compliance ULCVs which are not intended for mass market. Regardless, the exact specification of future PHEVs is very much dependent on individual OEM strategies and is therefore inherently uncertain. As a consequence, keeping PHEVs at a fixed credit value is likely to result in a situation of credit misevaluation.

Instead, a more sophisticated approach is necessary which links the credit value to the emissions reduction potential of each individual PHEV. The following valuation formula is suggested:

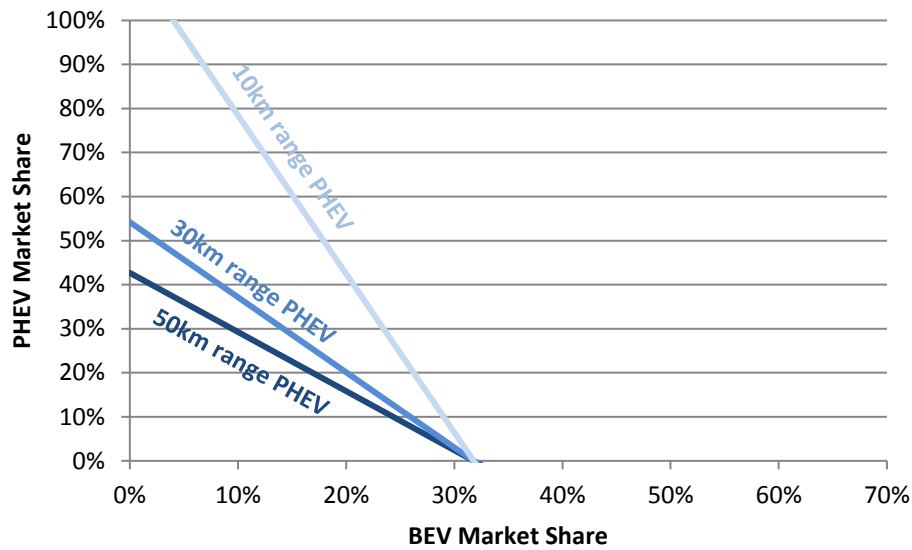
$$credit\ value = 1 - \frac{E_{ULCV}}{\bar{E}_{ICE}}; \quad credit\ value > 0$$

Recall that  $\bar{E}_{ICE}$  is the average emissions of conventional vehicles and its trajectory is indirectly pre-defined when the mandate and CO<sub>2</sub> target are set. This equation will correctly value the vehicle against its emissions reduction potential. ZEVs continue to receive a single

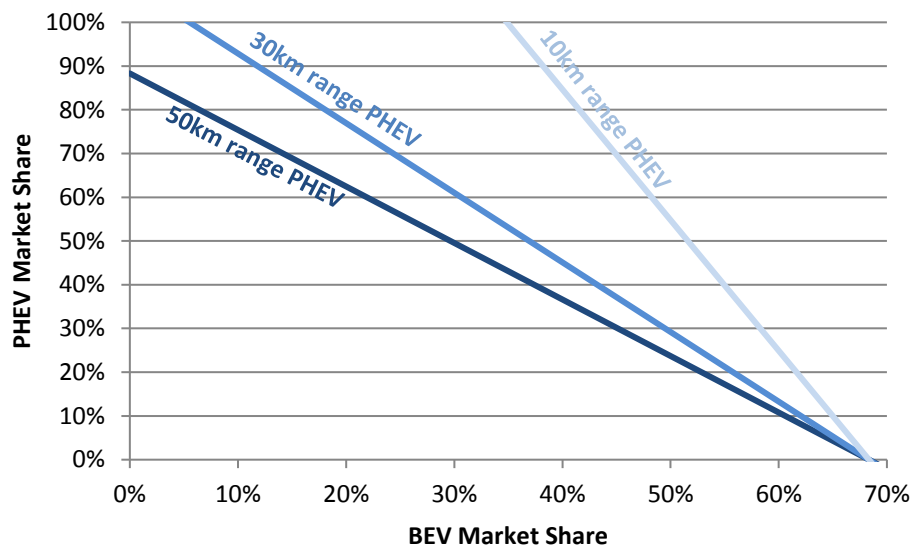
credit and other mandated vehicle will receive between 0 and 1 credits depending on the emissions relative to  $\bar{E}_{ICE}$  in that year.

The result is that any share of PHEVs that fulfils the mandate will both close the ZEV Gap and meet the CO<sub>2</sub> target precisely. In addition, OEMs are discouraged from producing low range “compliance” PHEVs, as they would be required to sell an extremely high market share in order to satisfy the mandate. Figure 22 shows that if the range of PHEVs is reduced too much it becomes impossible to meet the mandate even with a 100% market share.

**CARS - PHEV vs BEV share to meet 31.8% mandated credit % in 2030, PHEV credits based on emissions**



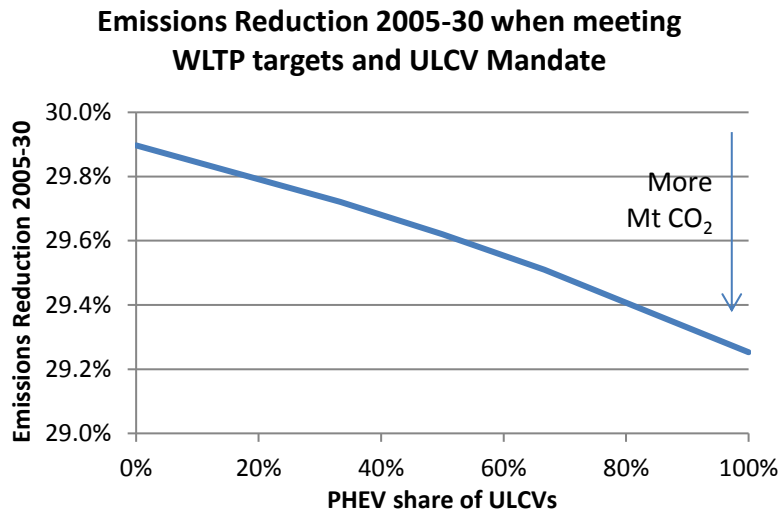
**VANS - PHEV vs BEV share to meet 68.3% mandated credit % in 2030, PHEV credits based on emissions**



**Figure 22: BEV/PHEV market shares required to meet the 2030 mandate for PHEVs with different ranges under a dynamic credit evaluation system**

### 7.2.2 Assessment of combined ULCV Mandate-CO<sub>2</sub> target in meeting Climate Goal

Figure 23 shows how meeting the CO<sub>2</sub> target and credit mandate with different BEV to PHEV ratios under this system affects emissions reduction 2005-30. It is largely successful in achieving the -30% Climate Goal but it can be seen that the emissions reduction is slightly lower with a high PHEV share.



**Figure 23: Effect of different BEV/PHEV ratios on meeting the -30% Climate Goal, under a mandate credit system based on WLTP emissions**

This is a result of PHEVs opening up the real world emissions gap, which for PHEVs exists due to two factors:

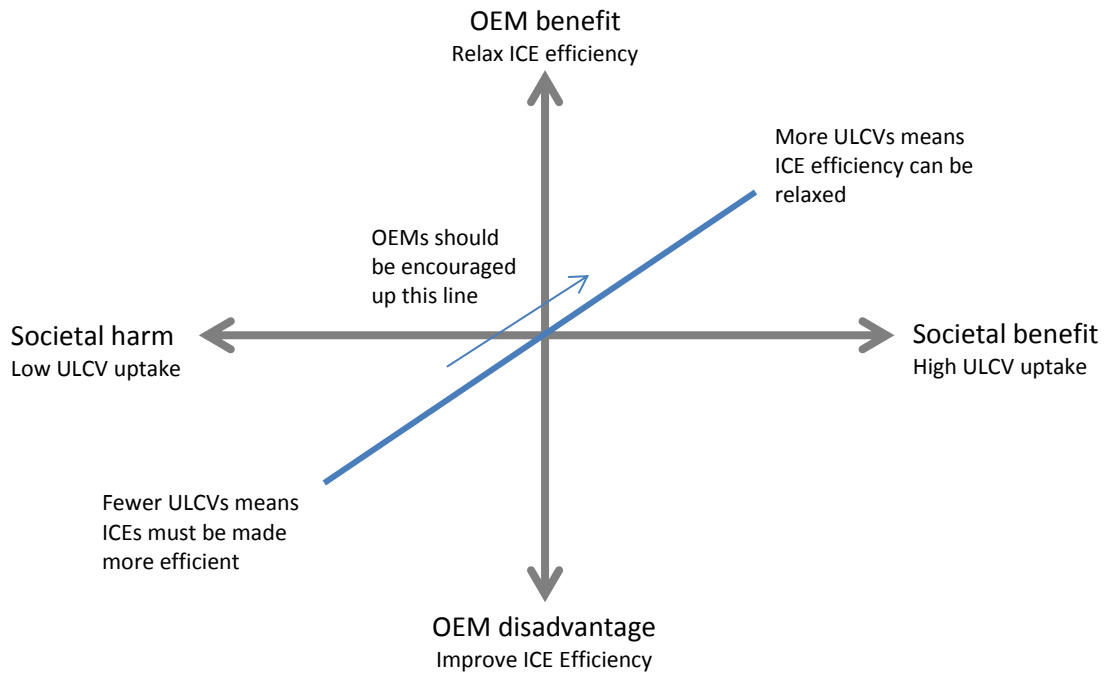
1. Discrepancy between the type-approval and real world fuel consumption under charge sustaining (fuel-powered) mode
2. Difference in the proportion of electric kilometres under type-approval and real world conditions (i.e. the utility factor)

Both factors are related to the utility factor, since a higher proportion of electric kilometres will also reduce the effect of the fuel consumption discrepancy.

A discrepancy between the real world and type-approval utility factor is a potential weakness in linking the credit value to WLTP emissions, and the impact of this is investigated in Section 8.5. This is particularly pertinent given the uncertain reliability of the utility factor function currently employed in the WLTP (see Section 3.1.1). An alternative approach could be to link PHEV credits to electric range, as per the credit system in place in the California ZEV Mandate. However, this would not necessarily be more accurate as a relationship between range and proportion of driving under electric power would still have to be agreed upon. This would also fail to take into account any changes to the efficiency of the PHEV powertrain, and could permit compliance PHEVs with a high electric range but inefficient engine. A preferred solution is to close the real world gap through ensuring the WLTP realistically reflects the proportion of driving under electric power. This would incorporate both electric range and fuel efficiency, and retain the simplicity of the mandate scheme by accounting for units of gCO<sub>2</sub>/km only.

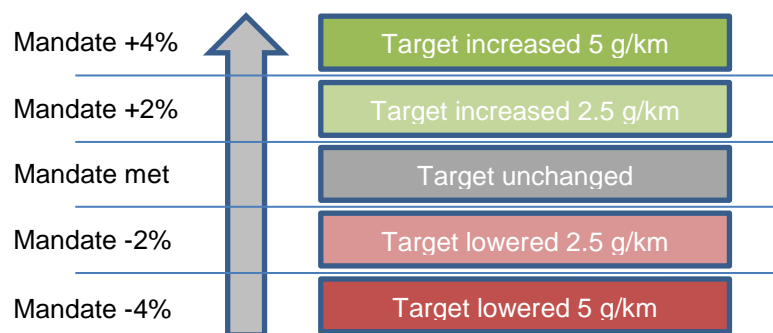
### 7.3 Flexible Mandate

OEMs are naturally rewarded for selling more ULCVs as it relieves some of the pressure on making their conventional powertrains more efficient. Although OEMs may currently view this as a less cost-effective option, as discussed, this is the most advantageous solution in the long term. High uptake of ULCVs should also be viewed as a broader benefit to society, due to their positive impact on air quality and their eventual enablement of zero-emission transportation. This mutually beneficial relationship is represented graphically in Figure 24.



**Figure 24: Representation of the benefit of ULCVs to society and OEMs with regards to decarbonisation**

A mandate essentially pushes OEMs towards the top right-hand quadrant of Figure 24, where society gains from more ULCVs, and OEMs gain from less demanding ICE efficiencies. However, as ULCV development is currently viewed as the more expensive option in the short term, OEMs may be unwilling to exceed the mandate or may even prefer to miss it and accept the regulatory penalties. The effectiveness of a mandate can therefore be amplified through a proposed Flexible Mandate system:

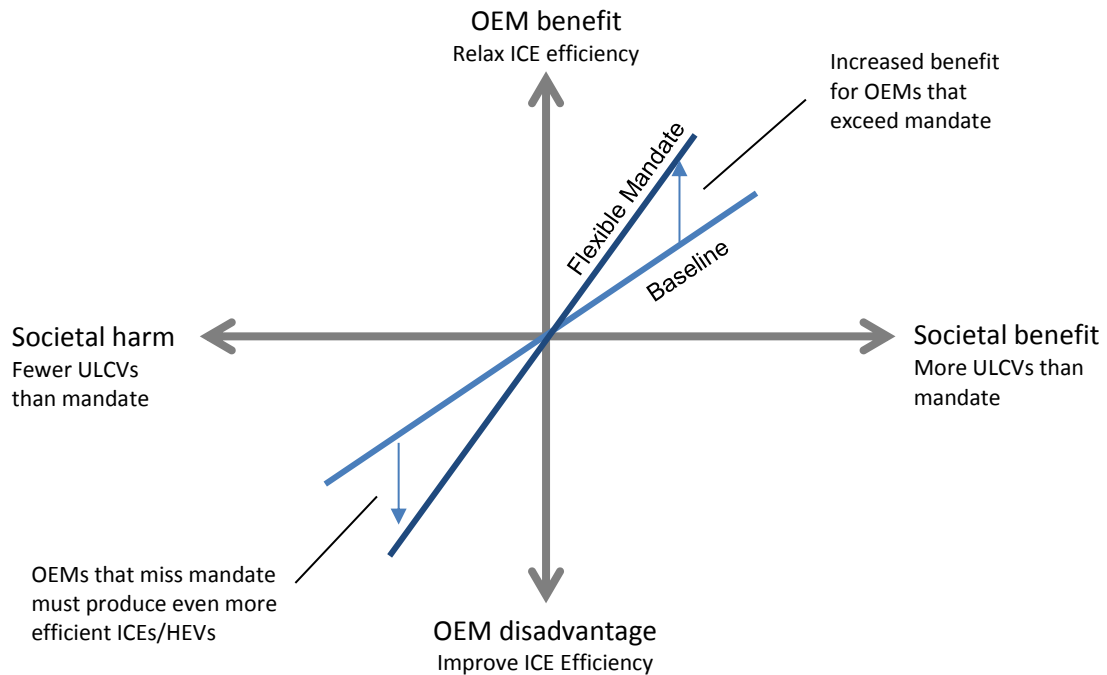


**Figure 25: Example of a Flexible Mandate scheme<sup>20</sup> (indicative values)**

<sup>20</sup> Reproduced from: Transport & Environment (2015) 2025 CO<sub>2</sub> Regulation: The next step to tackling transport emissions

In this mechanism, OEMs that exceed the mandate are rewarded with a slightly relaxed CO<sub>2</sub> target, and those that miss the mandate have a tighter target imposed (see Figure 25).

Figure 24 illustrated how OEMs are naturally rewarded for selling more ULCVs than required, since it allows them to relax slightly the efficiency improvements of their conventional vehicles. Conversely, OEMs that sell fewer ULCVs face having to make their conventional vehicles more efficient. The purpose of a Flexible Mandate is to leverage this benefit/disadvantage (see Figure 26).



**Figure 26: Representation of the leveraging effect of a Flexible Mandate on OEM benefit/disadvantage**

This also provides an alternative to imposing fines on OEMs that miss the mandate, and instead a financial penalty is levied indirectly by requiring OEMs to meet a stricter target. This avoids having to evaluate the negative externality of missing the mandate, and ensures that money that would normally be collected as fines is instead spent efficiently by the OEMs to lower vehicle CO<sub>2</sub> emissions.

In practice, unless OEMs on average exactly meet the mandate and CO<sub>2</sub> target, such a scheme will always bring lower benefits to society compared with a normal mandate, as illustrated in Figure 27. For example, if OEMs on average exceed the mandated levels of ULCVs, the overall CO<sub>2</sub> emissions from new cars rise as they are allowed to produce less efficient conventional vehicles than under a non-Flexible Mandate. If fewer ULCVs are sold than required under the mandate, additional CO<sub>2</sub> emissions reduction is required from more efficient ICEs but this may not fully compensate for the shortfall of ULCVs (which have other benefits in terms of NO<sub>x</sub>, noise and preparing the market for high sales volumes in the 2030s). As the goal of both the CO<sub>2</sub> target and mandate is long term decarbonisation, there is a risk a Flexible Mandate may reduce the positive impacts on society.

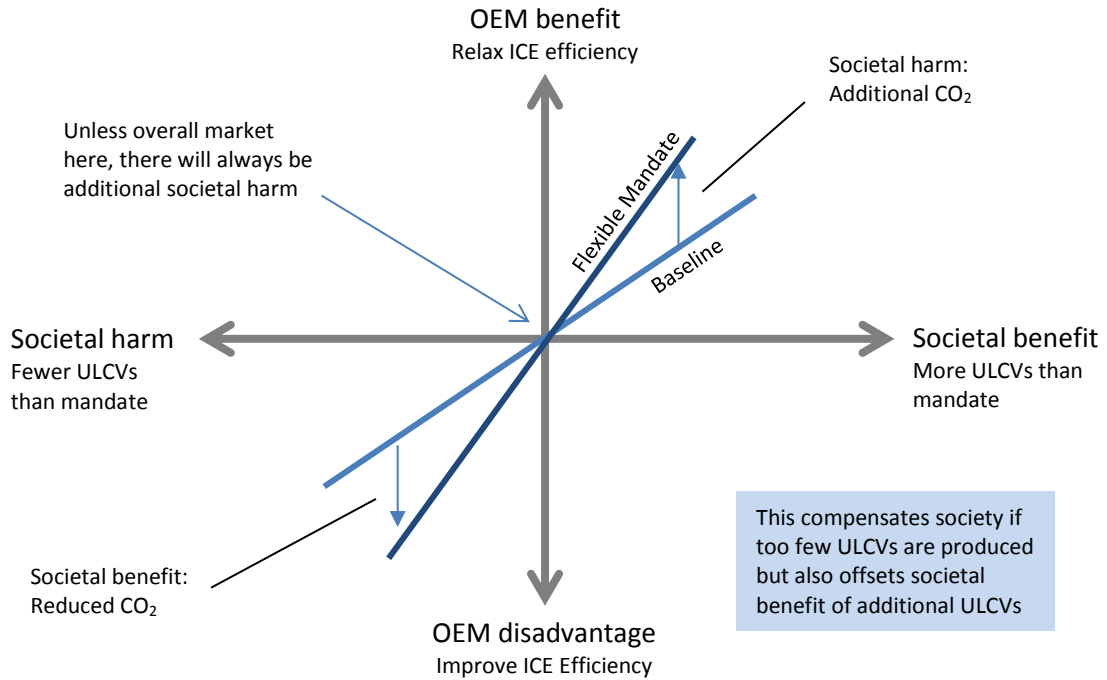


Figure 27: Illustration of the likelihood for additional societal harm with a Flexible Mandate

Figure 28 provides examples of the potential impact on meeting the -30% Climate Goal with a Flexible Mandate. For simplification, this scenario assumes no PHEVs as they have the effect of changing the real world emissions gap.

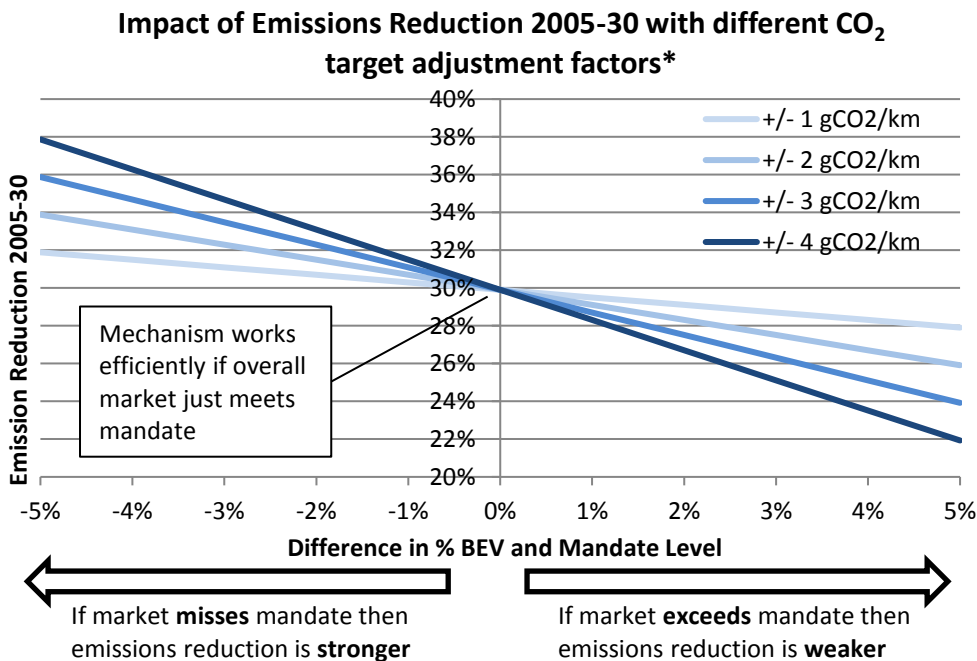
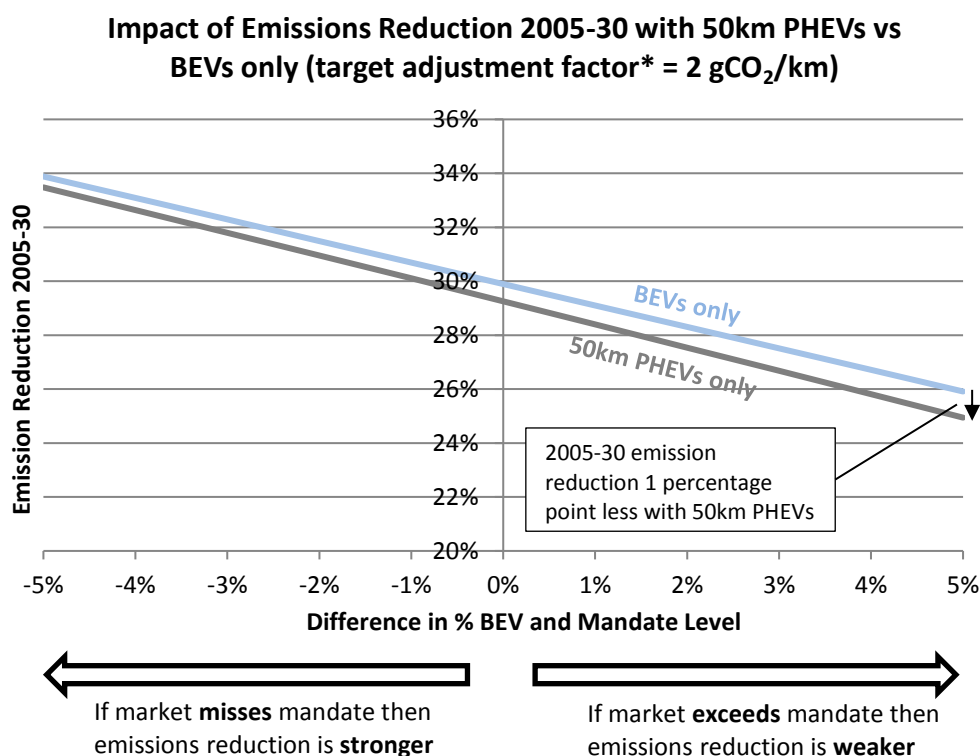


Figure 28: Impact on meeting the -30% Climate Goal for a Flexible Mandate with different \*target adjustment factors: the gCO<sub>2</sub>/km change in target per % point difference to mandate)

It can be seen that the impact of the Flexible Mandate on emissions reduction 2005-30 can be of the order of several percentage points. For example, if the target is increased by 2 gCO<sub>2</sub>/km for every 1 percentage point that the mandate is exceeded, then consistently exceeding the mandate by 5 percentage points would result in emissions reduction 2005-2030 of 25.9%. This is considerably lower than the 30% required, and equivalent to an additional 24.6 Mt of CO<sub>2</sub> per year in 2030.

The same analysis can be carried out for a scenario where all ULCVs are 50 km PHEVs. The result of this is shown in Figure 29. As discussed in Section 7.2.2, PHEVs open up the real world gap which adds to the real world emissions. However, the effect is relatively minor in relation to the excess emissions allowed by the Flexible Mandate. Consistently exceeding the mandate by 5 percentage points with PHEVs rather than BEVs decreases 2005-30 emissions reduction by an additional 1 percentage point, equivalent to 6Mt of CO<sub>2</sub> per year more in 2030.

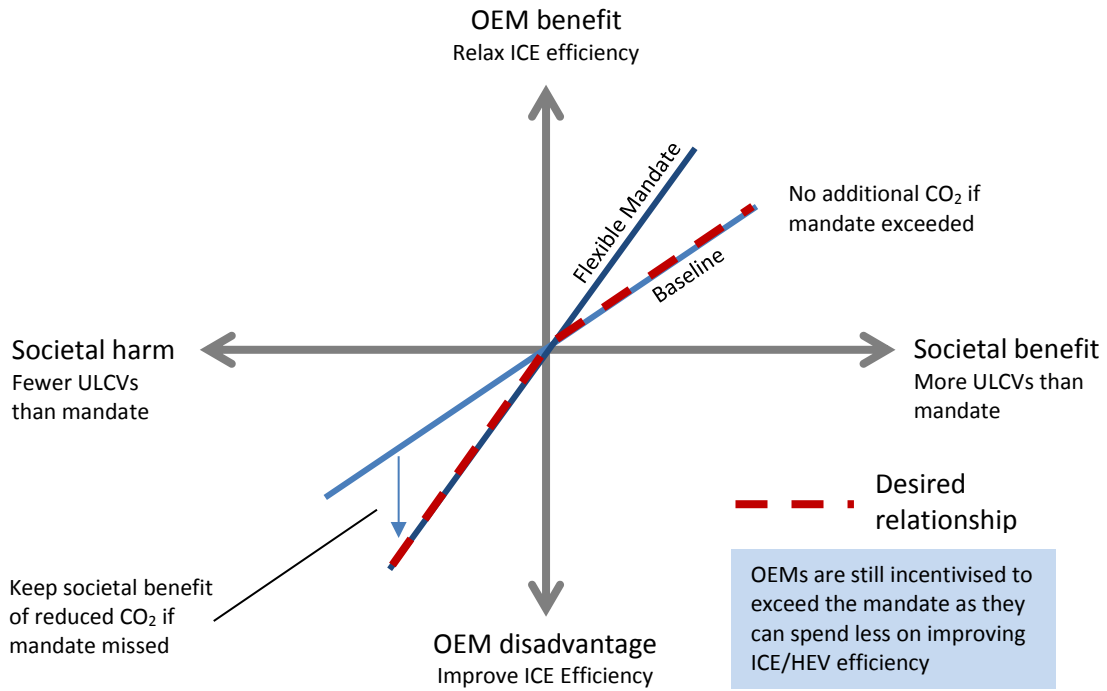


**Figure 29: Impact on meeting the -30% Climate Goal under Flexible Mandate with PHEVs vs BEVs (\*target adjustment factor = 2 gCO<sub>2</sub>/km per % point difference to mandate)**

### 7.4 The “Upside-only” Flexible Mandate

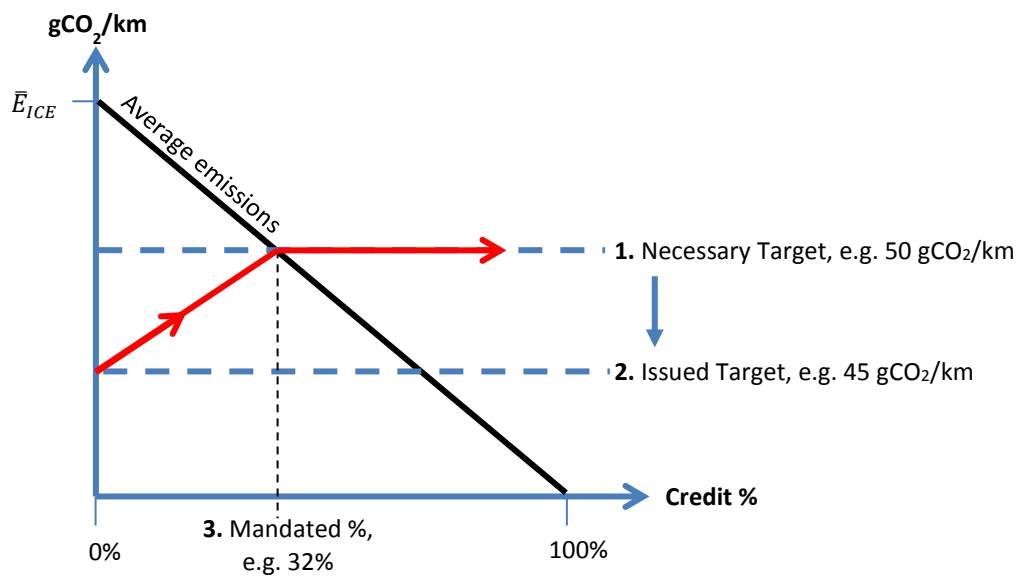
Ideally, the Flexible Mandate should be adjusted to remove/limit the additional societal harm (allowing higher CO<sub>2</sub> emissions) when the market exceeds the mandate, while continuing to amplify the disadvantage of missing it. This is represented graphically in Figure 30.





**Figure 30: Representation of an idealised mandate policy. The disadvantage of missing the mandate is amplified, but OEMs are not overly rewarded for exceeding the mandate at the expense of reduced societal benefit.**

Such a scheme could be achieved by amending the Flexible Mandate to only adjust the target for those that do not meet the mandate. No relaxation is then sanctioned for the OEMs that exceed it. However, removing the reward of exceeding the mandate means this policy would simply add an additional layer of penalty to the existing CO<sub>2</sub> standards. However, an example of a mechanism that achieves the same ideal relationship shown in Figure 30, but is entirely reward based, is presented in Figure 31.



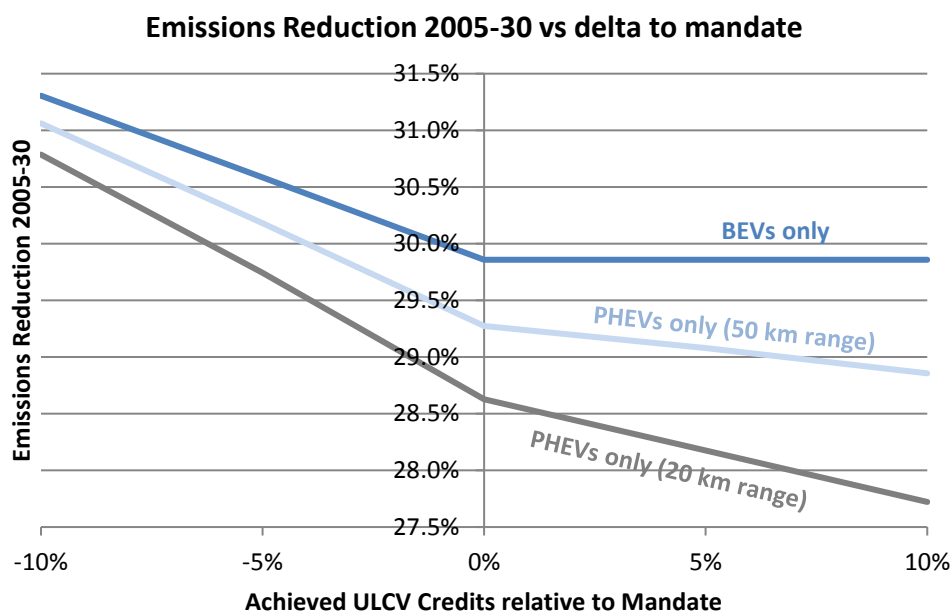
**Figure 31: Representation of the Upside-only Flexible Mandate. An OEM's Specific CO<sub>2</sub> Target is defined by the red line at their achieved credit %**

Here, the target issued to the market is set below what is actually necessary in order to meet the -30% Climate Goal, e.g. at 45 gCO<sub>2</sub>/km when 50 gCO<sub>2</sub>/km is what is needed. These are the “Issued Target” and “Necessary Target” respectively. The mandated credit level is set at that which would bridge the ZEV Gap to the “Necessary Target” (50 gCO<sub>2</sub>/km). As credits are accumulated by an OEM, they are rewarded through an increase (i.e. relaxation) of their Specific CO<sub>2</sub> target. Once the credit mandate is achieved, the Specific CO<sub>2</sub> target is no longer increased. However, as ULCVs reduce average emissions, OEMs still gain the natural benefit of relaxing conventional vehicle emissions if they choose to exceed the mandate.

This mandate has the benefit of being exclusively reward-based, and like the Flexible Mandate, does not require penalties to be enforced for non-compliance, since these are levied through the existing policy of CO<sub>2</sub> standards. It also clearly demonstrates to OEMs the mind-set that increasing ULCV share results in less demanding efficiency improvements to their conventional vehicles.

This mechanism is completely analogous to the Flexible Mandate without target relaxation when the mandate is exceeded, however, the penalty of missing the mandate is now front-loaded. This is simpler from a policy design perspective as only the necessary and issued CO<sub>2</sub> targets and the ULCV mandate level need be set. A Flexible Mandate without the target relaxation element would require a CO<sub>2</sub> target, a target adjustment factor, and a ULCV mandate level. However, it would also likely require a limit to how low the target can be reduced to compensate for the loss of target relaxation.

This approach is also arguably similar to a super-credits system where a stricter target has been imposed and the target exceedance limit set to the original target. However, this is considerably more dynamic in its approach towards PHEVs vs ZEVs and allows emissions reductions of conventional vehicles to be encouraged as well.



**Figure 32: Impact of Upside-only Flexible Mandate in meeting the -30% Climate Goal**

Figure 32 shows this mechanism in practice and its impact on the reduction in stock emissions 2005-30. In the scenario with only ZEVs, the mechanism behaves as expected. If the market as a whole misses the mandate, then society is compensated through by

stronger emissions reductions in the overall vehicle parc. If the mandate is exceeded then the -30% Climate Goal is still met in all cases, and the additional societal benefit is delivered through higher numbers of ZEVs. However, when PHEVs are introduced, there is an additional impact of a widening real world emissions gap, which means that the emissions reduction 2005-30 continues to be undermined as the mandate is exceeded. Low range PHEVs exacerbate this effect although it is unlikely that these would be produced as they are discouraged through the linking of credit value to type approval emissions. It should be noted though that the effect is relatively small and worth a 0.5 - 1.0 percentage point loss in stock emissions reduction in the limit where all ULCVs are 50km PHEVs. In reality, the credit system will incentivise OEMs to both lift the electric range of their PHEVs, and thereby reduce the effect of the real world emission gap, and sell more ZEVs, as fewer are needed to fulfil the mandate. However, a further control could be put in place to limit PHEV sales as a proportion of all ULCV sales, although it is debatable as to whether reducing OEM flexibility in complying with the mandate and CO<sub>2</sub> target is either necessary or desirable.

## 8 Sensitivities

### 8.1 Impact of tightening and relaxing the Climate Goal

The EU’s 2030 Climate and Energy Package aims for a 30% reduction in emissions from 2005 levels across all non-Emissions Trading Scheme (ETS) sectors. The baseline of this study assumes that each sector is responsible for a proportional share of this requirement, and thus must undergo an equivalent 30% reduction. However, some sectors are easier to decarbonise than others, making it more cost-effective to allocate emissions reduction to some sectors in a disproportionate manner. The impact of apportioning more or less emissions reduction to the light duty transport sector can be shown by comparing the baseline -30% Climate Goal scenario with goals of -25%, -35% and -40% for light duty vehicles.

#### 8.1.1 CO<sub>2</sub> targets required for alternative climate goals

As per the baseline, suggested CO<sub>2</sub> targets for each of the alternative climate goals can be defined as those that result in a smooth downward trend in the average real world emissions of new vehicles. These are converted to WLTP targets through the average real world emissions gap resulting from the ECCo European Scenario and a 1:1 relative market share of BEVs and PHEVs (see Section 4.1). The resulting targets to achieve each of the alternative climate goals are presented in Figure 33.

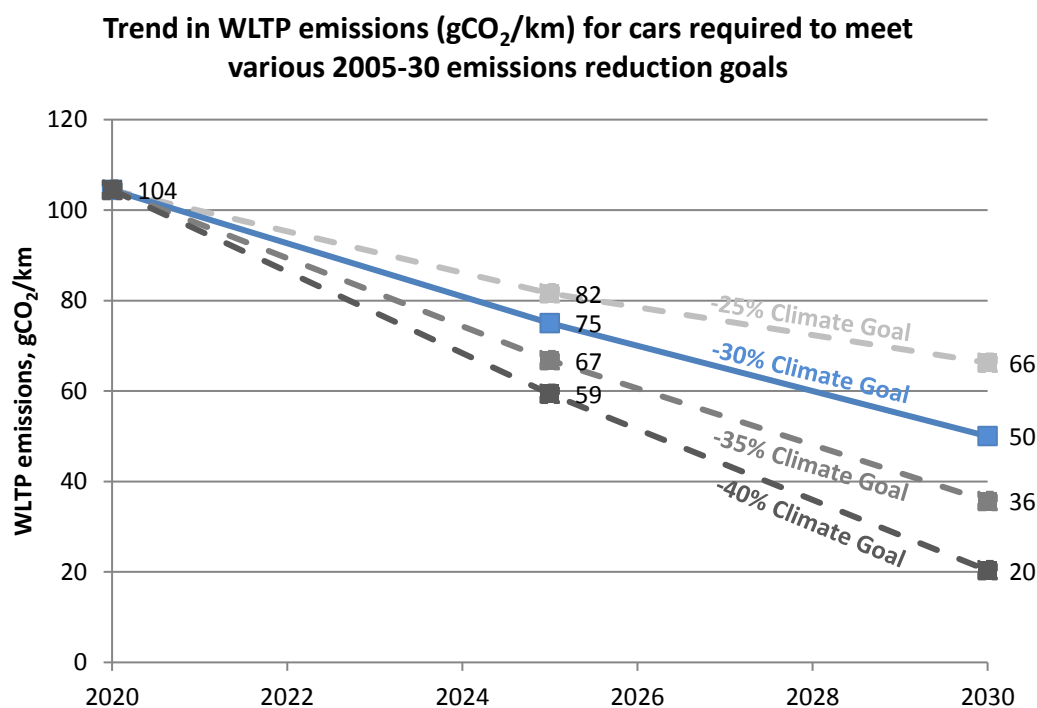


Figure 33: 2025 and 2030 WLTP targets required for cars to meet -25%, -30%, -35% and -40% Climate Goals

#### 8.1.2 Effect of climate goal on the ZEV Gap

In all of the Climate Goal scenarios presented in Figure 33, conventional ICEs and HEVs alone are insufficient to meet the target levels. Figure 34 shows the resulting ZEV Gap that must be bridged in order to meet each of these Climate Goals (see Section 7.1 for details on the ZEV Gap concept). Although the -40% Climate Goal looks to reduce emissions by

only an additional 10 percentage points over the -30% baseline, the market share of ZEVs required in 2030 is more than double (72% vs 32%).

**ZEV Gap: market share of ZEVs required to meet WLTP targets for alternative Climate Goals**

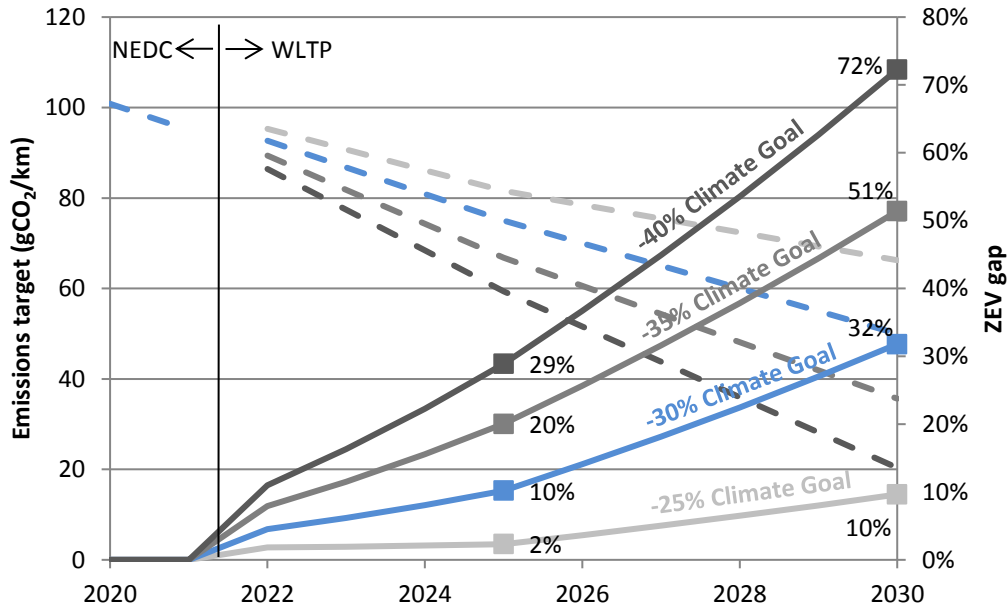


Figure 34: The ZEV Gap (solid lines) for the WLTP target trajectories (dotted lines) needed to meet -25%, -30%, -35% and -40% Climate Goals for cars

For each of these scenarios, the market shares of PHEVs (50km electric range) that could bridge the 2025 and 2030 ZEV Gaps are shown in Figure 35. Reducing emissions by 40% between 2005 and 2030 with 50km PHEVs alone would require a near 100% market share in 2030.

**CARS: BEV/PHEV shares to meet the WLTP targets under various Climate Goals**

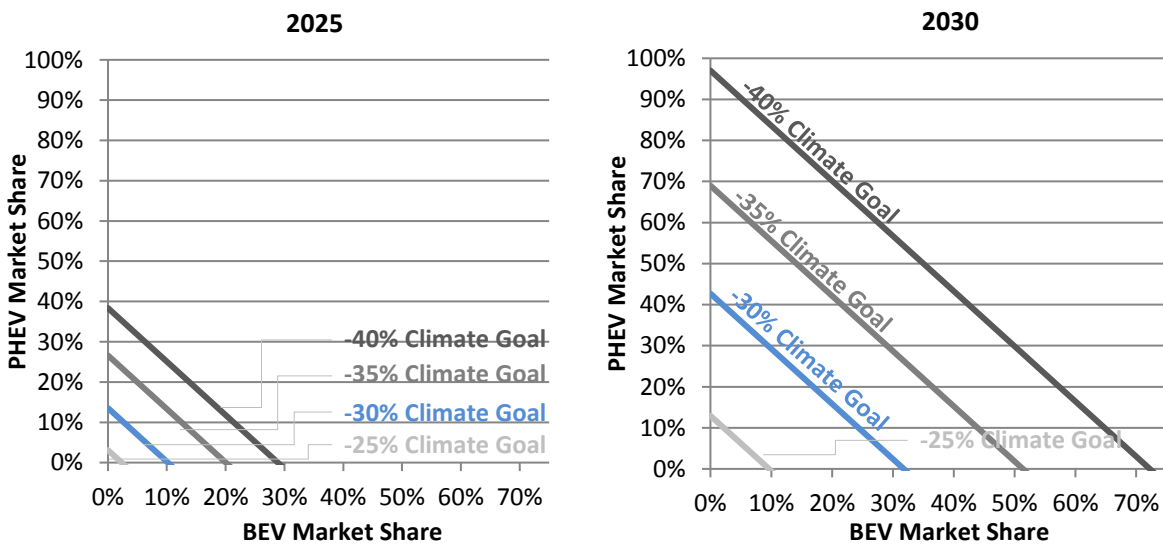
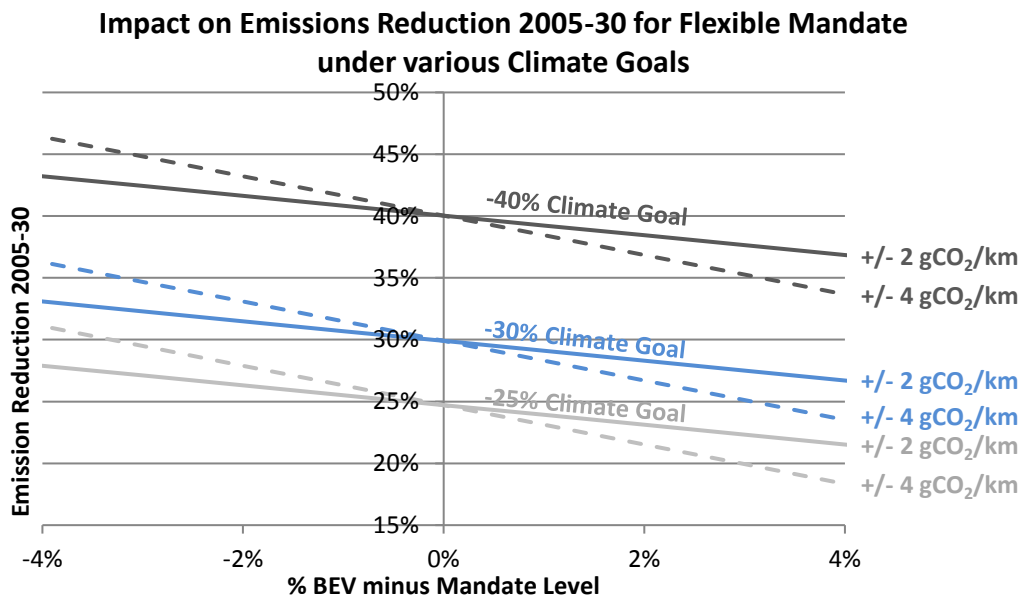


Figure 35: BEV/PHEV market shares required in 2025 and 2030 required to meet -25%, -30%, -35% and -40% Climate Goals for cars

### 8.1.3 Impact on the Flexible Mandate

The Flexible Mandate mechanism allows OEMs to relax or forces them to tighten their Specific CO<sub>2</sub> Target depending on how they perform against a ULCV mandate. In Section 7.3, the impact of this mechanism against overall emissions reduction between 2005-30 is investigated. Figure 36 shows a repeat of this analysis carried out for -40% and -25% Climate Goals.



**Figure 36: Impact of a Flexible Mandate on emissions reduction 2005-30 under various Climate Goal scenarios. Results presented for both a +/- 2 and +/- 4 gCO<sub>2</sub>/km change in target per % point difference to mandate)**

This shows that the change in emissions reduction due to performance against the mandate is independent of the climate goal set. For example, missing the mandate by 4 percentage points, where each percentage points decreases the CO<sub>2</sub> target by 4 gCO<sub>2</sub>/km, results in 2005-30 emissions reduction increasing by 8 percentage points under each of the -25%, -30% and -40% climate goal scenarios shown. However, under a stronger emissions reduction pathway, it is more likely that the market will fall short of the ULCV mandate and vice versa. Note also that the results presented in Figure 36 are under the constraint that all ULCVs are BEVs, and therefore do not include the effect of PHEVs altering the real world emissions gap.

### 8.1.4 Impact on the Upside-only Flexible Mandate

The effectiveness of the Upside-Only Flexible mandate presented in Section 7.4 can also be tested against different climate goal scenarios. Figure 37 shows how overall 2005-30 emissions reduction would change depending on OEMs’ performance against the ULCV mandate, for a range of climate goals. This is presented for scenarios where all ULCVs are BEVs, and all ULCVs are PHEVs with an electric range of 50 km.

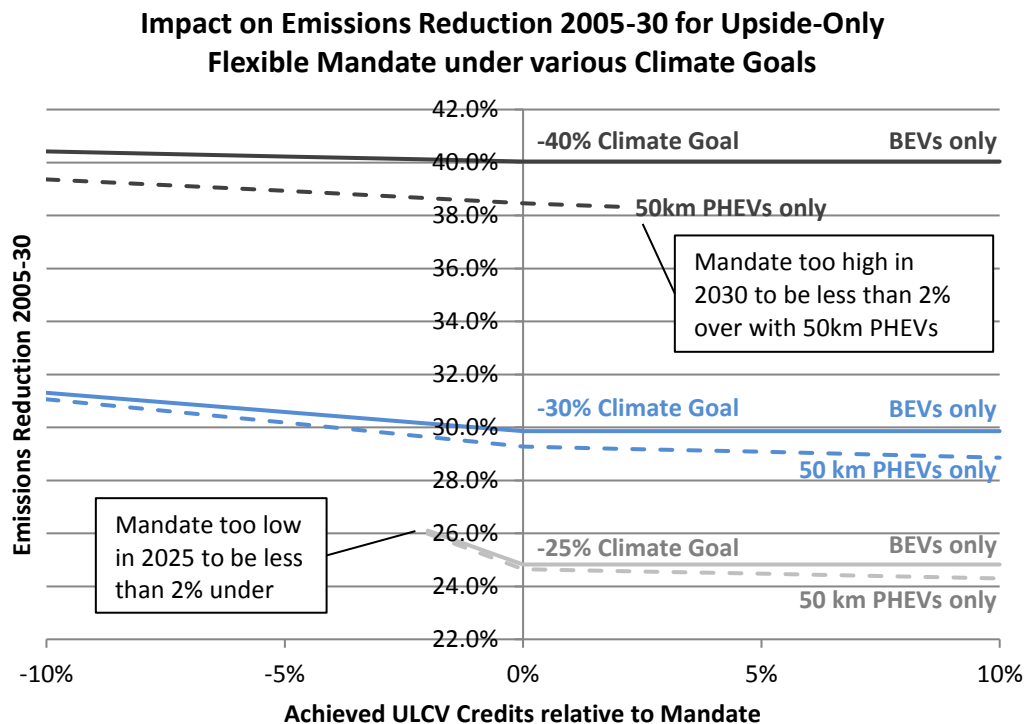


Figure 37: Impact of an Upside-only Flexible Mandate on emissions reduction 2005-30 under various Climate Goal scenarios. Results presented for scenarios with BEVs only, and PHEVs (50km range) only.

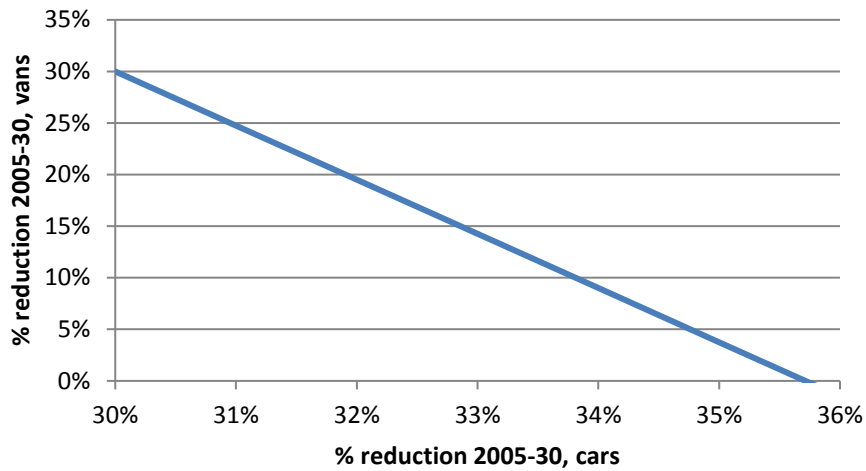
Unlike for the Flexible Mandate (see Figure 36), the change in emissions reduction 2005-30 due to OEM performance against the mandate is dependent on the Climate Goal. For a stronger Climate Goal, the benefit for emissions reduction is smaller if the mandate is under-achieved. However, this must be considered against the fact that under-achievement is likely to be larger for a stronger Climate Goal.

Introducing more PHEVs has a negative impact on emissions reduction as they tend to open up the real world emissions gap. This effect is greater for a stronger Climate Goal, because more PHEVs are needed to meet the lower CO<sub>2</sub> targets. However, there is a limit to how much the market can exceed the mandate with PHEVs alone, and thus the negative effect on emissions reduction is also limited.

## 8.2 Alternative Car and Van Targets for Combined -30% Climate Goal

The predicted growth in the van stock results in strong CO<sub>2</sub> targets to reduce emissions by 30% over 2005 levels in 2030. As stated in Section 4.2, the relative size of the car market means a slight decrease in car CO<sub>2</sub> targets allows for a larger relaxation of the van targets, while still achieving a combined 30% reduction in emissions 2005-30.

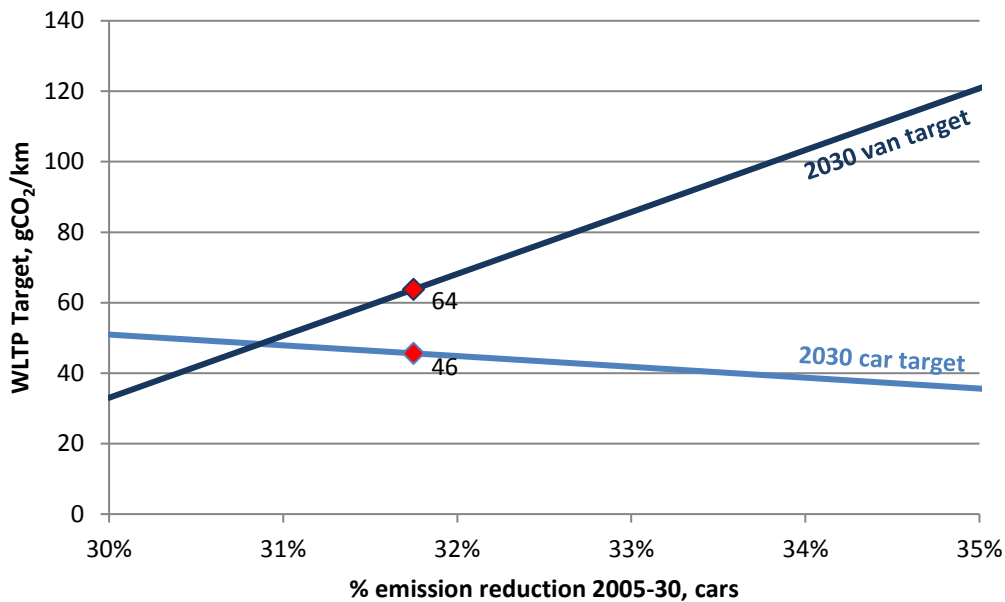
**Percentage reduction in car and van stock emissions 2005-30 that meets combined -30% Climate Goal**



**Figure 38: Relationship between percentage reduction in car emissions 2005-30, and the % reduction in van emissions 2005-30 that achieves a -30% reduction across the two stocks**

Figure 38 illustrates how increasing the demand on the reduction of car emissions 2005-30 by a single percentage point, eases the burden on the van stock by 5 percentage points.

**Car and van WLTP targets in 2030 that meet combined -30% Climate Goal**



Corresponding % emission reduction 2005-30, vans					
30%	25%	20%	14%	9%	4%

**Figure 39: Relationship between 2030 car and van targets (WLTP) that result in a combined 30% reduction in emissions 2005-30**



Figure 39 shows combinations of 2030 WLTP targets for cars and vans that would meet an overall -30% Climate Goal, for a given reduction in car emissions 2005-30. These targets result in a smooth downward trend in real world emissions between 2020 and 2030. It is observed that every 1 gCO<sub>2</sub>/km tightening of the 2030 car target, allows for a ~6 gCO<sub>2</sub>/km relaxation of the 2030 van target. For the target points highlighted, the ZEV gap for both cars and vans in 2030 is 36%, providing a more even sharing of the effort to electrify.

### 8.3 A shift to smaller or larger cars over time

The recent trend in European car sales has seen notable growth in the dual purpose (Segment H) market. In the baseline, segment shares were kept constant beyond 2015, however, continued growth in Segment H, at the expense of all other segment, will place an upward pressure on the market average emissions. To test the impact of this, an alternative segment share scenario was devised in which the Segment H market share increases by 1.2 percentage points per year, which is the historical average rate between 2001-13<sup>15</sup>.

Alternatively, the market may undergo a shift to smaller car segments (A & B) as a way for OEMs to reduce average emissions. In this case, a scenario whereby the combined A and B segment share grows from the current 35% to 50% in 2030 is presented in Figure 40.

#### Alternative Segment Scenarios

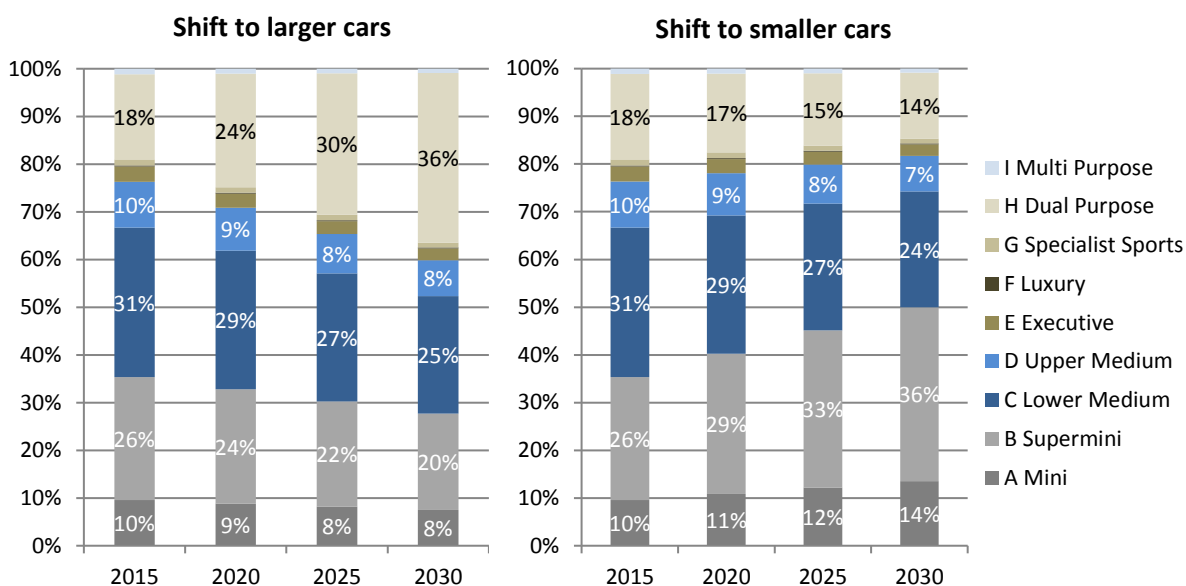
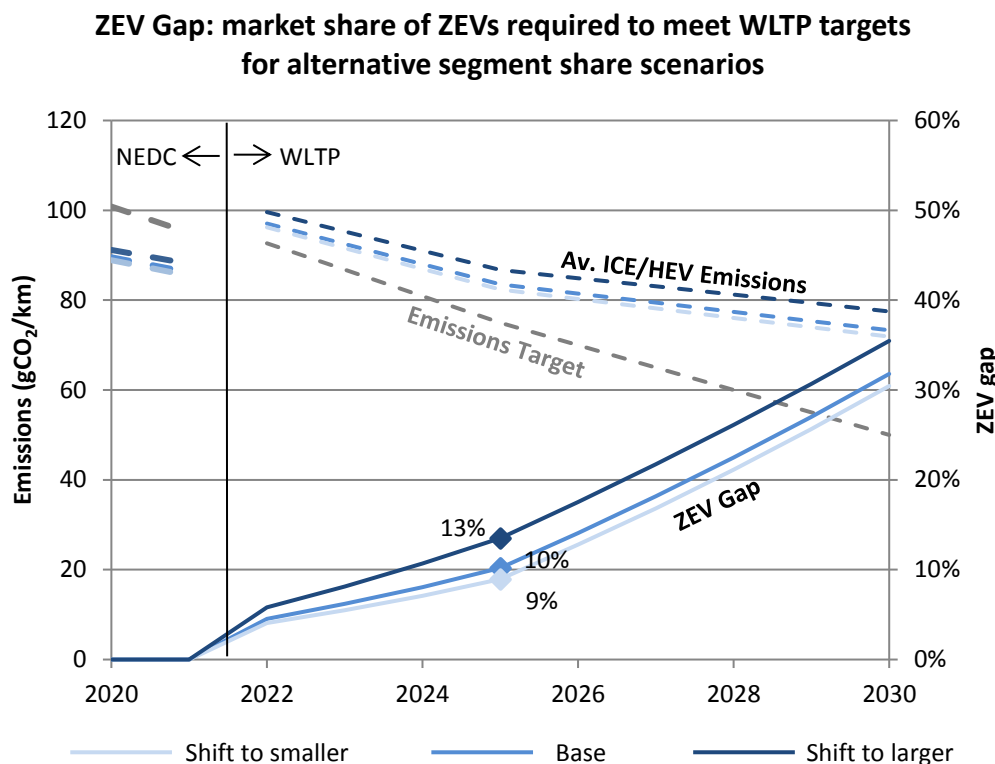


Figure 40: Alternative segment share scenarios 2015-30

Although segment shares have no impact on the required CO<sub>2</sub> target trajectory, a shift to smaller and larger cars will affect the average emissions of conventional cars ( $\bar{E}_{ICE}$ ) and thus the ZEV Gap. Figure 41 shows how the effect of these alternative segment share scenarios is relatively small. By 2030, the difference in  $\bar{E}_{ICE}$  between the “shift to smaller” and “shift to larger” scenarios is only 6 gCO<sub>2</sub>/km, and the difference in the resulting 2030 ZEV gap is 5 percentage points.



**Figure 41: Average ICE/HEV emissions (dotted lines) under alternative segment share scenarios and resulting ZEV Gap (solid line) under the -30% Climate Goal target scenario**

Under the different segment share scenarios, the impact on meeting the -30% climate goal will be negligible as the CO<sub>2</sub> target levels will still have to be met. Assuming the mandate is based on the baseline ZEV Gap, the impact will manifest itself in the requirements for conventional ICEs/HEVs emissions. For example, under the ‘shift to larger’ scenario, conventional ICEs/HEVs would have to be made to emit on average ~3 gCO<sub>2</sub>/km less between 2025 and 2030 in order to comply with the CO<sub>2</sub> target, as long as the mandate was met. However, this should not be viewed as a weakness to this policy as its overarching purpose is to bring about decarbonisation at the required rate. Discouraging OEMs from marketing unnecessarily large vehicles is just as important as encouraging improvements in efficiency.

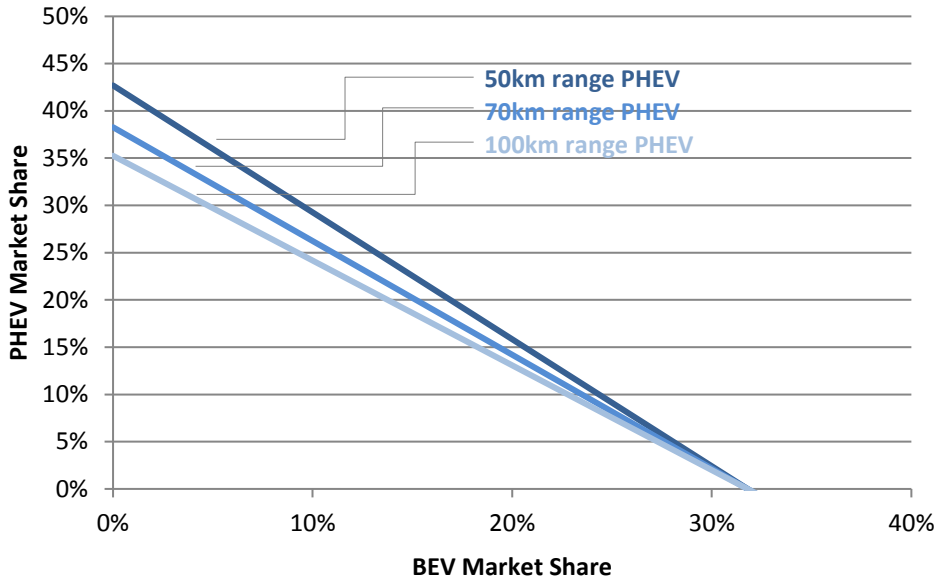
### 8.4 PHEV electric ranges improve over time

The baseline assumes that OEMs will take advantage of falling battery costs by dropping the price of PHEVs, thus improving their economics, rather than increasing their battery pack sizes and range. However, the latter may occur if consumers show a high willingness to pay for electric kilometres, or policy measures result in OEMs placing a high value on low emissions. For example, as shown in Sections 7.2-7.4, the mandate credit valuation system would act as a driver for higher PHEV ranges.

Figure 42 shows the impact of higher PHEV range on the market share required to attain the mandated credit levels. Higher PHEV range results in lower type-approval emissions, and hence fewer PHEVs are needed to fulfil the mandate. However, the impact is considerably less pronounced than reducing PHEV range, as observed in Section 7.2.1: Figure 22. For example, if PHEV range is decreased from 50km to 30km, the share of PHEVs required in 2030 increases by 11.5 percentage points. Conversely, increasing PHEV

range from 50km to 70km, results in the required PHEV market share dropping by only 4.4 percentage points. The reason lies in the utility factor function, shown in Figure 4, for which the marginal gain in the proportion of electric kilometres decreases with range.

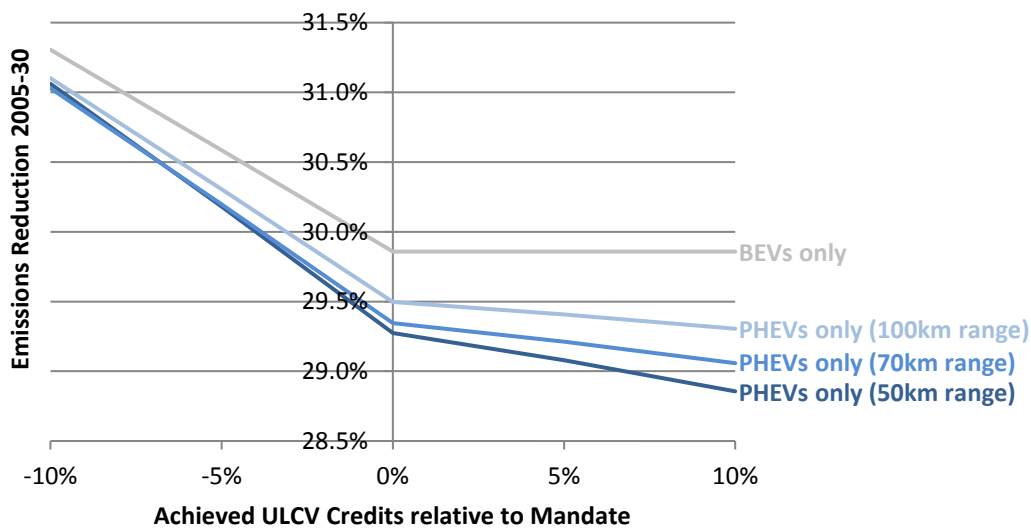
**CARS - PHEV vs BEV share to meet 31.8% mandated credit % in 2030, with higher range PHEVs**



**Figure 42: BEV/PHEV market shares required to meet 2030 mandate level (-30% Climate Goal), with higher electric range PHEVs**

The same trend is observed for high range PHEVs under the Upside-only Flexible Mandate (Figure 43). Emissions reduction 2005-30 improves with increasing PHEV range, as this closes the real world emissions gap. However, comparison with shifting to lower range PHEVs (see Figure 32) shows that the marginal benefit of higher electric range with regards to emissions reduction gradually decreases.

**Emissions Reduction 2005-30 vs delta to mandate**

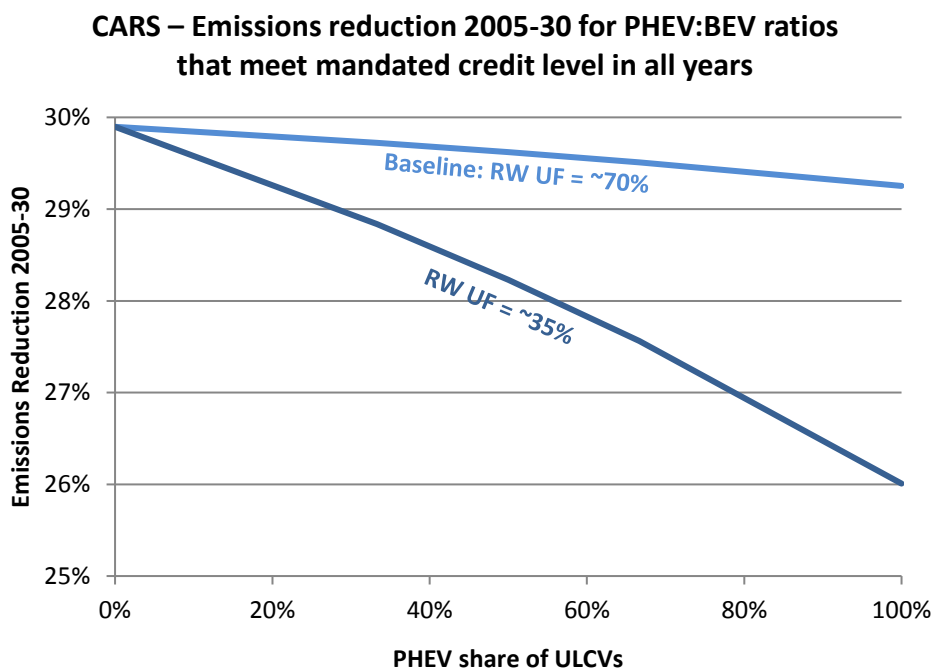


**Figure 43: Impact of increasing PHEV range on emissions reduction 2005-30 under the Upside-only Flexible Mandate mechanism**

### 8.5 Credit valuation based on real world utility factor

A fundamental assumption of the policies discussed in this study is that PHEV owners will maximise their proportion of electric kilometres. This is not an unreasonable assumption given that running a car on electricity is significantly cheaper than fuel per kilometre. However, evidence from Dutch PHEV drivers<sup>21</sup> suggests that the proportion of driving carried out under electric power is currently 30-40%, considerably lower than the 60-70% predicted by the utility factor function (Figure 4). Many of these users are company car drivers who do not pay for their fuel and so although the current policy landscape has incentivised PHEV purchases, drivers have little financial reason to charge their vehicles. Should this behaviour continue then the difference in real world and type-approval utility factor will result in significant growth in the real world emissions gap under a high PHEV uptake scenario.

Figure 44 shows the impact on the emissions reduction in the 2005-30 period with increasing PHEV market share under two scenarios with differing percentage of driving in electric mode. Under the baseline scenario, the real world utility factor is calculated from the utility factor function (Figure 4) and the real world electric range. In the alternative scenario, the utility factor is half that in the baseline (~35%), aligning it with what has been observed in the Netherlands. In both cases, the mandate and CO<sub>2</sub> targets are complied with, yet it can be seen that real world charging behaviour has a significant consequence on meeting the -30% climate goal.

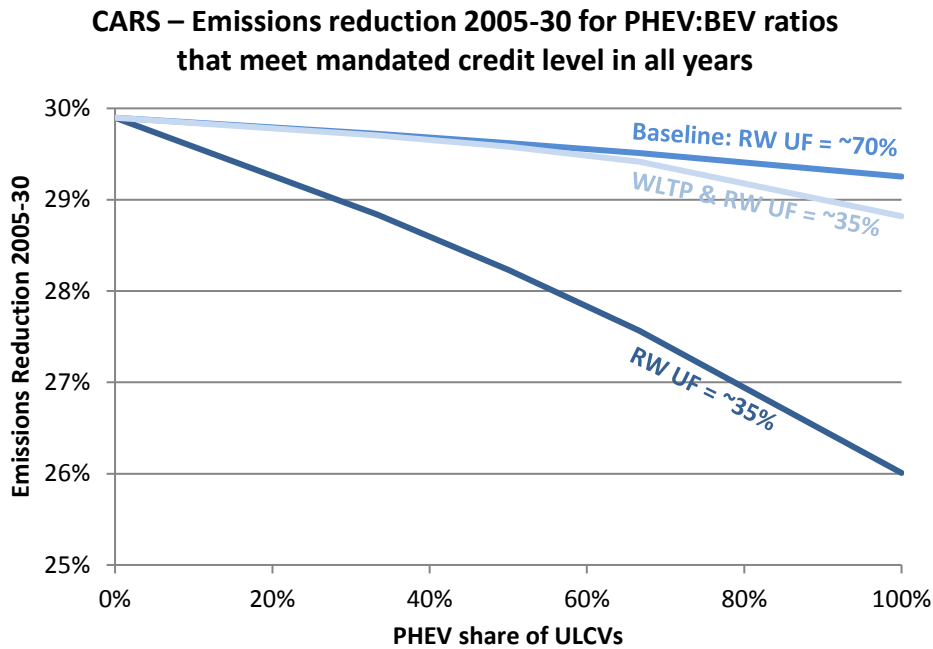


**Figure 44: Emissions reduction 2005-30 for different PHEV utility factors, where mandate and CO<sub>2</sub> targets always met. Baseline: utility factor calculated from real world electric range; Alternative: baseline utility factor multiplied by 0.5.**

A solution to this issue is to base the utility factor for type-approval emissions against the real world proportion of driving under electric power. Figure 45 repeats the analysis presented in Figure 44, but with the same utility factor of ~35% used in the calculation of both WLTP and real world (RW) emissions. This closes the real world emissions gap for

<sup>21</sup> TNO (2015) Monitoring plug-in hybrid vehicles (PHEVs) in April 2012 - March 2015

PHEVs, thus improving the outlook for emissions reduction 2005-30 with high PHEV uptake. The reason for emissions reduction continuing to lie below the baseline is that the lower utility factor increases the contribution of the discrepancy between WLTP and real world fuel consumption, which in turn widens the real world emissions gap slightly.



**Figure 45: Impact of modifying the utility factor for PHEVs in the real world and WLTP type-approval process**

This solution highlights the importance of assigning a realistic utility factor when defining the type-approval emissions. As PHEV uptake grows, the proportion of driving under electric power has the potential to add a significant portion to the overall emissions gap. It is critical that this is sufficiently represented in the utility factor calculation in the WLTP.

## 9 Electric Quadricycles

Small four-wheeled micro-cars, known as quadricycles, have the potential to electrify a portion of total vehicle kilometres travelled, particularly in urban areas. The EU regulates such vehicles as category L, alongside mopeds, motorcycles and motor tricycles. Quadricycles are differentiated from passenger cars through limits to their weight, power and top speed.<sup>22</sup> The most popular electric example of this type of vehicle is the Renault Twizy, with more than 16,500 sales in Europe since its release in 2012<sup>23</sup>.

The California ZEV Mandate also includes provision for small electric quadricycles, denoted “Neighbourhood Electric Vehicles”. Since 2012, credits earned from these vehicles cannot be used to fulfil the ZEV credit requirement, but can contribute to the PZEV credit mandate. From 2018, NEVs will be worth 0.15 credits, reduced from 0.3 credits currently, subject to speed and range requirements. Given that from 2018, ZEVs can earn up to 4 credits per vehicle, NEVs are clearly not considered to deliver significant emissions reductions compared with normal cars.

However, as population density in urban areas is typically higher in Europe than in the US, and annual mileage is generally lower, electric quadricycles may have a greater capacity to replace vehicle kilometres currently driven by passenger cars in Europe. However, due to their speed and power restrictions, electric quadricycles clearly do not have the capability to replace all car passenger kilometres. Therefore, a credit valuation against vehicle emissions, as for PHEVs, is not appropriate as it would overvalue their contribution to decarbonisation. Instead, it is proposed that they should be valued against the number of passenger kilometres they could realistically replace relative to a car, and the associated reduction in CO<sub>2</sub> emissions.

Should a driver purchase an electric quadricycle then it is unlikely that it will be enough to satisfy all their driving needs. Consequently, they may require an additional car, either rented or owned, for the remainder (they could also use public transport but modal shift is not considered here). This arrangement can be treated in a similar fashion to PHEVs, but rather than considering proportion of driving in fuel and electric modes, the proportion of driving in the quadricycle and car should be estimated. Similarly, this can be related to vehicle range, however, unlike PHEVs, it is assumed that due to their speed and range restrictions electric quadricycles are unsuitable for highway and motorway driving.

To estimate the potential to replace car passenger kilometres, the range of an archetypal electric quadricycle was maintained at the 100 km level (NEDC) of the current Renault Twizy for the period 2015-30. Although mass is restricted to 450kg, this does not include the battery and so there is in fact no mass limitation on vehicle range. In theory, therefore, they could accommodate a larger battery, space and chassis strength permitting. However, a major selling point of these vehicles is their comparatively low cost to cars so it is likely that OEMs will take advantage of advances in battery technology by lowering the weight and price rather than increasing the range.

Renault does not publish an official figure for the electricity consumption. However, range is tested on the NEDC urban driving cycle. It is assumed, therefore, that the gap between type approval and actual range is the same as for plug-in electric cars. For an A-segment car,

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<sup>22</sup> Regulation (EU) No 168/2013 Of The European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles

<sup>23</sup> Sales data provided by left-lane.com, <http://left-lane.com/european-car-sales-data/renault> [Accessed 08/07/2016]

the Cost and Performance Model estimates the NEDC range is 25% higher than real world range in 2015, decreasing very slightly to 22% in 2030. The real world range of electric quadricycles is therefore assumed to remain constant at 80 km. BEV drivers rarely discharge their battery fully and nearly always leave a “safety margin” of charge. This is assumed to be 20%,<sup>24</sup> resulting in average useable range of an electric quadricycle being 64 km. If a “round trip” is considered to consist of an outbound and return trip of equal length then this range is suitable for carrying out individual trips of up to 32 km.

Based on the capabilities of this generic quadricycle, a suitable value for the CO<sub>2</sub> credit value for each vehicle (relative to a full size EV) can be estimated as follows:

**Proportion of trips and distance addressable by quadricycle** - Trip statistics from the UK National Travel Survey revealed that trips of less than 32 km accounted for 53% of total kilometres driven. Trip statistics for the overall EU are not available at the same level of detail but evidence suggests that average trip distances in the UK are similar across the other Member States.<sup>25</sup> Under this approach, electric quadricycles could be rewarded for the full 53% they could decarbonise, thus receiving a credit value of 0.53 per vehicle.

**Annual driving distance** - Aggregating mileage data from Twizy owners, submitted to Spritmonitor.de, shows an average annual mileage of 9,100 km. Over the period 2012-2015, average annual mileage in the EU is estimated from the EU Stock Model to be 13,500 km. The average occupancy ratio of cars in Europe is 1.62, according to the TRACCS database, and since the Twizy has two seats this is unlikely to constrain usage significantly and the two mileages are directly comparable. This suggests the Twizy can instead replace 67% of average car mileage, and 0.67 credits would be fairer. However, the Spritmonitor.de data is likely bias towards early adopters whose driving patterns may be well suited to short range quadricycles, and so overstates their likely usage among mass-market drivers.

**Accounting for motorway trips not accessible for quadricycles** - It is important to note that both approaches fail to take into account that the decarbonisation effect of quadricycles is confined to distance travelled on low speed roads (i.e. not trunk roads or motorways) due to their limited maximum speed. This lack of suitability for a proportion of driving types should be reflected in the credit valuation. From the UK’s National Travel Survey, non-highway and non-motorway driving accounts for 66% of total mileage.<sup>26</sup> This provides an appropriate scaling factor to apply to the credit values above, resulting credit values per vehicle of 0.35 (based on trip distance) to 0.45 (based on annual driving distance). This is higher than in the California ZEV Mandate, which values NEVs at about 10% that of a standard BEV, however NEVs have a more limited top speed.

**Table 2: Suggested credit valuation range for electric quadricycles**

<b>Low</b>	Based on trip statistics and range	0.53
<b>High</b>	Based on average Twizy mileage	0.67
<b>Corrected</b>	Accounts for unsuitability for highway driving	<b>0.35 - 0.45</b>

<sup>24</sup> My Electric Avenue charging study recorded steep drop off in frequency of charging events with an initial state of charge less than ~20%. MEA (2015) Work Activity 3 “Model Validation and Data Analysis” – Report for Deliverables 3.1, 3.2, 3.3. and 3.4

<sup>25</sup> JRC (2012) Driving and parking patterns of European car drivers - a mobility survey

<sup>26</sup> UK Department for Transport Road Traffic Estimates: Great Britain 2014

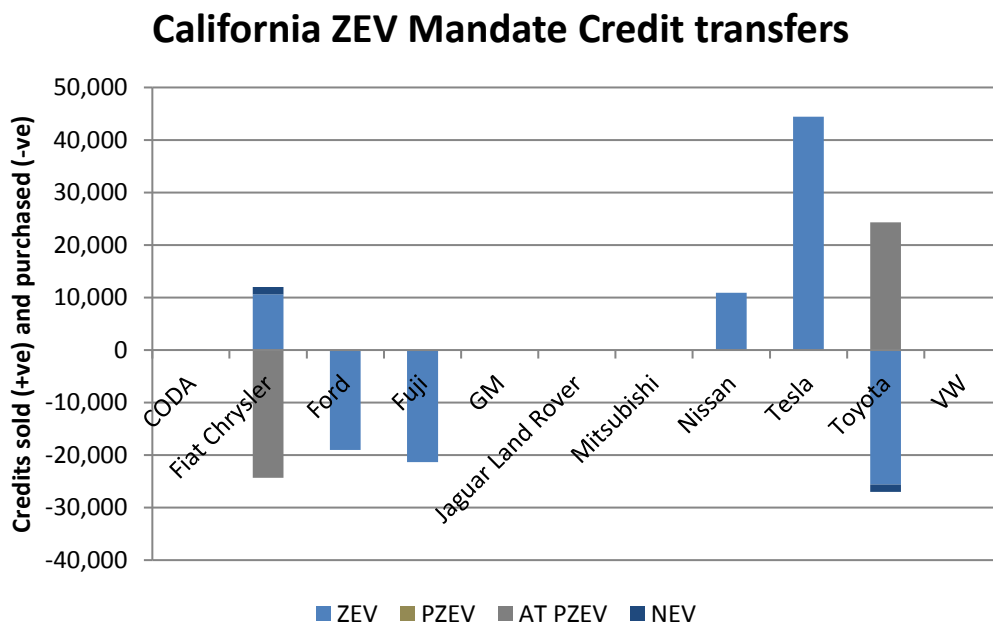
While the approach above can be used to understand the theoretical capabilities of quadricycles relative to full size BEVs, the real-world CO<sub>2</sub> savings will depend strongly on which transport mode the quadricycle is displacing. If they directly substitute the journeys that would have been made by a full size car, then crediting them generously in a mandate is justified given that they are displacing petrol/diesel cars, with additional benefits for congestion, use of road space etc. However, if they are instead displacing scooters, motorbikes or public transport and represent a modal shift towards cars, then this should be reflected in a lower credit value. Further work is required, for example in the form of surveys to understand usage patterns and modal shifts in quadricycle owners, to further refine an appropriate credit value. As a safety mechanism against low cost quadricycles being produced as compliance products instead of full size EVs, it is suggested that a limit should be defined on the maximum contribution that quadricycles could make to meeting the mandate.



## 10 Mandate Credit Trading & Banking

### 10.1 Credit Trading

Trading of California ZEV Mandate credits has allowed OEMs that accumulate surplus credits to generate additional revenue by selling them to OEMs with a credit deficit. This additional revenue can be used to support R&D efforts towards ULCV technology, and is essentially funded by OEMs that choose not to develop such vehicles. This is a key feature of the policy as it has no net cost to the taxpayer and allows the mechanism to be designed with the entire market treated as a single entity. This ensures the policy achieves its primary aim of reducing vehicle emissions without directly penalising a single OEM, as all OEMs have the option to comply through increasing supply of mandated vehicles or purchasing credits. If the market as a whole does not meet the mandate then there is a net penalty due from the OEMs to compensate, but this will be paid by the OEMs that fail to accumulate enough credits.



**Figure 46: California ZEV Mandate Credit transfers for each OEM between October 31<sup>st</sup> 2014 and September 30<sup>th</sup> 2015.<sup>27</sup> Purchase of credits shown as negative credit transfer. Converted from g/mi NMOG to ZEV credit units (through dividing by 0.035)**

In Europe, the allowance for OEMs to form pools over which average vehicle emissions are measured to test compliance with the CO<sub>2</sub> target has a similar effect to credit trading scheme. Decarbonising the collective market is all that the regulation is concerned with, and an additional mandate mechanism should maintain this.

For a fixed mandate, the penalty for non-compliance is a fine linked to the credit deficit. If no credit trading was permitted, then OEMs that choose not to develop ULCVs could still comply by forming a pool with OEMs that do. In this sense, the current system employed in the CO<sub>2</sub> target regulation still holds. However, the addition of a further regulatory target makes optimizing the composition of these pools more difficult for OEMs. Although a pool may comply with the CO<sub>2</sub> target, it may not necessarily generate enough ULCV credits. This

<sup>27</sup> <http://www.arb.ca.gov/msprog/zevprog/zevcredits/2014zevcredits.htm> [Accessed: 12/07/2016]

creates inefficiency in the mechanism as it undermines the approximation of the market as a single entity i.e. while the market as a whole may generate enough credits, some penalties will still have to be paid by non-compliant OEM pools.

Consequently, in the case of a ULCV mandate, a credit trading system is likely to be a more suitable mechanism. If the mandate level is designed in conjunction with the CO<sub>2</sub> target, in the case of a combined target/mandate mechanism (see Section 7), a question exists over whether the trading of a credit should also result in the transfer of that vehicle for the purposes of calculating the average CO<sub>2</sub> emissions. Without this, the benefit of selling ULCVs is leveraged in a similar fashion to the Flexible Mandate: An OEM that generates surplus credits can earn revenue by selling them, as well as benefitting from the reduction in their average emissions. Meanwhile, a non-compliant OEM must both purchase credits and improve their vehicle efficiency. If improving the conventional vehicle is cheaper, this system compensates the OEMs that must spend more in the short term on ULCV development.

This may be seen as providing too much advantage to compliant OEMs; however, an additional problem with transferring the vehicle emissions level along with the credit value is that it may trap credits in some OEMs' accounts. For example, an OEM that meets a 75 gCO<sub>2</sub>/km target and 10% ULCV mandate with 30,000 BEVs and 70,000 100 gCO<sub>2</sub>/km ICEs, would generate 20,000 surplus credits and have average emissions of 70 gCO<sub>2</sub>/km. These credits may be required by an OEM that sells no ULCVs but ICEs and HEVs with fleet average emissions of 75 gCO<sub>2</sub>/km. If the second OEM purchases all the surplus credits to comply with the mandate, and the BEV emissions ratings are transferred as well, the average emissions of the first OEM will rise to 87.5 gCO<sub>2</sub>/km, and so they will not sell. This is a result of credits being valued at their emissions reduction potential relative to the average emissions of all conventional vehicles ( $\bar{E}_{ICE}$ ), not just from that particular OEM. If the emissions of conventional vehicles differ between two OEMs, transfer of a vehicle's credits along with its emissions rating will change the average emissions of the OEMs by different amounts. If this results in the average emissions of the 'seller' rising above the target, then the trade will not take place. Therefore, even if the market sells enough ULCVs to meet the mandate as a whole, trapped credits may result in more ULCVs having to be sold than mandated and/or some OEMs having to pay a fine. For this reason, the credit trading system and CO<sub>2</sub> target compliance should be kept separate, although whether the credit accounts of each OEM within an OEM pool should also be combined is immaterial in this respect.

A similar mechanism exists in US, with the California ZEV Mandate operated separately to the federal Corporate Average Fuel Economy (CAFE) standards, which sets a fleet average target for each OEM based on miles per gallon. This is an analogue to the EU's CO<sub>2</sub> standards, but is governed using a credit system. OEMs are awarded credits if their average new vehicle fleet exceeds the target, the number received calculated as the delta to the target multiplied by the number of vehicles sold and the average vehicle lifetime expected.<sup>28</sup> Conversely, OEMs that miss the target are debited credits in a similar manner. A credit trading scheme allows OEMs with a credit debt to purchase banked or surplus credits from another OEM. When credits are transferred between OEMs, their value undergoes a conversion process to take into account different lifetime mileages, average fuel economy, fuel economy targets and model years between the two manufactures. This is essentially a more sophisticated system than the OEM pooling permitted under the EU CO<sub>2</sub> standards that allows all OEMs together to be treated as a single entity. Crucially, the transfer of CAFÉ

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<sup>28</sup> Schoettle and Sivak (2014) An overview of CAFE credits and incorporation of the benefits of on-board carbon capture

credits does not require the transfer of accompanying ZEV Mandate credits. This is equivalent to not including the emissions ratings for compliance with the CO<sub>2</sub> target when transferring ULCV mandate credits.

## 10.2 Credit Banking

Banking of credits enables surplus credits to be used towards compliance with the mandate in future years. The risk is that a year of overall credit surplus in the market will allow for credit debt in subsequent years i.e. more ULCVs than required one year may mean fewer than mandated in the following years. Since the CO<sub>2</sub> target will still have to be met, the impact on meeting emissions reduction goals will be minimal. But, allowing fewer ULCVs than the mandate in a particular year will require OEMs to improve the efficiency of their conventional vehicles to meet the CO<sub>2</sub> target, and this is undesirable. The impact of this is likely temporary: If the market accumulates surplus credits one year, then fewer ULCVs than the mandate can be sold in the following years, until eventually the banked credits run out and the market must return to achieving the mandate. If the market continues to exceed the mandate, then this will render the mandate redundant as the shift to ultra-low carbon transportation will have occurred even faster than required. The danger is that if the mandate remains in place long term then the large number of banked credits could permit a shift back towards efficient conventional ICEs without contravening the mandate policy. This is unlikely given OEMs will have shifted their focus to ULCV technology development and emission standards would probably prohibit widespread ICE use. However, to combat this risk, credits should be set to expire after a fixed time limit.

The conversion process employed in the US CAFE regulation highlights an additional dynamic for any allowance to bank surplus ULCV mandate credits. Under the credit valuation scheme suggested in this study, valuing a credit against its emissions relative to conventional vehicles means its credit value should decrease year on year as conventional vehicles become more efficient. If credits are allowed to be banked then there is an argument that they should be continually revalued against that year's  $\bar{E}_{ICE}$ . However, the effect of this discrepancy in valuation is in fact quite small. For example, if the mandate is exceeded in 2025 by 5.0 percentage points this will generate 880,000 surplus credits. This could allow 880,000 fewer credits to be generated in a later year, such as 2030. However, because sales are expected to increase between 2025 and 2030, this will allow the mandate to be missed by just 4.8 percentage points. If the credits are re-evaluated to the 2030  $\bar{E}_{ICE}$  then this decreases only a small amount to 4.6 percentage points, equivalent to ~60,000 more PHEVs (compared with overall sales in the EU of 18.4m cars).

## 10.3 Implications for a Flexible Mandate

Under the Flexible and Upside-only Flexible Mandate schemes, there is no direct financial penalty to missing the mandate, only an adjustment in the CO<sub>2</sub> target. Trapped credits are therefore less of an issue, but could still result in OEMs being unduly punished with a lower target if they cannot access surplus credits. Ultimately, this could have the same financial implications as in the fixed mandate, but fines are levied due to missing the CO<sub>2</sub> target rather than the mandate. Furthermore, design of the mandate levels still relies on the market approximating to a single entity and so a similar credit trading scheme is recommended. However, as these systems rely on adjusting the Specific CO<sub>2</sub> Targets, credit accounts would have to be held at the OEM pool level rather than for individual OEMs. Credit banking should also be made available as it will provide OEMs with an element of control over their Specific CO<sub>2</sub> Target, however, the mechanism will not allow them to relax it beyond the "Necessary Target", and thus will not compromise meeting the Climate Goal.

## 11 Conclusions

This study has assessed the potential for various policy mechanisms to achieve the ultimate aim of reducing light duty transport emissions by 30% between 2005 and 2030 through improving vehicle efficiency or shifting to ultra-low or zero emission powertrains. It has incorporated the latest evidence on likely changes in vehicle efficiency for a wide range of powertrains, growth in the car and van stock, and consumer attitudes towards conventional vehicle technology, such as internal combustion engine and hybrid vehicles. Effort has been made to ensure that the assumptions made are aligned with the latest evidence from automotive experts, as well as the latest cost curves used by the European Commission, since these are likely to form the basis of setting post-2020 light vehicle policy. The major findings of this study are set out below.

**2025 CO<sub>2</sub> standards to meet climate goals exclusively through regulation: 75g CO<sub>2</sub>/km for cars and 82g CO<sub>2</sub>/km for vans**

For both cars and vans, CO<sub>2</sub> target levels have been identified which encourage a smooth downward trend in both car and van emissions and result in stock emissions falling to 30% below their 2005 level in 2030 i.e. in line with non-ETS goals. If car and van stocks are treated separately then average new cars are required to have WLTP type-approval emissions of 75 gCO<sub>2</sub>/km in 2025 and 50 gCO<sub>2</sub>/km in 2030 (assuming a degree of re-optimisation of test cycle flexibilities between 2020 and 2025). This represents a 65% decrease in real world emissions between 2015 and 2030. The corresponding van targets are 82 gCO<sub>2</sub>/km in 2025 and 33 gCO<sub>2</sub>/km in 2030, which imposes an 80% reduction in new van emissions between 2015 and 2030. The deep reductions in new van emissions reflect the anticipated growth in the EU van fleet, which require lower emissions per vehicle to meet the overall -30% Climate Goal.

The policies assessed in this work have treated cars and vans entirely separately. In order to relieve the heavier burden on individual vans to decarbonise, tighter target levels could be introduced for cars. Vans are estimated to currently make up only 17% of light duty vehicle emissions, and so a small change in car targets results in a disproportionate change in the required van target to still meet the -30% Climate Goal. It has been shown that every 1 gCO<sub>2</sub>/km tightening of the 2030 car target permits a ~6 gCO<sub>2</sub>/km rise in the 2030 van target.

The proportion of driving carried out under electric power by PHEVs has also been shown to be a potential area of uncertainty for policy design. This adds an additional and significant factor to the real world emissions gap. Consequently, it is critical that this be realistically assessed and included in the WLTP type-approval process.

**Market shares of ultra-low carbon vehicles required from 2021 (vans) and 2022 (cars)**

Conventional ICEs and full hybrids will at some point be unable to meet increasingly stringent CO<sub>2</sub> standards, and ultra-low carbon technology will be essential. This can be quantified as the “ZEV Gap”, the market share of zero-emission vehicles needed to meet a CO<sub>2</sub> target based on the average emissions of conventional vehicles. Under the baseline target scenario, where the emissions of vehicles are forecast to improve based on a natural technology deployment cycle and with expected growth in full hybrid sales, this requirement for ultra-low carbon vehicles to meet emissions targets begins in 2022 and grows to 10% in 2025 and 32% in 2030. This is not unrealistic given some of the electrification targets announced by OEMs. The Volkswagen Group, for example is aiming for 25% of its cars sold to be electric by 2025, while Volvo have a target of one million plug-in cars sold by 2025. Assuming Volvo continues to sell approximately 500,000 cars per year, this equates to 20%

of their sales between 2015 and 2025. For vans, the ZEV Gap would appear immediately after 2020 and grow to 30% in 2025 and 68% in 2030, as the required decarbonisation is considerably stronger. As well as ZEVs, non-zero emission ULCVs, such as PHEVs, can be used to bridge this gap but a higher market share is required.

### Policy options to encourage ZEV uptake

The required number of ULCVs in the new vehicle fleet is likely to need additional policy instruments, to ensure that this is achieved with deployment of ULCVs rather than accelerating the improvement of conventional combustion technology. This will avoid investment being spent on developing incremental technology which will eventually become incapable of delivering long-term decarbonisation goals. A number of possible mechanisms have been assessed to bring about this objective:

- The existing system of Super-credits is intended to encourage the supply of vehicles with emissions less than 50 gCO<sub>2</sub>/km. This has arguably directed more focus towards their development; however, super-credits come with the disadvantage of allowing average emissions to be greater than the target level. As ULCVs are yet to make significant market share the impact remains low, but our analysis shows that when low CO<sub>2</sub> targets begin to require ULCVs to be sold, a super-credit scheme both permits lower ULCV uptake and higher average emissions than needed to meet climate goals. Extending the existing 2020-22 super-credits scheme to 2030 would reduce the required market share of ZEVs by 5 percentage points and increase overall annual emissions for cars by 2%, equivalent to an additional 31 Mt of CO<sub>2</sub> between 2020 and 2030. This compromises both the -30% climate goal and ULCV development for long term decarbonisation beyond 2030.
- A ULCV mandate would provide a stronger guarantee of ULCV uptake compared with super-credits. However, on its own a mandate would be unable to ensure the required decarbonisation pathway as it sets no limits on the emissions of non-mandated vehicles. Instead, it is recommended that a ULCV mandate is designed in conjunction with a CO<sub>2</sub> target and ZEV Gap (the ZEV market share required to meet a CO<sub>2</sub> target) in order to control the emissions of conventional vehicles as well. This achieves both the aim of reducing overall emissions and discouraging excessive focus on conventional vehicle technology. To meet a -30% emissions reduction, the 2025 mandate level needs to lie at approximately 10% i.e. if CO<sub>2</sub> targets were set at 82g for ICE/HEV, 10% ZEVs would be required in 2025 to bridge the gap to a CO<sub>2</sub> target of 75 gCO<sub>2</sub>/km.
- A Flexible Mandate can be used as an additional incentive to comply with the regulation, whereby an OEM's CO<sub>2</sub> target is adjusted in relation to their performance against a ULCV mandate. This leverages the benefit of exceeding the mandate with regards to meeting the CO<sub>2</sub> target and vice versa. However, should the market as a whole perform better than the mandate requires, this has the potential to increase emissions. The benefit of having higher than expected ULCV uptake therefore comes at the expense of higher CO<sub>2</sub> emissions, and may undermine the reason for the policy. For example, consistently exceeding the mandate by 5 percentage points, with a target adjustment of 2 gCO<sub>2</sub>/km per percentage point difference, would result in emissions reduction between 2005 and 2030 of only 25.9%.
- An alternative mechanism has been proposed which attempts to capture only the upside of the Flexible Mandate. OEMs are encouraged to meet the mandate with the opportunity to have their CO<sub>2</sub> target increased, but exceeding it does not compromise the -30% Climate Goal. It was shown that for ZEVs, the system compensates society when the mandate level is missed with greater emissions reduction 2005-30, and effectively limits the 2005-30 emissions reduction at no less than 30% when the

mandate is exceeded. However, the Upside-only Flexible Mandate requires a lower CO<sub>2</sub> target than necessary to be issued.

- In order to incorporate non-zero emissions ULCVs into the mandate, a credit valuation system is proposed. This evaluates each mandated vehicle against their emissions reduction potential, for which they receive a certain credit value. For example, a PHEV with type-approval emissions of 40% of the average emissions of conventional ICEs and HEVs would receive 0.6 credits, compared with 1 credit for a ZEV. OEMs are mandated to achieve a certain number of credits. This allows PHEVs to contribute to closing the ZEV gap, but their higher emissions mean that a higher market share is needed. Valuing vehicles against their emissions discourages OEMs from making “compliance” vehicles that only meet the minimum mandated specification. However, the real world emissions for PHEVs are largely dependent on the proportion of driving carried out on electric power, and so although they may meet a type-approval standard, they have the potential to open up the real world emissions gap if driven less on electric power. Meeting the mandate with a higher number of PHEVs may invalidate the assumed gap upon which the WLTP target were set in order to meet the -30% Climate Goal.

#### **Additional mandate features**

- The setting of CO<sub>2</sub> target and mandate levels in this study relies on the market being treated as a single entity. Decarbonisation is required by the entire automotive industry, and so the regulation should not look to unduly penalise certain OEMs. The current CO<sub>2</sub> standards achieve this by allowing OEMs to form pools over which their average emissions are calculated. This can be achieved in a ULCV mandate system by allowing the trading of credits between OEMs or OEM pools. However, it is recommended that the mandate credits and average emissions be accounted for separately. Otherwise an OEM that meets the CO<sub>2</sub> target with a combination of ZEVs and high emission vehicles would be unable to sell all their surplus credits as it may result in their average emissions rising above the target. This would trap the credits in the OEM's account, thus rendering the policy less effective.
- A credit value for electric quadricycles has been proposed so they can be incorporated into the regulation creating an incentive to bring these vehicles to market and secure wider benefits such as decreased congestion and better use of road space. Based on the capability to electrify the mileage of cars on an individual basis, a credit value of 0.53-0.67 would be appropriate. However, care should be taken to not overly reward them as their limited range and speed means they are not able to fully decarbonise light duty transport. Applying an urban mileage penalty of 0.66, which accounts for their unsuitability for highway and motorway driving, arrives at a credit value of 0.35-0.45. Further work is required, however, to understand usage patterns and modal shifts in quadricycle owners, to better reflect the decarbonisation potential. To manage the risk of low cost quadricycles being produced as compliance products, it is suggested that a limit should be defined on the maximum contribution that quadricycles could make to meeting the mandate.

## 12 Appendix

### 12.1 Cost and Performance Model

This section outlines the assumptions and methodology employed in the development of the Car and Van Cost and Performance Models, which are used to forecast future emissions of the powertrains and segments covered in the study.

#### 12.1.1 Conventional Petrol and Diesel ICEs

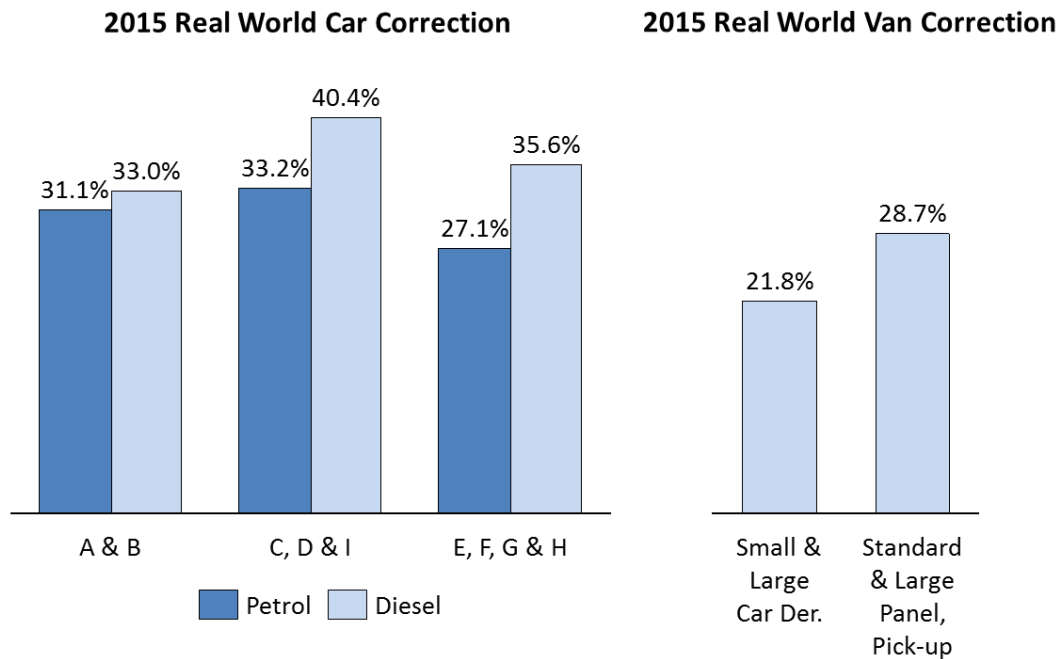
The model uses a representation of 'average' 2015 petrol and diesel ICEs within each segment, denoted 2015 ICE Archetypes. These vehicles were characterised by taking a sales-weighted average of a range of attributes for the top five best-selling models in each segment and fuel type. The performance attributes are all considered on an NEDC type-approval basis. Improvements to the emissions of these vehicles are forecasted by considering changes to their deployed efficiency technology. The Ricardo-AEA 2015 Cost Curve study<sup>9</sup>, which forms the basis of the EU Commission's own cost curves, features the deployment schedule and efficiency gain for 45 separate technologies over the period 2015 to 2030. The same multiplicative method is used to calculate the combined effect of deployed technology, and CO<sub>2</sub> emissions are forecast by applying the change to the overall vehicle efficiency over time.

As well as proving efficiency gains in terms of the NEDC, Ricardo-AEA's Cost Curves study also includes the impact of each technology on the WLTC and a real world (RW) driving cycle. This allows for changes in vehicle performance to be forecast in terms of these additional cycles. However, this requires the 2015 ICE Archetypes to be expressed in terms of the WLTC (the cycle used in the WLTP) and real world driving to be used as a starting point, which described below.

#### 12.1.2 Conversion to WLTP and Real World Driving

In 2015, Element Energy and ICCT undertook a study to investigate the size of the gap between NEDC type-approval and real world emissions.<sup>11</sup> A comparison of reported real world fuel consumption figures revealed a 35% increase over a NEDC type-approval for cars and 26% for vans. The reasons for this gap can be grouped into two factors: the poor representation of the NEDC for real world driving, and the increased exploitation of flexibilities in the test procedure (such as test temperature) to maximise performance in the laboratory test. Further exploitation of flexibilities will reduce type-approval emissions, but real world emissions will remain unaffected.

The current size of the emissions gap can be used to convert the NEDC fuel consumption of the 2015 ICE Archetypes to reflect real world conditions. The conversion factors used are presented in Figure 47. Future real world performance is forecast from the real world figures in 2015 by factoring in changes in the efficiency technologies expressed in terms of the real world driving cycle from the Ricardo-AEA Cost Curve study.



**Figure 47: 2014 NEDC to real world emissions gap, used to convert 2015 ICE Archetypes to real world**

Similarly, the 2015 ICE Archetypes can be converted to WLTP type-approval values using average conversion factors from ADAC EcoTest laboratory results.<sup>10</sup> This includes results from 378 cars tested since October 2011 on both the NEDC and WLTC, and provides data for both petrol and diesel cars. However, it is expected that many of the flexibilities currently allowed will be tightened in the move to WLTP type-approval, and this must be accounted for when converting from NEDC. The study by Element Energy and ICCT concluded that for cars in 2014, test cycle flexibilities contributed on average 24 percentage points of the 35% gap from NEDC to real world energy consumption. It is proposed that when transitioning to WLTP this will fall to just 8%. For vans, the use of flexibilities is less severe and is estimated to currently contribute 20 percentage points, which also falls to 8 percentage points under the WLTP.

It is assumed that no changes in employed flexibilities occur in the WLTP until 2020, after which the gap due to flexibilities opens up again from 8 percentage points in 2020 to 17 percentage points in 2025 due to manufacturer optimisation of the new test procedure. No additional optimisation is assumed post-2025, as Real Driving Emission testing is introduced.

### 12.1.3 Hybrids and Plug-in Vehicles

The fuel consumption of full hybrid and plug-in electric vehicles is based on the fuel consumption of the equivalent petrol and diesel ICE, and takes into account the fuel saving benefits of regenerative braking, stop-start systems and a slightly higher efficiency of an optimised internal combustion engine. Hybrids also benefit from the efficiency gain of non-powertrain technologies applied to the 2015 ICE Archetypes, for example mass reduction, improved aerodynamics etc.

For PHEVs, it is necessary to factor in the proportion of driving under electric power in order to give an overall fuel consumption figure. This is discussed in Section 3.1.1.



## 12.2 The ECCo Model

The EU CO<sub>2</sub> target is concerned with average new car emissions levels across all powertrains and segments, and so knowing the predicted emissions of each individual powertrain is not enough to test future compliance with hypothetical target scenarios. In addition, a realistic view of the market share of each powertrain in the period 2015-30 is also required. For the investigation of potential ULCV mandates in this study, a realistic baseline scenario for the relative market penetration of HEVs versus ICEs, and petrol versus diesel within each segment was devised.

Element Energy’s Electric Car Consumer (ECCo) tool uses a consumer-centric approach to calculate the market shares of the different powertrains based on policy inputs, vehicle attributes, consumer purchase attitudes, refuelling/recharging availability and economic and grid inputs. At its core is a rational consumer choice model, populated with behaviour coefficients taken from an extensive consumer survey of attitudes to plug-in vehicles. Although designed for the UK car and van markets, ECCo was used to model the changes in petrol/diesel share, and uptake of full hybrids within each segment. These parameters were then mapped to the current composition of the European vehicle market which provides a baseline projection for the relative market shares of conventional powertrains in the period 2015-30. It is assumed in the baseline that segment shares remain at 2015 levels i.e. that there is no systematic trend toward bigger or smaller cars.

## 12.3 EU Stock Model

The EU Stock Model developed for this study provides a tool to estimate the average emissions of the car and van stock up to 2030, based on the average emissions for new vehicles in each of the preceding years.

The TRACCS database provides stock, sales and mileage data by vehicle age for the period 2005-2010. This was used as a starting point to define a historical scrappage rule described by the equation:<sup>29</sup>

$$P(t) = \exp\left(-\left[\frac{t+b}{T}\right]^b\right); \quad P(0) = 1$$

$$T = \frac{t_{0.5} + b}{\ln(2)^{\frac{1}{b}}}$$

$P(t)$  is the probability that a vehicle will survive  $t$  years after its registration. The parameters  $b$  and  $t_{0.5}$  for both cars and vans were estimated through a regression analysis using a least squares approach against the TRACCS data. The model was calibrated against sales and stock data for the period 2011-2015 provided by multiple data sources,<sup>30</sup> but corrected to ensure a smooth trend from the TRACCS data. The resulting function models a gradual increase in the probability of being scrapped with age, with the average vehicle being scrapped at 16 years.

<sup>29</sup> Form of the scrappage rule is that used in the REMOVE model. Thessaloniki (2008) European Database of Vehicle Stock for the Calculation and Forecast of Pollutant and Greenhouse Gases Emissions with REMOVE and COPERT

<sup>30</sup> Car stock data 2011-14 from Eurostat, van stock data 2011-2014 from Anfac: European Motor Vehicle Parc 2014, car sales data 2011-15 from ACEA, van sales data 2011-14 from ICCT Pocketbook 2014

It was noted that the average age of cars has increased in Europe from 8.6 years in 2009 to 9.7 years in 2015,<sup>31</sup> despite the fact there has been long term growth in the new vehicle sales market. In part this was due to a contraction of sales after Europe entered recession in the late-2000s. However, it is also a result of the increasing technical life of vehicles due to improved build quality and better maintenance. To account for this, a correction factor was applied to the scrappage rule from 2010 which decreases over time. For cars, the decline is gradual and is stopped in 2015 to avoid an accumulation of unrealistically old cars in the 2020s. Although it is possible that cars will continue to get older, it is proposed that the economic downturn in Europe demonstrated the additional technical life that was possible with existing cars, and the market has now settled at a new normal. For vans, the slowdown in scrappage occurs more suddenly in 2009, and the correction factor is held constant from this point onwards. The result is a car and van stock model that closely matches historic stock and sales figures.

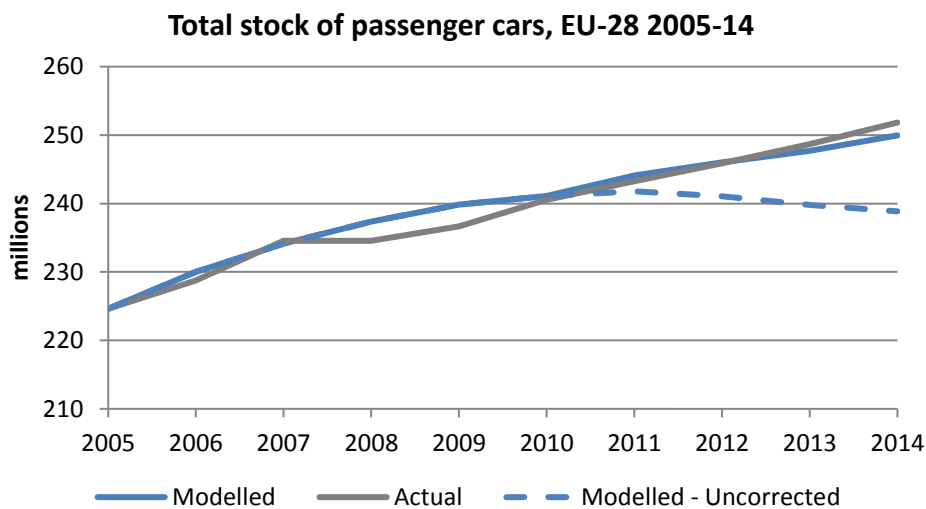


Figure 48: Comparison of actual EU-28 car stock with modelled (both corrected for increasing vehicle age and uncorrected)

Future stock and total vehicle kilometres travelled were estimated using the forecasted % increases from the TREMOVE model.

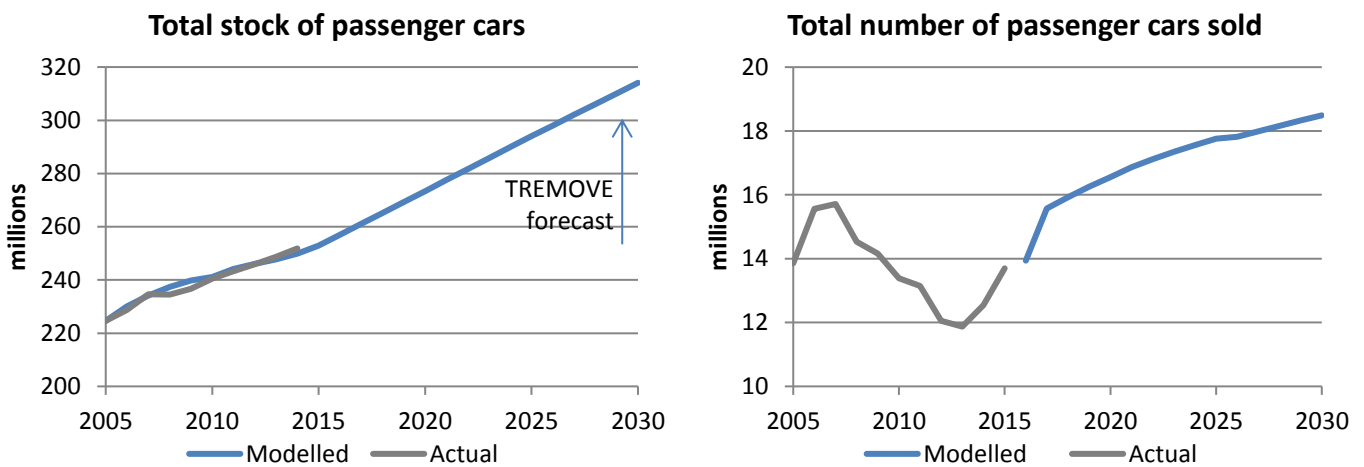


Figure 49: Forecasted car sales and stock from the EU Stock Model

<sup>31</sup> ACEA Pocket Guide 2015-16

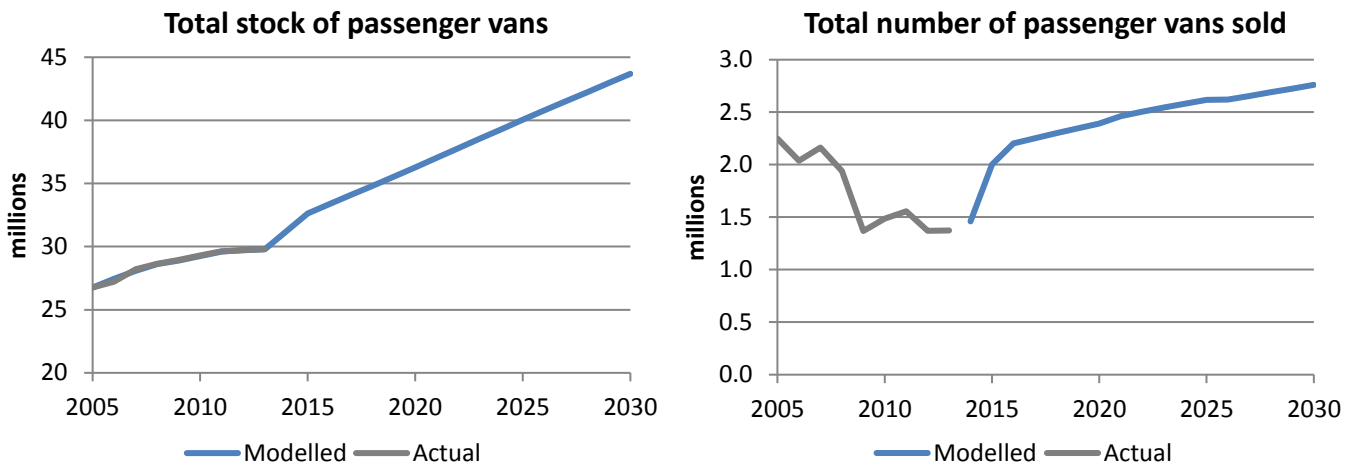


Figure 50: Forecasted van sales and stock from the EU Stock Model

Both car and van models also incorporate a relationship between vehicle age and annual mileage, to account for the fact that older cars tend to be driven less. These relationships were derived from analysis of the TRACCS database. This allows for the contribution of each vehicle vintage to overall emissions to be more accurately represented.