Assessing the impacts of selected options for regulating CO2 emissions from new passenger cars and vans after 2020

Final Report for the European Commission, DG Climate Action

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Note: From 1 September 2015, we rebranded as Ricardo Energy & Environment, a trading name of Ricardo-AEA Ltd. The legal entity of Ricardo-AEA Ltd remains unchanged and all formal company information presented in this proposal, including previous years' financial accounts, are all in the name of Ricardo-AEA Ltd.

In November 2012, Ricardo plc acquired the assets and goodwill of AEA Technology plc and formed a new company, Ricardo-AEA Ltd. The entire capability and resources previously represented by AEA Technology plc were transferred to Ricardo-AEA, as were all employees. Consequently, where specific projects or track record referenced in this proposal were undertaken and completed prior to the acquisition, for contractual reasons, these continue to be identified as AEA Technology plc.

Executive Summary

Road transport accounts for more than a fifth of the EU's greenhouse gas (GHG) emissions and over two-thirds of its 'domestic' transport emissions. The EU has a long-term objective of an 80 to 95% reduction in greenhouse gas (GHG) emissions by 2050 compared to 1990 and for the transport sector, a 60% GHG reduction objective.

As part of the European Commission's overall strategy to meet these long-term objectives, Regulations setting targets for tailpipe CO_2 emissions for cars and vans were introduced[1]; these set targets for the fleet average CO_2 emissions of all new cars and vans registered in the EU for 2021 and 2020, respectively.

Since 2013, the Commission has carried out a significant work programme to support the development of a possible post-2020 legislative regime, including several technical studies.

To build on this programme of work, Ricardo Energy & Environment, supported by TEPR, TU Graz and E3M Lab, was commissioned to provide technical support to the European Commission on "Assessing the impacts of selected options for regulating CO_2 emissions from new passenger cars and vans after 2020" (hereafter, the 'project').

The aim of the project was to provide the European Commission (DG Climate Action) with technical support in developing its impact assessment for the post-2020 policy framework for regulating CO_2 emissions from new passenger cars and vans. The project covered different elements of the potential policy framework, and the modelling of the potential impacts of a range of options for each of them.

The results of the analysis of different policy design criteria carried out in this project were to be used by the European Commission to support the Impact Assessment (IA) underlying its proposal for post-2020 regulatory CO_2 targets for cars and vans.

The main conclusions that may be drawn from the analysis conducted during the project are summarised below.

Options for target level and timing

The options for target level and timing analysed in this project included:

1. CO_2 reduction ranging from 10% to 50% by 2030, versus the 2021/2020 car/van targets (on a WLTP basis).
2. Targets set at either 2030 only, at 2025 and 2030, or annual targets (2023-2030).

For these options, the main conclusions that may be drawn from the analysis are the following:

- All of the analysed options for the target level are effective in reducing GHG emissions compared to the baseline scenario. As expected, GHG emission reductions increase with increasingly strict targets.
- From a timing perspective, setting targets only at 2030 (instead of also at 2025) results in an 18% reduction in GHG emissions reductions versus the baseline scenario in the central (30%) ambition case, with only a small improvement in cost-effectiveness. This option would result in a reduction in the social equity benefits found for greater CO_2 reduction levels, as well as a reduction in the net total cost of ownership (TCO) savings from a societal and end-user perspective.
- From the TCO perspective, the greatest direct benefits are shown for the 30% ambition level for cars for the societal and first end-user perspectives. and for the higher ambition levels (up to 50% reduction) for LCVs. However, for second end-users, and also when including the external cost reduction benefits in the accounting for the societal perspective, the greatest net benefits are found at the high (~40% reduction) ambition level for cars.
- The overall cumulative direct and external system costs for the whole light-duty vehicle (LDV) parc increase as the CO_2 target ambition increases.
- Other external cost savings, principally from a reduction in air pollution and noise, increase as CO_2 targets become more ambitious. Together with the reduced externalities associated with GHG

[1] Passenger car CO_2 Regulation (EC) 443/2009 (European Union, 2009), and van CO_2 Regulation (EU) 510/2011 (European Union, 2011).

emissions, these outweigh net increases in direct costs. This results in cumulative net societal benefits (i.e. cost savings) which increase in absolute magnitude with increasing ambition levels.

- There are significant social equity benefits. Households that purchase more efficient vehicles in the second-hand car market benefit to a greater extent from the annual fuel savings by only paying a fraction of the additional cost of the first owner. Net TCO benefits are greatest for the high ambition (40% reduction) scenario in 2030 for second users.
- Modelling (GEM-E3 model) showed that the overall macro-economic impacts are relatively small. In the central ambition (30% reduction) option, the cumulative impact on GDP over the period 2020-2040 is found to be well below 1% from the baseline, with total employment slightly increasing in 2030 with respect to the baseline despite lower labour intensity assumptions for electric vehicle (EV) manufacture. Results were very similar for other ambition levels, as the impacts are low compared to the size of the overall economy.
- *Possible impacts of lower diesel share:* Analysis has shown that even high ambition CO_2 targets can be achieved cost-effectively in case of extreme reductions in the market share of diesel vehicles by 2030. However, the effectiveness of the overall CO_2 targets could be reduced due to a higher WLTP-RW gap for gasoline versus diesel cars. More ambitious targets would help mitigate for this risk.

Options for distribution of effort amongst manufacturers

The options for distribution of effort amongst manufacturers analysed in this project, included mass utility options (similar to current Regulations), footprint utility options, a uniform target (all manufacturers meet the same CO_2 target), or a uniform reduction (all manufacturers reduce emissions by the same percentage). For these options, the main conclusions that may be drawn from the analysis are the following:

- Varying the CO_2 reduction ambition level does not significantly alter the relative effects on different manufacturer types of different distribution of effort options.
- At the fleet-wide average level, the differences in cost increase relative to the vehicle price between the mass/footprint utility slopes investigated are relatively small compared to the overall cost increases (except for manufacturers of mostly smaller vehicles or mostly larger vehicles). Nevertheless, flatter slopes show the lowest % increases in vehicle price for mass and footprint.
- Considering the cost impacts, both the Uniform Reduction and Uniform Target options appear to be viable alternatives to mass and footprint based utility parameters, but other considerations make them less attractive. For example, the Uniform Reduction option would require an additional mechanism ensuring that the fleet wide target is met over time, and also poses significant risks to manufacturers of smaller vehicles who have limited possibilities to reduce CO_2 by increasing shares of smaller vehicles to help meet the target; larger manufacturers may much more easily enter smaller vehicle markets to help reduce their average CO_2. Overall, these two options pose greater difficulties for manufacturers at either extreme of the market in the absence of any additional mechanisms. For LCVs, the Uniform Target option results in significantly higher manufacturing cost increases versus the other utility options.
- Based on the analysis, the impacts on the overall fleet average TCO on a societal and end-user perspective of different options is negligible. However, the limited differences in impacts on costs for larger premium manufacturers versus average or smaller vehicle manufacturers would also carry through to a TCO type analysis at this level.
- The Uniform Target and the Mass and Footprint Utility options with the flatter slopes are likely to favour smaller and average vehicle manufacturers the most, which may be also more favourable to lower-income groups.

Options for incentives to stimulate the market uptake of low emission vehicles

The options for incentives to stimulate the market uptake of zero and low emission vehicles (LEV) analysed in this project included a range of different LEV share targets/benchmarks, set as mandates or as part of a credit-based system, and three core LEV qualifying criteria (0g/km, 25g/km (40 g/km for vans), 50g/km with graduated credits). For these options, the main conclusions that may be drawn from the analysis are the following:

- The specific design criteria for potential LEV incentives have a strong influence on the effectiveness of a given level of LEV mandate or crediting system – i.e. to achieve the same level of effect in terms of increasing the uptake of xEVs, different incentive levels would have to be set depending on the design criteria chosen.
- Overall, all the design options considered tend to increase the proportion of zero emission vehicles coming onto the market, weaken the implicit gCO_2/km target for conventional ICEVs and hybrids.
- A one-way crediting system providing for a less strict CO_2 target when exceeding an LEV objective threshold, without a penalty for not meeting that threshold, can only result in a weakening of the effectiveness in terms of both TTW and WTW CO_2 reductions. A two-way crediting system could result in a net outcome either with greater or lower CO_2 reductions. In both cases a cap on the extent to which the CO_2 target may be relaxed will help to minimise such effects.
- LEV incentive options are found to contribute to a further reduction in the external costs related to noise and air pollution, especially thanks to the increased market share of zero emission vehicles.
- Stronger LEV incentives may facilitate more rapid xEV cost reductions; for the options investigated, this resulted in net benefits for the cumulative cost-effectiveness indicator and total cost of ownership (TCO) for certain scenarios for passenger cars. However, for scenarios with similar xEV costs, the implementation of the LEV mandates was found to worsen these metrics, relative to scenarios without them. Cost-effectiveness and net TCO benefits were found to be highest for ZEV (zero emission vehicle) mandates.
- For LCVs, whilst there were still net TCO benefits compared to the baseline (REF) scenario, the introduction of the LEV mandates considered was found to increase the TCO compared to the equivalent case with no mandate, even for very low xEV cost assumptions.
- From the perspective of competition between manufacturers, there were no significant quantitative distribution of effort implications identified in the analysis resulting from the LEV incentive options explored. However, some manufacturers may currently be in a better position than others to deliver higher shares of xEVs. In the absence of flexibility mechanisms (such as trading), some manufacturers would likely struggle to meet high LEV mandates or benchmarks.
- Manufacturers of mostly smaller LCVs (which are often car-derived or share technology with cars) would likely find it easier to fulfil LEV mandates than manufacturers that sell more larger LCVs that may not so easily share technology (e.g. where this is shared with smaller HDVs, rather than LDVs) and where heavier model BEV versions could fall beyond the kerb weight limit for the regulations (out of scope).

Options for flexibility mechanisms

The options for flexibility mechanisms analysed in this project, included the derogations for niche- and small volume manufacturers, and credits for 'off-cycle' technologies that achieve real-world emissions savings that do not show up on the regulatory tests. For these options, the main conclusions that may be drawn from the analysis are the following:

- *Small Volume and 'de minimis' derogations:* Continuing the derogations for small volume manufacturers (SVM) would have extremely small impacts on the overall effectiveness of the regulations, while avoiding significant negative competitiveness implications for such OEMs otherwise.
- *Niche Manufacturer Derogation:* Whilst unlikely to result in a very significant reduction in the overall effectiveness of the regulations, there would be significant competitiveness risks for retaining the current approach unchanged. These (together with impacts on effectiveness) could be mitigated through a combination of: (a) setting targets relative to the 2021 derogated targets and consistent with the overall ambition level, and (b) amending the qualifying criteria to reduce the upper sales limit, or setting an alternative definition based on global sales.
- *Accounting for off-cycle technologies:* Clear and significant potential economic and CO_2 reduction benefits have been established through the inclusion of rewards for off-cycle technologies.

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Glossary

Abbreviation	
BAU	Business as Usual
BEV	Battery Electric Vehicle (fully electric)
CNG	Compressed Natural Gas
CO2	Carbon dioxide
ETS	Emission Trading System
FCEV	Fuel Cell Electric Vehicle (running on hydrogen)
FQD	Fuel Quality Directive (98/70/EC)
GHG	Greenhouse Gas
H2	Hydrogen
HDV	Heavy Duty Vehicle (lorries, buses and coaches)
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
kWh	kilo-Watt-Hour
LCV	Light Commercial Vehicle (van)
LDV	Light Duty Vehicle (Car or LCV)
LEV	Low Emission Vehicles (includes BEVs, PHEVs, REEVs and FCEVs)
LNG	Liquefied Natural Gas
MJ	Mega-Joule
MS	Member State
Mt	Mega ton
NEDC	New European Driving Cycle
NGO	Non-Governmental Organisation
NOx	Nitrogen Oxides (includes nitrogen monoxide and nitrogen dioxide)
OEM	Original equipment manufacturer
PC	Passenger car
PEMS	Portable Emissions Measurement System
PHEV	Plug-in Hybrid Electric Vehicle
RE	Renewable Energy
REEV	Range Extended Electric Vehicle
RW	Real world
TA	Type Approval
TC	Test cycle
TCO	Total Cost of Ownership
TTW	Tank-to-wheel
VAT	Value Added Taxes

Abbreviation	
WLTP	Worldwide harmonized Light vehicles Test Procedures
WTT	Well-to-tank
WTW	Well-to-wheel
xEV	Electric vehicles (includes BEVs, PHEVs, REEVs and FCEVs)
ZEV	Zero Emission Vehicle (includes BEV and FCEV)

1 Introduction and overview

1.1 Introduction

Ricardo Energy & Environment, supported by TEPR, TU Graz and E3M Lab, was commissioned to provide technical support to the European Commission on "Assessing the impacts of selected options for regulating CO_2 emissions from new passenger cars and vans after 2020" (hereafter, the 'project').

The aim of the project was to provide the European Commission (DG Climate Action) with technical support in developing the Impact Assessment for its proposal for the post-2020 policy framework for regulating CO_2 emissions from new passenger cars and vans. The project covered different elements of the potential policy framework, and the modelling of the potential impacts of a range of options for each of them.

The results of the analysis of different policy design criteria carried out in this project were to be used by the European Commission to support the Impact Assessment (IA), underlying its proposal for post-2020 regulatory CO_2 targets for cars and vans.

1.2 Study context

Road transport accounts for more than a fifth of the EU's greenhouse gas (GHG) emissions and over two-thirds of its 'domestic' transport emissions.

The EU has a long-term objective of an 80 to 95% reduction in greenhouse gas (GHG) emissions by 2050 compared to 1990. For the transport sector, a 60% GHG reduction objective has been set out in the 2011 Transport White Paper (European Commission, 2011a) and Low Carbon Economy roadmap (European Commission, 2011b). This was confirmed by the Commission in the July 2016 European Low-Emission Mobility Strategy (European Commission, 2016d).

In 2014, the European Council endorsed (i) a binding EU target of a domestic reduction in greenhouse gas emissions of at least 40% by 2030 compared to 1990, (ii) a binding EU target of at least 27% for the share of renewable energy consumed in the EU in 2030, and (iii) an indicative EU target of at least 27% for improving energy efficiency in 2030 compared to projections of future energy consumption based on the current criteria. The transport sector must contribute to the three targets. As part of the measures needed to achieve these goals, in its 2015 Energy Union Communication (European Commission, 2015) and its 2016 Low-Emission Mobility Strategy Communication (European Commission, 2016d), the Commission committed to bringing forward proposals for regulating Light Duty Vehicle (LDV) CO_2 emissions for the period beyond 2020.

The EU's climate and energy policy framework for 2030 has an economy-wide GHG reduction target of 40% (compared to 2005 levels by 2030); this target is split between the ETS and non-ETS sectors and translates to a reduction of 30% for non-ETS sectors by 2030 (compared to 2005).

In 2007, the Commission proposed the introduction of a regulatory framework for the average CO_2 emissions of the new car fleet, and the new light commercial vehicles (i.e. vans) (European Commission, 2007a). This resulted in the adoption of two Regulations setting targets for tailpipe CO_2 emissions for cars and vans:

- The passenger car CO_2 Regulation (EC) 443/2009 (European Union, 2009), which requires that the fleet average CO_2 emissions of all new cars registered in the EU be 130 gCO_2/km by 2015 and 95 gCO_2/km by 2021;
- The van CO_2 Regulation (EU) 510/2011 (European Union, 2011), which sets a target of 175 gCO_2/km to be achieved by 2017 and a target of 147 gCO_2/km to be met by 2020.

In 2014, the Regulations were amended by defining the modalities for implementing the 2020/21 targets.

1.3 Study objectives

This study has focused on assessing a range of options for defining CO_2 emission targets for the post-2020 time-period, considering the broader climate and energy policy objectives of the EU and the priorities of the Commission. In this context, the objectives of this work were to:

1. Work with the Commission to develop and design in detail a set of options for post-2020 legislative measures for reducing CO_2 emissions from new cars and LCVs;
2. Use qualitative and quantitative approaches (including modelling) to assess the impacts of these options; and
3. Compare the relative advantages and disadvantages of the different options in a robust and systematic manner.

In addition, given that options for reducing CO_2 emissions from new cars and LCVs are an important element of the EU's economy-wide decarbonisation strategy, it is very important that the modelling and analysis carried out in this study are aligned with the approaches that were used to support the impact assessment of the 2030 Climate and Energy package and subsequent policy proposals.

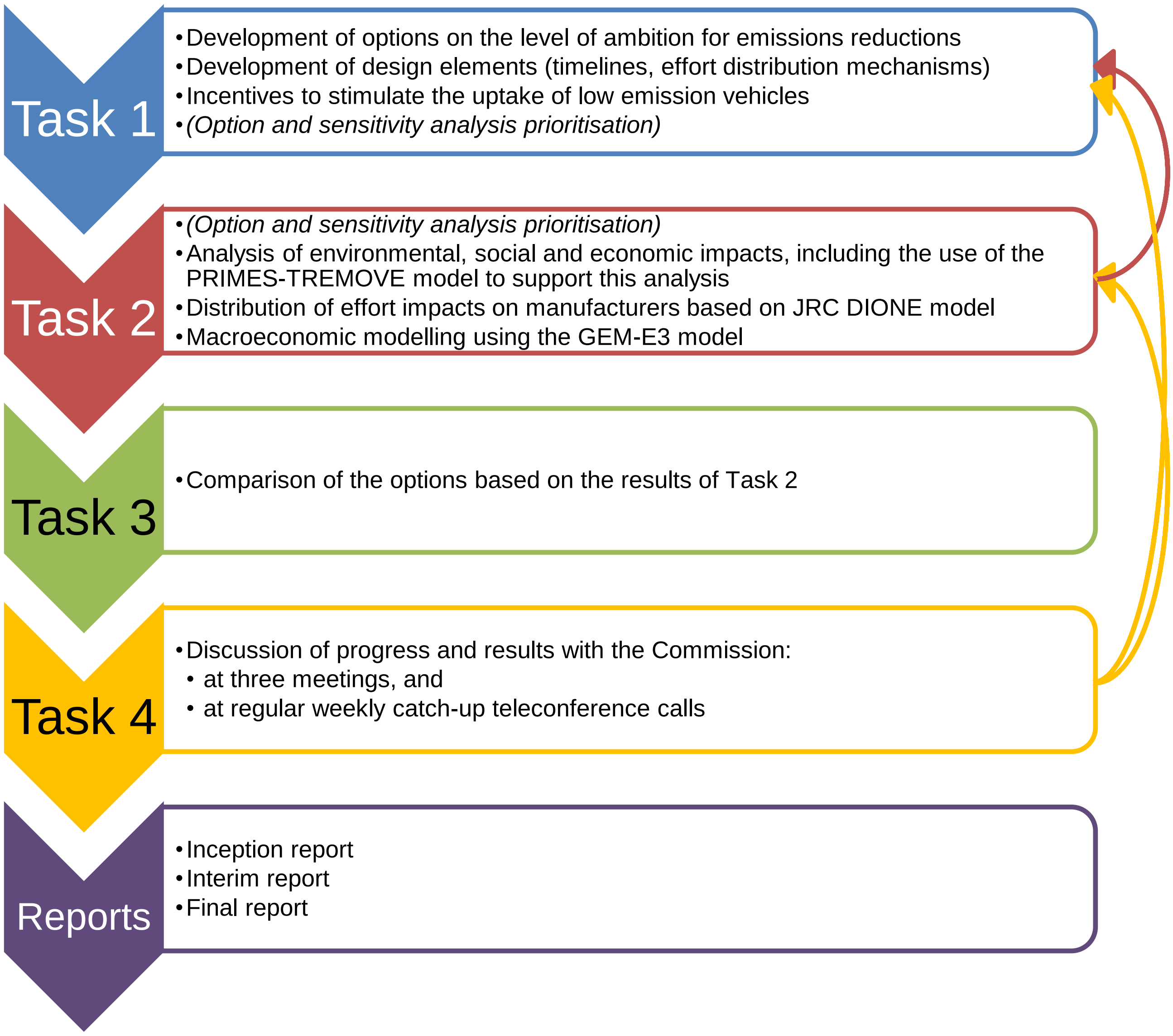
The following sections provide an outline of the methodology and then a summary on the progress and draft results against the different project tasks.

1.4 Overview of the project methodology

This section provides a high-level description of the project methodology, which was further refined during the project. Figure 1.1 provides a summary overview of the key tasks carried out during this project. This final report summarises the work carried out during the project on these tasks, which is summarised in the following report sections following this introduction:

- Overview of the methodological approaches used in the analysis (Section 2);
- Support the Commission in defining in detail the options to be examined (Task 1) (Sections 3 - 6);
- Detailed assessment of the economic, social and environmental impacts (Task 2) (Sections 3 - 6);
- Comparison of the options and plausible combinations thereof (Task 3) (Sections 3 - 6).

Figure 1.1: Project task overview



2 Methodological Approaches

This chapter provides a summary of the methodological approaches utilised in the project, and some details of the key assumptions and datasets used in the analysis. A list of the selected design elements considered in this report for the post-2020 regulations is provided, which was the starting point for the further analysis through a combination of quantitative and qualitative assessment.

The detailed discussion and analysis of each of the regulatory design elements is presented in Sections 3 to 6 of this report.

2.1 Development of design options and summary of assessment methodologies

A first sub-task was to develop a list of regulatory design options and combinations that could be investigated in the project. The short-list of the main elements was set out at the start of the project, and has been in part informed by other recent analysis in this area for the Commission (CE Delft et al., 2017).

The quantitative analysis has used several methods to assess different impacts of regulatory design options and combinations, including the following:

- *PRIMES-TREMOVE (P-T) modelling*: this was the primary means of estimating environmental and economic impacts across a range of impact categories, and upon which subsequent analysis was also based.
- *GEM-E3 modelling*: The GEM-E3T model has been used to assess the macroeconomic and employment implications of a series of options (combinations of design options).
- *JRC DIONE Model family (JRC-DIONE)*: The EC Joint Research Centre (JRC) is developing and running the DIONE family of software applications to analyse road vehicle fleet scenarios with regard to energy consumption, emissions and costs (JRC, 2017). In the framework of the present study, the DIONE Cross-Optimization Module was used to calculate cost-optimised outputs by manufacturer of average marginal capital cost increases, and the DIONE Fuel and Energy Cost Module provided fuel costs per vehicle for different scenarios and distribution of effort options. This was combined with inputs on operation and maintenance cost to calculate the average Total Cost of Ownership (TCO) from the societal perspective, and for the first end-user and second end-user.
- *Social impacts analysis (Social IA)*: post modelling analysis conducted based on the outcomes from PRIMES-TREMOVE, GEM-E3T and the JRC DIONE model.

The different design options explored are discussed in more detail in Sections 3 to 6 of this report, with a comparison of different design options presented at the end of each of the main Sections 3 to 5. Table 2.1 provides a summary of the options identified for further assessment in this project and of the methods used to assess the key impacts of these options. Most of the options listed were investigated (at least in part) using quantitative analysis. Further information on the inputs to the quantitative analysis and the modelling approaches adopted are presented in the next subsections of this report.

Table 2.2 provides a summary of the different impact areas analysed and the methods used for the assessment (in Task 2), as presented in Sections 3 to 6 of this report. Certain elements (such as annual targets and a number of flexibilities) and impacts (such as on innovation, SMEs, etc.) have only been assessed qualitatively.

Table 2.1: Overview of the design elements assessed and the methods used

Key: ✓ = Method used O = Not used/relevant for assessment

Design element	Options	Main method(s) for assessment				
		P-T	GEM-E3T	JRC-DIONE	Social IA	Other
Target year (Chapter 3)	• 2025 and 2030 • 2030 only	✓	O	O	O	O
Target ambition level (Chapter 3)	Targets at 20%, 25%, 30%, 40% and 50% reduction by 2030 on 2021 (1)	✓	✓	✓	✓	O
Distribution of effort (Chapter 4)	• Mass in running order (various slopes) • Footprint (various slopes) • Uniform reduction • Same target	O	O	✓	O	O
LEV incentives (Chapter 5)	• No mandate • LEV mandate (various) (2) • Crediting system	✓	O	✓	O	O
Flexibilities (Chapter 6)	• Accounting for off-cycle technologies (include/exclude) • Niche manufacturer derogation for cars	✓	O	O	O	O
Sensitivities (Chapter 3)	• WLTP-RW gap • Alternative cost assumptions • Lower diesel share	✓	O	✓	O	O
Target year (Chapter 3)	• Annual targets	O	O	O	O	✓
Flexibilities (Chapter 6)	• Pooling • Banking and borrowing • Trading • Other derogations	O	O	O	O	✓

Notes: P-T = PRIMES-TREMOVE modelling analysis, GEM-E3T = GEM-E3 modelling analysis, JRC-DIONE = JRC DIONE model, Social IA = social equity impact analysis.

(1) More details on the specific reduction trajectories evaluated are presented in Section 3.1. (2) More details are provided in Chapter 5 on the different LEV incentive options evaluated.

Table 2.2: Overview of the impact areas analysed and the methods for assessment

Key: ✓ = Method used O = Not used/relevant for assessment

Impact area	Sub-impact area	Method for assessment				
		P-T	GEM-E3T	JRC-DIONE	Social IA	Other
Greenhouse gas emissions reductions	• Direct (TTW) emissions • Overall (WTW) emissions	✓	O	O	O	O
Increasing the uptake of LEVs	• Shares of LEVs / xEVs	✓	O	O	O	O
Social equity (distribution between household income groups)	• Distribution of costs by social strata	✓	✓	O	✓	O
Competition between manufacturers	• Total average vehicle manufacturing cost increase vs baseline • Distributional impacts based on utility parameter/slope	✓	O	✓	O	O
Costs and cost-effectiveness	• Average Total Cost of Ownership (TCO) • Total direct system costs and external costs: ○ Cost-effectiveness ○ Cost-Benefit Analysis	✓	O	✓	O	O
International competitiveness (wider EU economy)	• GDP, Gross value added • Employment	✓	✓	O	O	O
Other impacts	• Total energy consumption • Air quality, Noise • [Congestion, Accidents]	✓	O	O	O	O
Administrative burden	• Administrative burden	O	O	O	O	✓

2.2 Updating of the PRIMES-TREMOVE and GEM-E3 Models and development of the baseline scenario

This section provides a summary of updates and further development of the main quantitative models used to assess the impacts of the different options, and the development/characterisation of the baseline scenario. The following steps were taken to update the PRIMES-TREMOVE model and the main assumptions in the context of the project:

1. Update of PRIMES-TREMOVE to incorporate the switch from the NEDC to the WLTP regulatory testing cycles and protocols;
2. Update of the WLTP versus real-world performance (see Appendix 2);
3. Update of the vehicle CO_2/efficiency cost-curves included in the model;
4. Modification of PRIMES-TREMOVE to define and differentiate low emissions vehicles (LEVs);
5. Modification of PRIMES-TREMOVE to introduce incentive options for LEVs;

6. Updating the operation and maintenance cost assumptions for xEVs.

A summary of these elements is provided in the following subsections, with information also provided on the development of the key inputs to the quantitative modelling.

2.2.1 Defining the baseline scenario

The quantitative analysis required the use of a scenario that would serve as the basis for comparing all the policy scenarios. This scenario is referred to as the “baseline” scenario (with short name in charts/tables ‘REF’). For this, the Reference scenario 2016 (European Commission, 2016e) was taken as the starting point, to which several updates and model enhancements were made as presented below. The Reference scenario presents the latest outlook from the European Commission in the form of projections regarding energy, transport and greenhouse gas emissions in the EU until 2050.

2.2.2 Development of inputs to the quantitative modelling

2.2.2.1 Baseline scenario

For setting up the baseline scenario, the following new information was used in the PRIMES-TREMOVE (P-T) modelling:

a) Technology cost-curves:

- *By segment:* The ‘Small’ and ‘Large’ car segments were retained, corresponding to ‘Small car’ and ‘Big car’ in P-T. and the Lower/Upper Medium car segments were aggregated to ‘Medium cars’ based on their current market split. The three LCV categories defined under the SR4 study (Ricardo Energy & Environment et al, 2016) (Small LCV, Medium LCV and Large LCV) were aggregated into a single LCV category, to line up with P-T.
- *By powertrain:* converting the format of the cost-curves for compatibility with P-T.

b) **NEDC-WLTP correlation factors**: these factors differentiate by vehicle powertrain and size. Input for this was based on work by the JRC (JRC, 2017a);

c) **WLTP-RW (real-world) uplift (%):** future trajectory disaggregated by powertrain type.

d) **CO_2 emissions targets** for 2015 and 2020/21 converted from NEDC to WLTP equivalents.

For the baseline scenario, the “typical” (= central) cost-curves were utilised for the years up to 2020 and the “high cost” cost-curves for the period thereafter[2].

2.2.2.2 Techno-economics Input for policy scenarios and sensitivities

For each of the policy scenario runs **Technology cost-curve inputs** were utilised in the modelling**:** tailored to the specific option being investigated, differentiated by cost-scenario (typical, low, high). These cost-curves were developed based upon a project carried out by Ricardo Energy & Environment entitled “Improving understanding of technology and costs for CO_2 reductions from cars and LCVs in the period to 2030 and development of cost curves" (further referred to as "SR4” project) (Ricardo Energy & Environment et al, 2016).

A control panel was developed for the definition of scenarios using combinations of the different design options, to ensure that consistent tailored outputs could be provided for input to the PRIMES-TREMOVE model. The specific details of the information/data that were specified were dependent on the final definitions of the different options under investigation, discussed further in the later sections of this report.

PRIMES-TREMOVE considers cost-curves that associate the potential for reducing the specific energy consumption of a vehicle option with an additional cost. The model incorporates cost curves for all vehicle options. The additional costs and improvements in the specific energy consumption are compared relative to a 2005 representative "baseline" car.

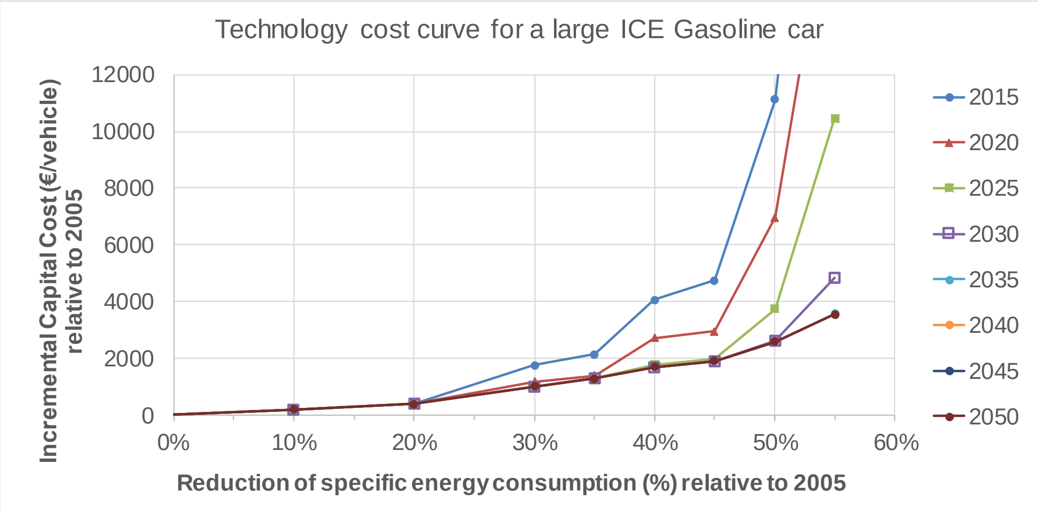
Examples of how cost-curves are fed into the PRIMES-TREMOVE model as an input are shown in Table 2.3 and Figure 2.1 below.

[2] Background information on the development of the cost curves can be found in (Ricardo Energy & Environment et al, 2016), together with details on the final cost-curves used in this project in (JRC, 2017).

Table 2.3: Example of cost-curves used as an input for PRIMES TREMOVE for a large Gasoline ICE car

	% Reduction of specific energy consumption relative to 2005	Additional cost to 2005 gasoline vehicle (costs in 2013 Euros)							
		2015	2020	2025	2030	2035	2040	2045	2050
A1	10%	196	196	196	196	196	196	196	196
A2	20%	407	388	388	388	388	388	388	388
A3	30%	1755	1175	1008	1008	1008	1008	1008	1008
A4	35%	2142	1399	1283	1283	1283	1283	1283	1283
A5	40%	4053	2718	1776	1692	1692	1692	1692	1692
A6	45%	4751	2953	1959	1907	1907	1907	1907	1907
A7	50%	11129	6967	3733	2597	2576	2576	2576	2576
A8	55%	29773	19455	10462	4855	3558	3549	3549	3549

Figure 2.1: Illustration of a cost-curve included in the model



2.2.2.3 Summary on the basis of the cost-curves utilised in this project

The SR4 technology and cost-curve project (Ricardo Energy & Environment et al, 2016) gathered available data on the cost and performance of CO_2 reducing technologies and developed a methodological approach for estimating their trajectories in CO_2 abatement performance and cost to 2030. The project report for that study provides a detailed summary of the processes, consultation activities (involving all relevant stakeholder groups) and highly-detailed analysis conducted during that project.

The methodological approach used to estimate the potential future costs of different technologies was developed, tested and refined with stakeholders using the Delphi survey method during the project. As part of the analysis for the SR4 project, a statistical uncertainty analysis model was then developed to produce a series of alternative cost trajectories from 2015 to 2030 for each technical option (and for each LDV segment and powertrain it could be applied to) using the final cost methodology. A Latin Hypercube Sampling (LHS) process for uncertainty analysis was used in this model to estimate the most likely (central) future costs for each technology option, and also Low and High cost estimates. These Low and High costs were based on 1 standard deviation from the central (central cost) value (i.e. a 68% confidence interval). More detail on the methodological approach is provided in the SR4 report.

The final step of that project was to develop CO_2 reduction cost-curves on a WLTP basis for different LDV segment and powertrain combinations and for different years, based on the final technology CO_2 performance and cost dataset developed during the project (Ricardo Energy & Environment et al, 2016). The cost-curves were developed through a series of steps (summarised below) that started with developing a cost-optimised output of combinations of different CO_2 reduction technologies. This first output, factored in incompatibilities between different technologies and powertrain types. A more detailed summary of the methodological development is provided in the SR4 project report:

Step 0. Raw data points are outputted from the JRC DIONE Cost Curve Module

Step 1. 2013 Baseline adjustment to account for the percentage CO_2 savings (and costs) resulting from technologies that have *already* been applied to the 2013 baseline vehicles.

Step 2. Scaling for batteries (xEVs only) to account cost savings resulting from an ability to downsize the battery (for the same km range) following the addition of other efficiency improvements.

Step 3. Scaling for overlapping technologies to avoid over-accounting for the potential net CO_2 reductions from packages including individual technologies that address the same area of loss.

Step 4. Re-baseline xEV relative to 2013 conventional vehicles (xEVs only) to present xEV cost curves as relative to conventional 2013 powertrain equivalents (i.e. including the xEV powertrain benefits).

Following the completion of the SR4 project, the Commission carried out further consultations with European vehicle manufacturers that resulted in amendments of the assumptions used for some of the technological options, as set out in Annex 2 of (JRC, 2017). The resulting cost-curves developed by JRC are described in Annex 1 of that report.

In addition, a series of "very low" cost-curves were developed for this project for xEV powertrains only, based on new evidence, for example from (BNEF, 2017), that future battery costs might decline even more rapidly than assumed for the low cost scenario (see also Table 2.5). These cost-curves are a further 20% lower than the low cost curves for PHEVs and 30-40% lower for BEVs between 2020-2030, and are summarised in (JRC, 2017).

Table 2.4 below summarises the different projected costs used for the battery packs.

Table 2.4: Battery pack cost projections utilised in this project

Battery pack cost, €/kWh	2015	2020	2025	2030	2040	2050
High	375	260	228	205	180	160
Central	375	202	169	149	120	100
Low	375	174	134	102	75	65
Very Low	375	124	97	65	55	50

Sources: (Ricardo Energy & Environment et al, 2016) (SR4) for Central, High, Low cost projections. Very Low battery cost projections are new estimates for this project, based on (BNEF, 2017).

In addition, Table 2.5 provides a summary of the cost-curve combinations used in the impacts analysis for different scenarios for this project, including a commentary on the relevance/likelihood of each option in the context of some of the regulatory design options explored. These options are discussed in more detail in Chapters 3 to 6 of this report.

Table 2.5: Cost-curve combinations used in the quantitative scenario analysis for this project

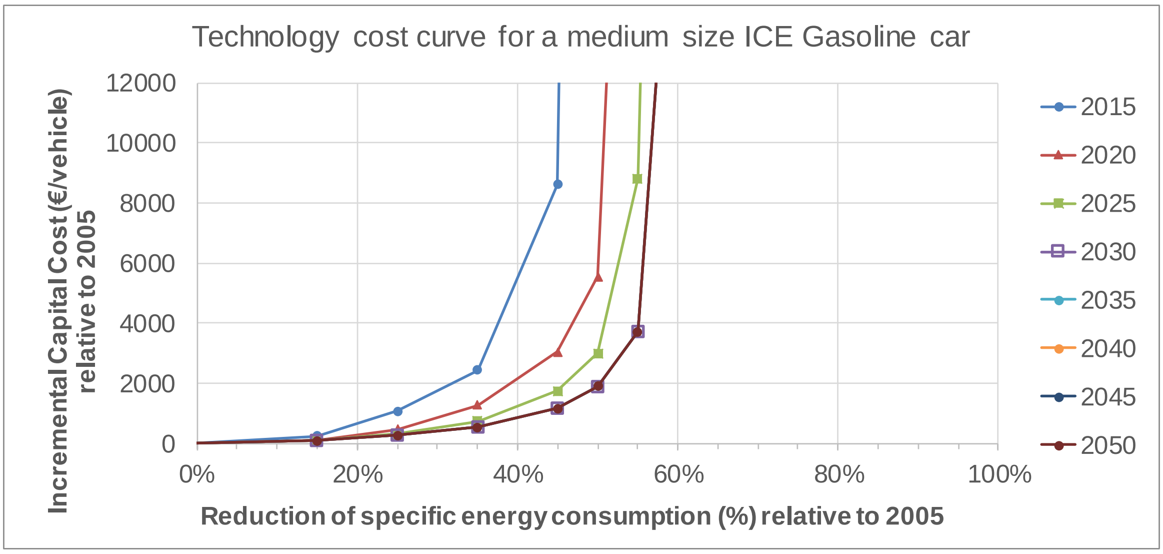
Scenario	Abbrev.	Description
Central	-	Central cost curves for all powertrains; this is the default assumption for all scenarios including post-2020 regulatory targets.
Low	-LO	Low cost curves for all powertrains. This scenario is more likely for higher ambition targets, which would be expected to increase the rate of deployment of CO_2 reducing technologies, driving down costs more quickly.
High	-HI	High cost curves for all powertrains. This scenario is more likely for lower ambition (or no) post-2020 targets, due to reduced rate of deployment of CO_2 reducing technologies. It is highly unlikely for central or higher ambition levels.
High ICE	-HICE	Combination of high cost curves for conventional and full hybrid powertrains, and central cost curves for xEVs. This scenario is more likely for lower ambition post-2020 targets, due to reduced rates of technology deployment.

Scenario	Abbrev.	Description
Low xEV	-LxEV	Low cost-curves for xEV powertrains; central cost curves for conventional and full hybrids. This scenario is more likely for central-higher ambition targets, or for scenarios with significantly higher uptake of LEVs.
Very Low xEV	-VLxEV	Very low cost-curves for xEV powertrains; central cost curves for conventional and full hybrids. This scenario is more likely for higher ambition targets, and particularly for scenarios with much higher uptake of LEVs.

Examples of the resulting cost-curve input parameters for other powertrain types are provided in Figure 2.2 below, reformatted to match the PRIMES-TREMOVE input format. The cost curves for full hybrid and plug-in hybrid technologies start from different points compared to the conventional cars. This is due to the fact that all three powertrain types are compared against the base conventional vehicle of 2005. Full hybrids, thanks to the hybridisation system and plug-in hybrids, thanks to larger battery capacity and electric motors, yield higher potentials for improvements in energy efficiency.

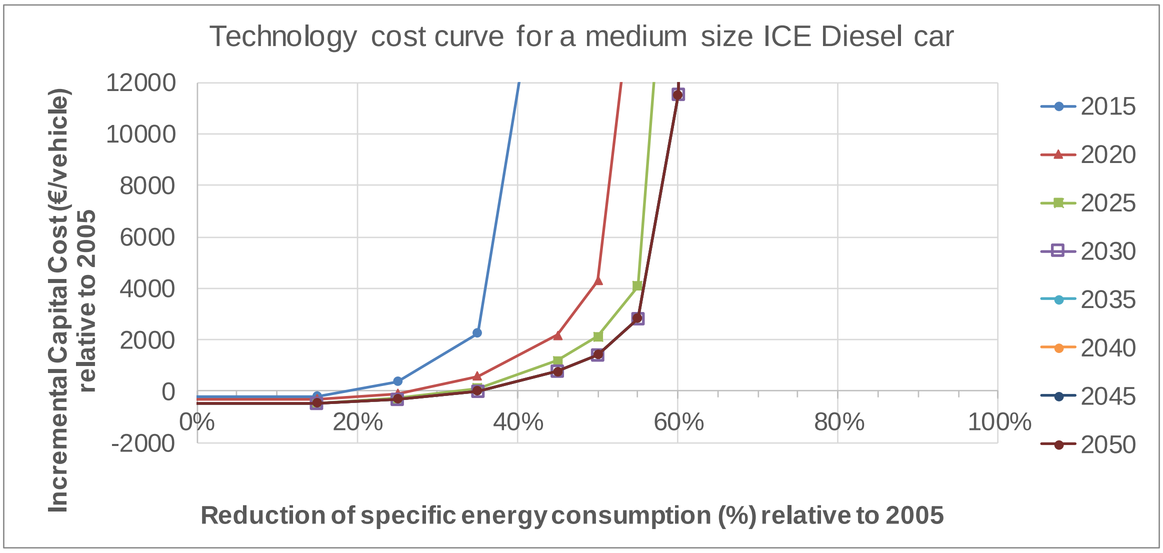
For diesel powertrains, the cost curves start below the x-axis, i.e. with negative costs, as the SR4 project found that medium downsizing options that resulted in net cost savings had not yet been taken up significantly in the vehicle parc (Ricardo Energy & Environment et al, 2016). The literature has identified significant progress in terms of efficiency improvement during the period 2005 and 2013 at little net impact on costs compared to the potential. During the preparation of the cost curves to feed into PRIMES-TREMOVE, considering the aforementioned progress, negative costs were therefore assumed for certain levels of efficiency progress (i.e. points of the cost curves). This also means that the efficiency progress along some points on the cost curves has already taken place in reality, relative to 2005.

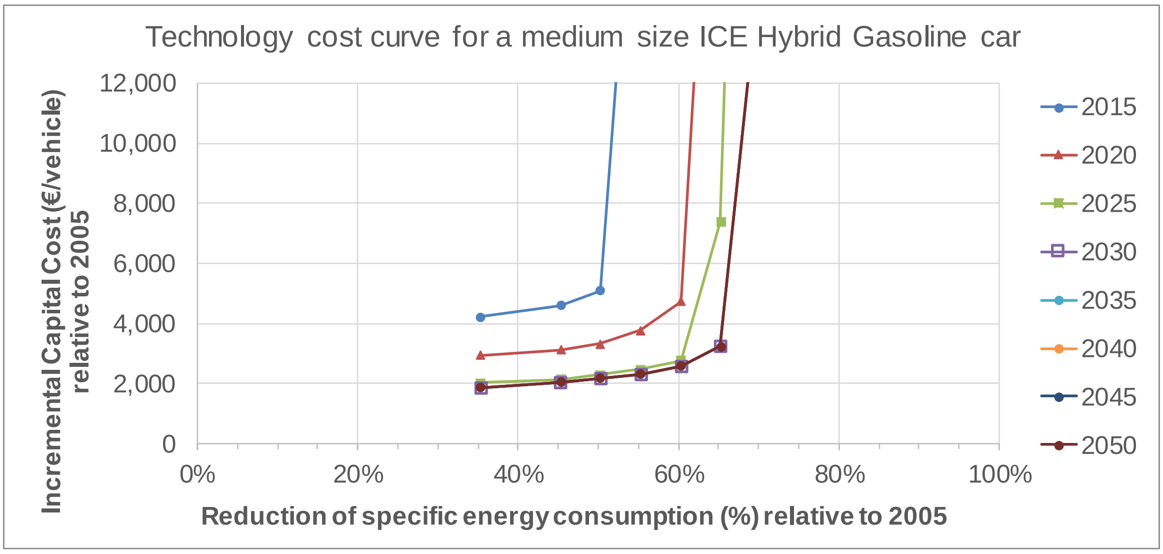
Figure 2.2: Charting of illustrative input cost-curve input data for PRIMES-TREMOVE model, Medium Size Car, Central Costs

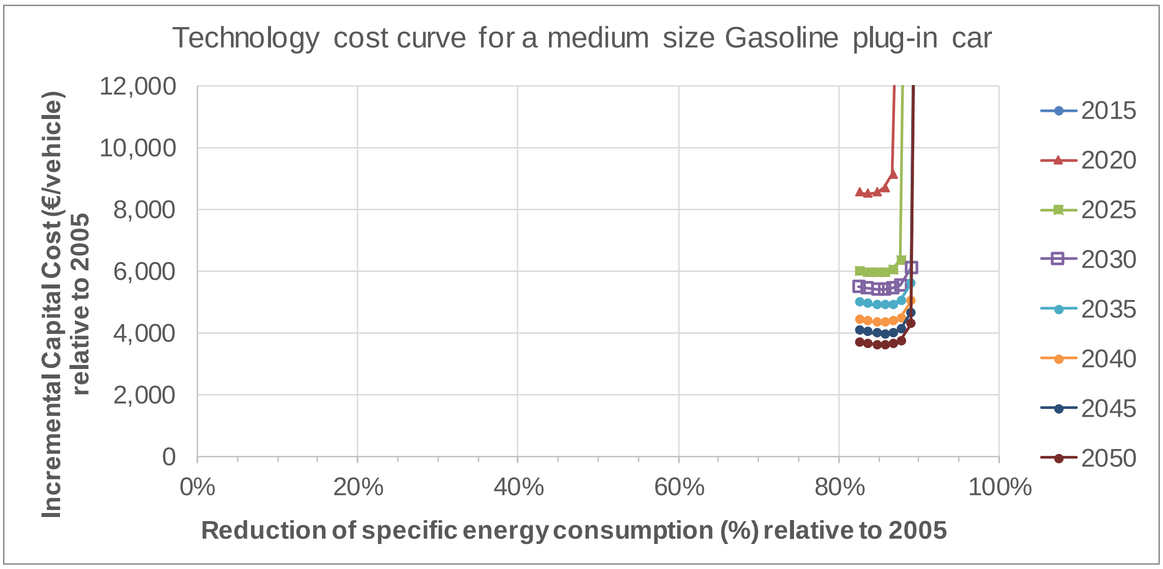


Notes: The cost-curves are unchanged for the periods 2030-2050 for ICE / Hybrids, so overlap in the figures above.

Figure 2.2: Charting of illustrative input cost-curve input data for PRIMES-TREMOVE model, Medium Size Car, Central Costs (continued)







Notes: The cost-curves are unchanged for the periods 2030-2050 for ICE / Hybrids, so overlap in the figures above.

2.2.3 Updating the operation and maintenance cost assumptions for xEVs

During the project, a methodology to assess the vehicle-level total cost of ownership (TCO) was developed as discussed in Section 0. For this, it was necessary to incorporate more detailed estimates for the fixed annual operation and maintenance (O&M) costs of different vehicle segments and powertrain types. The existing O&M costs are subdivided into three main components:

a) Annual insurance costs;
b) Annual maintenance costs;
c) Other ownership costs, mainly including fixed annual taxes.

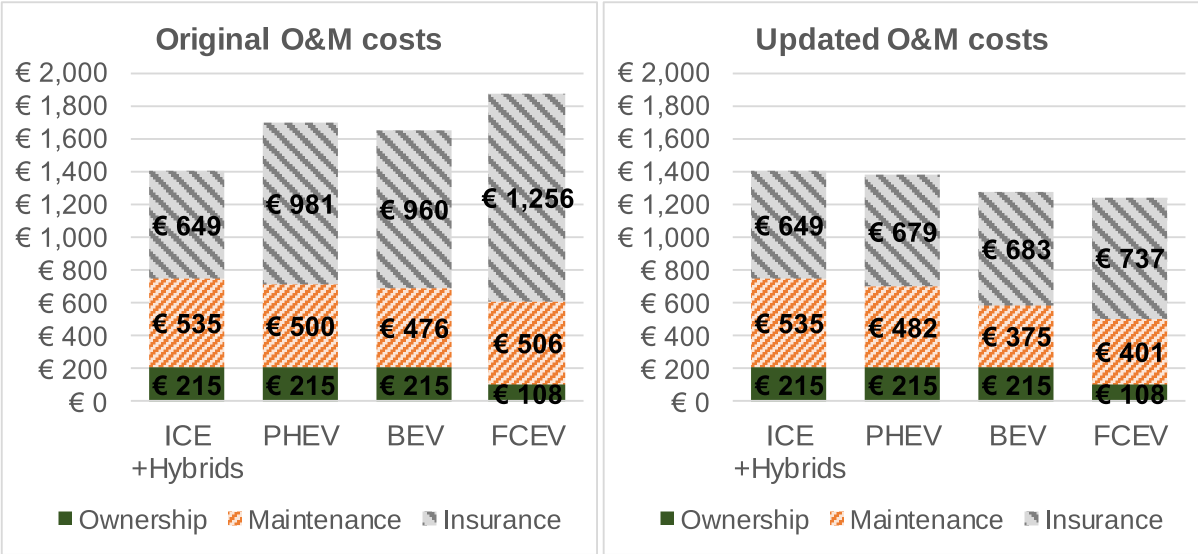
Analysis of the original data showed that the maintenance and insurance costs comprise the largest shares of the overall total O&M costs. This is illustrated in Figure 2.3 below for a medium car in 2025, with the maintenance costs for xEV powertrains only showing relatively low (5-15%) reductions versus conventional equivalents, but with vastly higher insurance costs (in some cases over double).

For maintenance costs, most recent estimates suggest reductions in the range of 25-40% compared to petrol/diesel vehicles (FleetNews, 2015) for BEVs, with slightly lower level savings for FCEVs and for PHEVs (due to increased complexity and remaining ICE systems). Recent analysis in (UBS, 2017), in relation to the Chevy Bolt, has also suggested maintenance savings could be even higher than this for BEVs. Higher historic maintenance cost estimates have often stemmed from the assumption that batteries of EVs could need replacing during the lifetime of the vehicle. However, evidence from real-world experience with EVs in recent years has shown that this is unlikely to be the case, and that EV batteries have much lower failure rates than combustion engines.

For insurance costs, the original estimates were based upon (CE Delft, 2013), which assumed an insurance premium for trucks of 1.5% per year of the vehicle retail price, which had been applied to previously much higher estimates for the costs of xEV powertrains. The rationale for this is a perceived higher risk for new technologies. However, this would be expected to diminish over time as the technology matures. In fact, the insurance premiums of many current electric cars are already often similar or even lower than those for conventional vehicles in some European countries. A contributing factor for this could be the assessment of risk made by insurance companies for EV drivers, versus other motorists, which forms an important part in setting insurance premiums. Information from (Aviva, 2017) suggests that only around 25% of the insurance premium for car insurance is directly attributable to the value of the vehicle (i.e. principally via repair and maintenance costs, and likelihood of theft). Around half of the cost of claims is actually due to third party personal injury, which is unrelated to powertrain type. The updated insurance costs for xEVs were therefore estimated using this 25% factor and the relative price differential between them and conventional vehicles.

The net result of these updates was a decrease in the cost of overall O&M costs for xEV powertrains in the region of 20-40%. The effect of this change is illustrated below in Figure 2.3.

Figure 2.3: Comparison of pre-existing O&M cost assumptions for medium cars for 2025 from the PRIMES-TREMOVE model with updated estimates for medium cars developed during this project



Notes: In 2025, it is assumed in the model that some tax breaks will still be available for FCEVs due to their lower market maturity. This benefit versus other powertrains is also present for other xEVs in earlier periods and is eliminated entirely by 2030 onwards for all powertrain types.

The Table A3 (in Appendix 3) provides a complete summary of the updated O&M cost assumptions for LDVs that were developed during this project, and which have been used in the TCO analysis. The main PRIMES-TREMOVE modelling analysis scenarios continued to use the pre-existing assumptions for consistency/comparability across all modelling runs, as it was found that the updated figures would most likely have little impact other than a systematic reduction in overall system costs.

2.2.4 Summary of key changes in the updated baseline relative to Reference 2016

Since the quantification of the Reference Scenario 2016 (European Commission, 2016e), more recent data (2015) on the annual new vehicle registrations were available and used for the purposes of this project.

The updated baseline scenario shows an increase in the overall CO_2 emissions from the transport sector in 2020 by 2.4% relative to Reference 2016. The difference mainly stems from passenger cars (i.e. an increase of 4.9% between the two scenarios). The difference between the two scenarios in terms of CO_2 emissions decreases by 2030 (i.e. to -0.6% between Reference 2016 and the new baseline).

The findings are similar also in terms of total energy consumption, with an increase under the new baseline compared to Reference 2016 of 2.3% in 2020 and a decrease of 0.3% in 2030. In particular, gasoline consumption increases in the new baseline compared to Reference 2016, both for 2020 and 2030 (5.6 and 2.4 Mtoe, respectively). Diesel consumption also increases in 2020, but in 2030 it decreases by 2.7 Mtoe in the updated baseline relative to Reference 2016. Deviations stem from differences in the evolution of the stock of diesel cars compared to gasoline cars from 2020 until 2030. The new cost curves are found to “favour” the uptake of gasoline cars more than diesel cars in terms of cost-effectiveness compared to the previous assumptions in the model.

The new baseline also factors in the updated WLTP-RW conversion factors. This leads to an increase in total transport CO_2 emissions in the updated baseline scenario compared to the Reference 2016 scenario. The penetration of electric vehicles steadily increases from 2025 onwards. This outweighs the negative impact of the increase in the gap between WLTP and real-world CO_2 emissions/fuel consumption performance.

Finally, the new policy scenarios analysed for this project, which are discussed in the later chapters of this report, also include coordinating policy conditions that are expected to be implemented alongside the post-2020 CO_2 targets, while these are not present in the baseline scenario. This concerns in particular:

- The market acceptance of advanced powertrain technologies;
- The availability of recharging infrastructure;
- More optimistic assumptions for the evolution of battery costs (i.e. versus the situation where these vehicles are not deployed/incentivised significantly in the baseline case).

These enabling conditions are also indicative of the effort needed in the transport sector for its transition to the mid- and longer-term (2050) decarbonisation targets.

2.3 Assessing the impacts of options for the distribution of effort between different manufacturers

This section provides an outline of the methodological approach developed to assess the impacts of options for distribution of effort (DoE) between different manufacturers, and additional information used in the analysis and presentation of the results.

2.3.1 Outline of the methodology for the analysis of distribution of effort (DoE)

For determining likely impacts of the different options for the distribution of effort the JRC DIONE Cross-Optimization Module was employed.

2.3.1.1 Setting CO_2 targets for the PRIMES-TREMOVE and JRC DIONE models

The PRIMES-TREMOVE model effectively models the European vehicle fleet as a single manufacturer, with vehicles subdivided into four LDV segments (small, medium and big cars, and a single segment for all vans). Manufacturers have different market shares in different segments and their fleets have different mass and footprint characteristics. Therefore, using a utility or other distribution function to define manufacturer-level targets will naturally result in different segments effectively meeting different CO_2 target levels based on the average characteristics of these segments (i.e. larger segments have larger footprint and mass). However, a small series of sensitivities run for the PRIMES-TREMOVE model confirmed that the overall impact of this effect was limited.

A consistent methodological approach was developed to calculate the CO_2 targets used to assess DoE impacts using JRC's DIONE model. This built on the analysis of the 2013 CO_2 monitoring database analysed as part of the SR4 cost-curves project (Ricardo Energy & Environment et al, 2016), which was essential to ensure the results will be fully compatible with these cost-curves (which are set relative to 2013). Analysis of the monitoring dataset was also used to determine the parameter equations for the utility-based approaches (discussed in later Section 4.1.1). These CO_2 targets are defined based on the utility curves (i.e. as discussed in Section 4.1.1), or other methods of effort distribution, and factoring in fleet-wide targets and other relevant design elements (i.e. target years and whether the niche manufacturer derogation is included (or not)) (see Chapter 6).

2.3.1.2 Off-model estimation of manufacturer-level costs

In order to estimate the manufacturer-level costs for different options for distribution of effort, Ricardo and JRC developed a methodological approach to utilise the outputs from the PRIMES-TREMOVE runs, in combination with an optimisation routine. An illustration of the methodology developed is provided in Figure 2.4 below, and involves the following key stages:

1) **Stage 1:** Outputs are taken from the relevant PRIMES-TREMOVE scenario on the derived powertrain shares by vehicle segment. These are then disaggregated to a manufacturer and segment level using two alternative weightings for xEVs (it is assumed petrol/diesel ICE+Hybrid shares remain broadly similar):
    a) *Equal increase:* all manufacturers receive a similar increase in share (by segment) of the xEV powertrains (scaled to the manufacturers market share), plus any existing deployment of xEVs already in their fleet (giving first-movers a small advantage).
    b) *LEV mandate:* all manufacturers have a similar share of xEVs, to simulate the potential effect of a LEV mandate that would apply equally to all manufacturers.
2) **Stage 2:** The derived manufacturer/powertrain/segment distributions are fed into the JRC DIONE Cross-Optimization Module, which calculates the optimal levels of CO_2 reduction for different

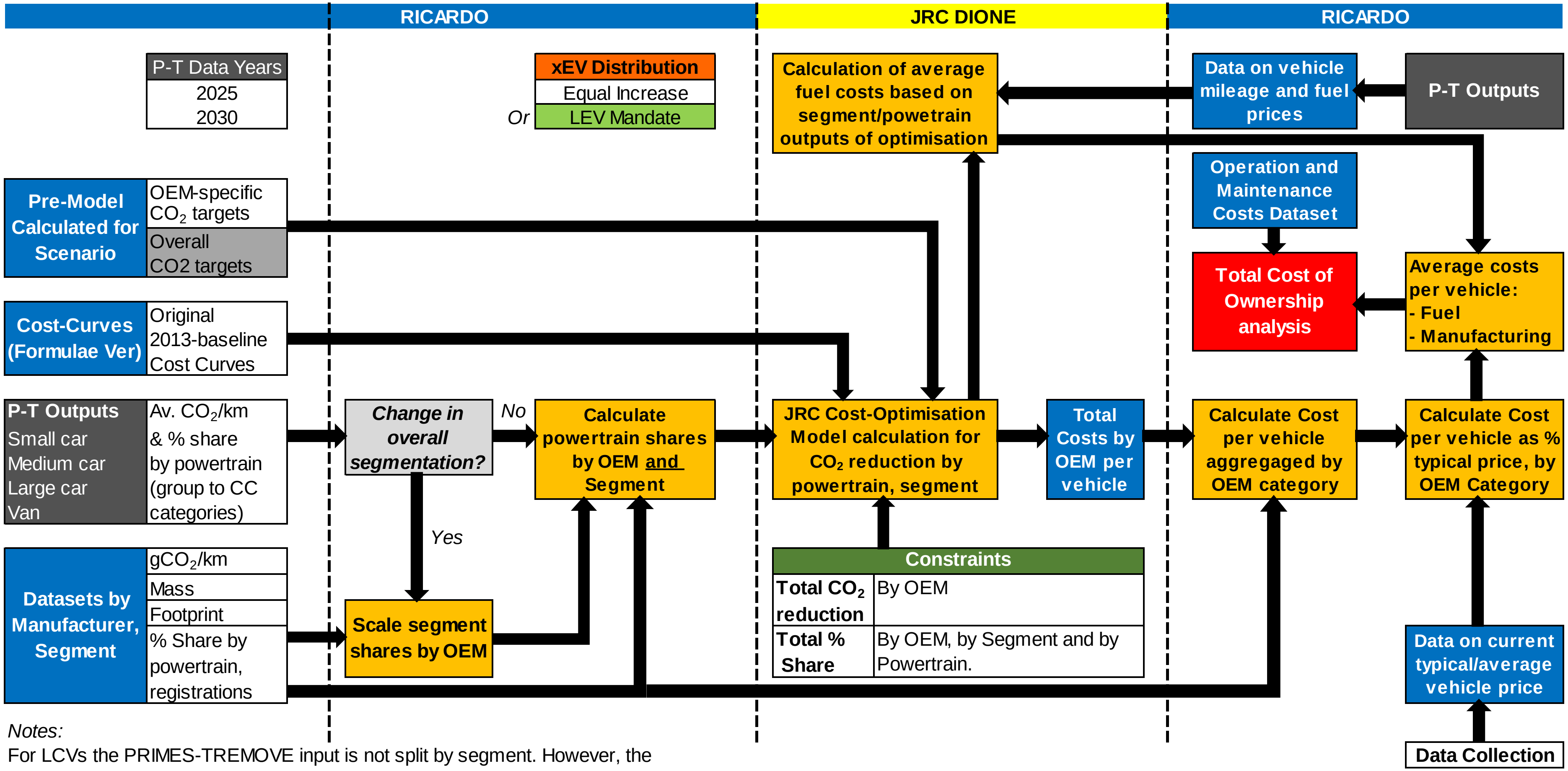
powertrains and segments using the relevant cost-curves. This optimisation is constrained only by the CO_2 target for the given year based on the specific distribution function. The output provides the average manufacturing cost increase per vehicle versus the 2013 baseline at the manufacturer level.

3) **Stage 3:** The increase in costs is set relative to the baseline scenario (i.e. meeting only the 2021/2020 target for cars and vans). Net average vehicle cost increases for different manufacturer categories are also compared relative to the current average vehicle price by manufacturer category. The source of this latter information is discussed further in Section 2.3.3 below.

In addition to these three stages for the DoE analysis, a fourth stage was added to feed into the total cost of ownership (TCO) analysis, which is discussed in more detail in Section 2.4:

4) **Stage 4:** Outputs of optimised CO_2 savings by segment/powertrain were used as an input to the JRC DIONE Fuel and Energy Cost Module, which yields fuel and energy costs per segment, powertrain and manufacturer. Percentage sales-weighted average net present value (NPV) of fuel costs was calculated using input datasets on fuel prices and annual mileage profiles for end-user and societal perspectives.

Figure 2.4: Illustration of the methodology developed for the calculation of distribution of effort impacts on vehicle costs off-model using the JRC DIONE model



Notes:

For LCVs the PRIMES-TREMOVE input is not split by segment. However, the distribution of effort off-model analysis can use more detailed segmentation, so it is useful to retain this through the calculations.

Other Assumptions:

Assume that relative OEM shares of total SI+Hybrid ICE and CI+Hybrid ICE are similar for a given segment.

Assume there is some flexibility to introduce alternative xEV powertrains, but at higher/lower rate for different OEM categories.

2.3.2 Development of manufacturer categorisation for passenger cars and LCVs

The impacts of different DoE options are presented for different "stylised" manufacturers (or manufacturer groups) to represent groups of manufacturers with similar characteristics. The definition of these "stylised" manufacturers was based on an assessment of each OEM's current share of different market segments and their readiness to increase the uptake of more advanced technology with regards to hybrids and low-emission vehicles. The rationale for this approach was to provide a focus on the general characteristics of OEMs, rather on the specific status of individual OEMs, as future fleet choices are more uncertain and could be affected by mergers/changes in ownership or pooling, etc.

The categorisation for passenger car manufacturers is presented in Table 2.6. It is based on an analysis of the CO_2 monitoring database from a previous project (Ricardo Energy & Environment et al, 2016), as well as a broader assessment of technology status (also discussed further in Section 4.2.2).

Small volume manufacturers (SVM, with <10,000 registrations) and *De minimis* manufacturers (<1000 registrations) which account for <0.1% of registrations overall, are not considered in the quantitative analysis.

Table 2.6: Proposed categorisation for passenger car manufacturers

Vehicle Segments	Technology Level	Proposed Categorisation
Smaller	Laggard	**1. Manufacturer of smaller vehicles**
Regular	Early market leader	**2. Advanced technology average vehicle manufacturer**
Regular	Average	**3. Average vehicle manufacturer**
Regular	Laggard	
Larger	Early market leader	**4. Advanced technology vehicle manufacturer of larger vehicles**
Larger	Laggard	**5. Laggard manufacturer of larger vehicles**

Notes:
Smaller = >75% A/B segment vehicles; *Larger* = >10% Large, or >50% Upper Medium /Large; *Regular* = other manufacturers. *Early market leader* = Higher deployment/market share of xEVs and/or hybrids; *Laggard* = Little/no deployment of xEVs, hybrids.

The categorisation for manufacturers of light commercial vehicles (LCVs), is presented in Table 2.7 based on an analysis of registrations in 2013. Sales of xEVs (which are all BEVs) are relatively low for almost all LCV manufacturers currently. However, manufacturers without xEV variants of LCVs do also provide xEV passenger cars, so distinguishing manufacturers on this basis might not lead to significantly greater insights. This will be investigated in more detail in the distribution of effort analysis presented in Section 4 of the report.

Small volume manufacturers (SVM, with <22,000 registrations) and *De minimis* manufacturers (<1000 registrations), which account for ~3% of registrations overall, are not considered in the quantitative analysis.

Table 2.7: Proposed categorisation for LCV manufacturers

Vehicle Size Segments	Technology Level	Proposed Categorisation
Smaller LCV/Car-based	xEV model sales	**1. Manufacturer of mostly Smaller LCVs**
Smaller LCV/Car-based	No xEV sales	
Larger LCVs	xEV model sales	**2. Manufacturer of Larger LCVs with xEVs**
Larger LCVs	No xEV sales	**3. Manufacturer of Larger LCVs**

Smaller = <50% large LCV sales, >15% small LCV or car-based sales; *Larger* = other manufacturers.

2.3.3 Information on average vehicle prices by manufacturer

An important consideration in assessing the distribution of effort between manufacturers is the potential impact on the manufacturing cost increase for different manufacturers relative to the average price of these vehicles, since certain segments (such as smaller budget vehicles) are much more price sensitive. This element also has relevance to social equity considerations, as premium models tend to be purchased by higher social strata which are less price-sensitive.

Information on the most current average prices of vehicles by manufacturer (including tax) was collected from readily available sources. For passenger cars, the average vehicle price was available for most vehicle manufacturers from ICCT's light duty vehicle statistical pocketbooks (ICCT, 2016). Where such data was not available Ricardo carried out a search of the vehicle prices from 2-3 European countries for the most popular model in each of the four car segments and three LCV segments and used these to calculate an estimated sales-weighted average based on the respective segment shares of the manufacturers sales.

Table 2.8: Estimated current average retail price (including tax) by manufacturer for passenger cars

Category	Average vehicle price, €
Smaller Vehicles	17,522
Advanced Tech Average	21,483
Average Vehicles	22,997
Advanced Tech Larger	35,028
Laggard Larger Vehicles	73,331
All	**27,496**

Table 2.9: Estimated current average retail price (including tax) by manufacturer for light commercial vehicles (LCVs)

Category	Average vehicle price, €
Smaller LCV	25,230
Larger LCV	32,269
Larger LCV with xEV	37,380
All	**30,238**

2.4 Calculating the total cost of ownership (TCO) for society and end-users

This section provides an outline of the methodology used to assess the impacts of different scenarios /design options on the average new vehicle total cost of ownership (TCO) from a social perspective (i.e. lifetime costs excluding taxes and margins) and end-user perspective (for 5-year ownership periods for first and second owners, including relevant taxes, and accounting for depreciation).

The following Table 2.10 provides a summary of the key assumptions used in the TCO analysis, which incorporates estimates for the three main components impacted by the regulations, i.e.:

a) Marginal capital (i.e. purchase) cost (and residual value at the end of the ownership period);
b) Operation and maintenance costs;
c) Fuel costs.

The results of the TCO calculations are presented as Net Present Value (NPV) costs, which accounts for the discounted value of future costs, based on the societal or end-user perspective.

For the end-user TCO calculations, the remaining residual value of the vehicle (i.e. the average marginal manufacturing cost/price increase) was also accounted for, according to the depreciation profile illustrated in Figure 2.5.

Table 2.10: Assumptions used in the total cost of ownership (TCO) analysis calculations

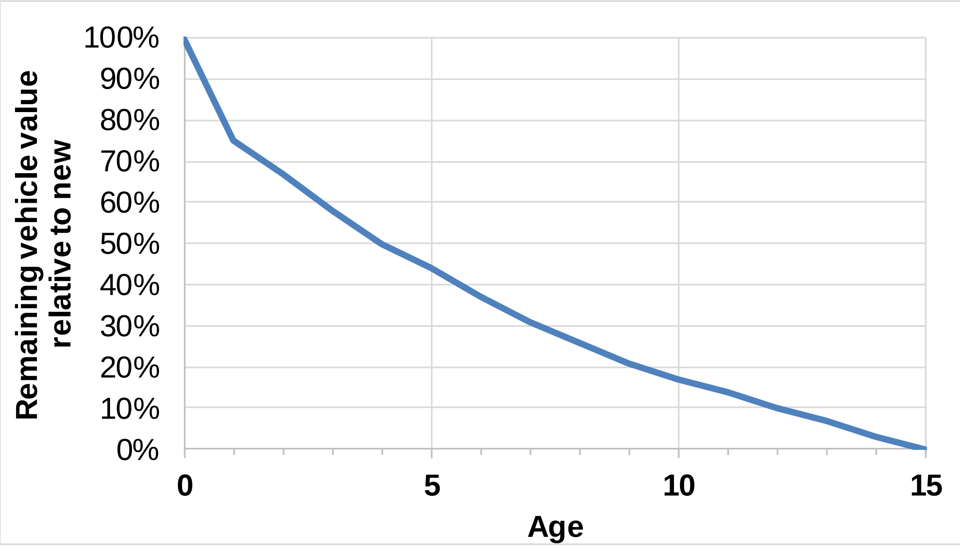
Element	Sub-category	Assumption	Notes
Discount Rate, %	Societal	4%	This societal discount rate is recommended for Impact Assessments in the Commission's Better Regulation guidelines[3].
	End user (cars)	11%	Consistent with PRIMES-TREMOVE
	End-user (LCVs)	9.5%	Consistent with PRIMES-TREMOVE
Period/age, years	Lifetime	15	Based on typical LDV lifetimes.
	First end-user	0-5	
	Second end-user	6-10	
Capital costs	All	% sales weighted average from JRC-DIONE.	Average marginal vehicle manufacturing costs (including OEM profit margins) calculated by JRC-DIONE Cross-Optimization for a given scenario.
Depreciation	All	See Figure 2.5	Based on (CE Delft et al., 2017).
Mileage profile	Total	See Table 2.11	Consistent with PRIMES-TREMOVE
	By age profile	PRIMES-TREMOVE	The overall mileage is distributed over the assumed lifetime of the vehicle in the analysis, according to an age-dependant mileage profile estimated based on PRIMES-TREMOVE model assumptions.
Mark-up factor	Cars	1.40	Used to convert total manufacturing costs to prices, including dealer margins, logistics and marketing costs and relevant taxes*. Consistent with values used in previous IA analysis according to (TNO et al., 2011), (AEA/TNO et al., 2009). The mark-up for LCVs excludes VAT, as the vast majority of new purchases of LCVs are by businesses, where VAT is not applicable.
	LCVs	1.11	
O&M costs	By LDV segment, powertrain type.	% sales weighted average of updated O&M costs.	Updated O&M end-user costs (incl. tax) based on data from PRIMES-TREMOVE, see Section 2.2.3.
VAT % rate	N/A	20%	Used to convert O&M costs including tax, to values excluding tax for societal perspective.
WLTP MJ/km	By LDV segment, powertrain, fuel	From JRC-DIONE	Calculated by JRC DIONE Fuel and Energy Cost Module, based on WLTP CO_2 reduction solutions from DIONE Cross-Optimization, and used in the calculation of average new vehicle fuel costs.
WLTP-RW factor	By LDV segment, powertrain, fuel	See Appendix 2.	Used to calculated real-world fuel consumption.

3 See: http://ec.europa.eu/smart-regulation/guidelines/tool_54_en.htm

Element	Sub-category	Assumption	Notes
Fuel prices	Including taxes	PRIMES-TREMOVE model trajectory 2025-2045.	Used in the end-user analysis
	Excluding taxes		Used in the societal analysis

Notes: * Average manufacturer profit margin is already accounted for in the cost-curves.

Figure 2.5: TCO assumptions on depreciation: the remaining value as percentage of the purchase price



Depreciation profile – remaining value as a percentage of purchase price								
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Depreciation	100%	75%	67%	58%	50%	44%	37%	31%
Year	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Depreciation	26%	21%	17%	14%	10%	7%	3%	0%

Notes: Based on (TML et al, 2016) and (CE Delft et al., 2017), adjusted to a 15-year end-point.

Overall lifetime mileage and age-dependent mileage profiles based on PRIMES-TREMOVE mileage data were used in the JRC DIONE Fuel and Energy Cost Module to calculate fuel costs, in combination with outputs of CO_2/energy consumption per km and % shares of new sales by LDV segment and powertrain type. These are summarised in Table 2.11.

Table 2.11: Lifetime vehicle mileage by LDV segment and powertrain based on PRIMES-TREMOVE

Lifetime activity, km	Passenger car				LCV		
	Small	Lower medium	Upper medium	Large	Small	Medium	Large
Petrol/BEV	155,667	177,068	184,015	213,348	107,455*		
Diesel/PHEV/REEV/FCEV	225,268	221,250	221,250	273,706	241,836		

Source: Estimates based on the PRIMES-TREMOVE model assumptions. * Petrol vans comprise a very small share of the EU vehicle fleet, and are mainly smaller vans used in applications with lower mileage where the higher cost of the diesel powertrain are less quickly offset by fuel savings.

2.5 Assessing the distribution of impacts across income groups (social equity)

The aim of this subtask was to assess the impacts of different transport policy scenarios across income groups. The analysis focuses on the potential repercussions for different household income categories of different options for regulating car manufacturers' CO_2 emissions. For this, we have considered five household categories depending on their income per capita. The analysis was based on a combination of quantitative post-processing analysis of the PRIMES-TREMOVE and GEM-E3 modelling outputs, and qualitative analysis based mainly on existing Commission studies in this area. Presented below is the methodological steps that were followed to assess such impacts. These are also further outlined in the following subsections:

A. Steps related to the socio-economic elements for the baseline scenario;
B. Steps related to the transport elements for the baseline and the policy option scenario;
C. Final steps related to the economic perspective to calculate impacts for the policy scenarios modelled with GEM-E3 only.

2.5.1 Steps related to the socio-economic elements for the baseline scenario

A1. Construction of a complete dataset of population distribution income for 2015. Data regarding the split of the population was taken from the Eurostat EU-SILC (Survey in Income and Living Conditions) database[4]

A2. The consumption by purpose statistics (COICOP) were used to determine consumption patterns by income group. This provided information on how much each income group spends on purchasing transport equipment and how much on operating it.

A3. Projection of the income distribution to 2050 was estimated to be consistent with the baseline scenario. This means that the GEM-E3 model was adjusted to the new baseline scenario of this project. This adjustment on the baseline scenario was necessary to ensure that the scenario results coming from the two models were consistent and robust. Consistency refers to the evolution of the economic activity of the sector of passenger cars (i.e. activity), composition of vehicle mix, fuel mix, evolution of fuel cost and vehicle purchasing expenditures.

2.5.2 Steps related to the transport elements for the baseline and the transport policy scenario

B1. Yield purchasing prices for the average vehicle per time-period and age cohort (i.e. categories: 0-5, 5-10, >10 years). Depreciation due to age applies. This step applies to both Baseline and the Policy scenario. Source: PRIMES-TREMOVE.

B2. Yield average specific fuel consumption per time-period and age cohort (averaging over all new vehicles purchased for each time-period). This step applies to both Baseline and the Policy scenario. Source: PRIMES-TREMOVE.

B3. Yield the evolution of the average energy price (i.e. weighted average over quantities of fuel sold and energy prices). This step applies to both Baseline and the Policy scenario. Source: PRIMES-TREMOVE.

B4. Assume certain utilisation of vehicles. This is the annual mileage the potential buyer is considering to carry out when deciding to purchase a car and remains unchanged across household categories. Source: PRIMES-TREMOVE.

B5. Calculation of annual fuel costs for the Baseline and the Policy scenario using information from Steps B2, B3 and B4. Costs are expressed in Euro/ average vehicle.

B6. Calculation of average annual expenditure per vehicle corresponding to each age cohort of vehicles and for each time-period. Fuel costs from Step B5 are used. Purchase prices for average vehicle

[4] Eurostat Database: ilc_di01

are used from Step B1 and are transformed into annuity payments. Calculation of annuity differs by household category due to different discount rates and economic lifetimes. Households with lower income per capita are assumed to bear higher discount rates and longer economic lifetimes for their cars.

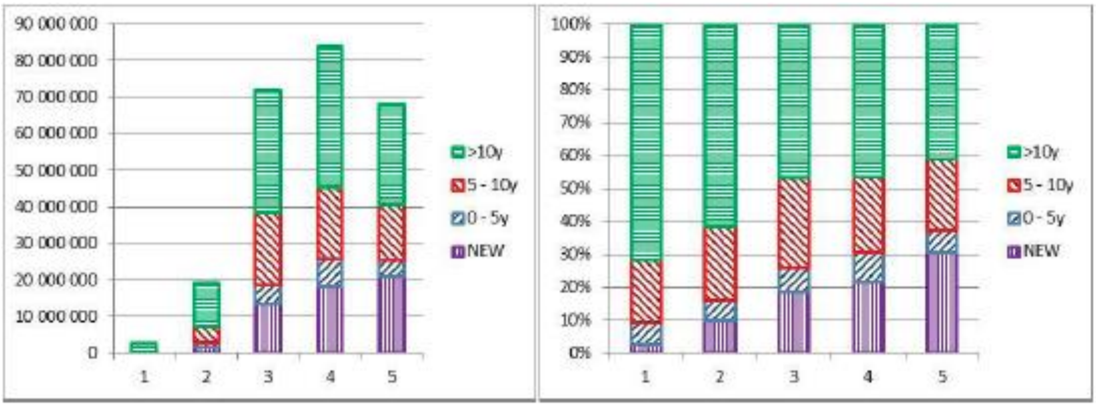
B7. Calculation of the average savings/expenditures in the Policy scenario relative to Baseline for each household, each vehicle age cohort and for each time-period. The change in the new vehicle mix changes the average characteristics (average purchasing price and average annual fuel costs as a result of the lower specific fuel consumption). The characteristics of the vintages are tracked down in modelling throughout the projection period. This results in differences in the total average annual expenditures between the policy scenario and the Baseline. Changes become visible mainly from 2030 onwards (since the policy implementation starts differentiating from 2025 onwards).

B8. Calculation of average expenditures/savings corresponding to each household income group by averaging over the age cohorts of the vehicles being purchased (i.e. assuming the patterns of age of vehicles purchased by income group- see Figure 2.6 below from (TML et al, 2016). The outcome from Step B8 reflects expenditures or savings in Euros/vehicle purchased for each household category.

B9. Calculation of total additional expenditures/savings corresponding to each income group. This figure will be derived by multiplying the costs (Euro/vehicle) from STEP B8 times the total cars purchased by household category (both new registrations and second-hand cars). The overall vehicles sold are known from the PRIMES-TREMOVE results for each scenario run. The split by household category will draw from the shares of the reported values from the figure above. The overall total difference in the policy scenario versus the Baseline will be harmonized with outputs related to capital and fuel cost expenditures from PRIMES-TREMOVE in the abovementioned scenarios.

Figure 2.6: EU estimates of the passenger car fleet, by income group and used car category

absolute figures	1	2	3	4	5	TOTALS
TOTAL	2 790 472	19 290 866	72 087 805	84 210 716	68 300 064	246 679 924
0 - 5y	181 284	1 139 602	5 328 798	7 697 836	4 706 162	19 053 682
5 - 10y	532 139	4 276 148	19 635 599	19 289 577	14 799 402	58 532 866
>10y	1 999 411	11 905 718	33 661 809	38 891 554	27 817 124	114 275 616
NEW	77 639	1 969 398	13 461 599	18 331 749	20 977 376	54 817 761
TOTAL USED	2 712 834	17 321 468	58 626 206	65 878 967	47 322 688	191 862 163
relative distributions	1	2	3	4	5	TOTALS
TOTAL	1%	8%	29%	34%	28%	100%
0 - 5y	1%	6%	28%	40%	25%	100%
5 - 10y	1%	7%	34%	33%	25%	100%
>10y	2%	10%	29%	34%	24%	100%
NEW	0%	4%	25%	33%	38%	100%
TOTAL USED	1%	9%	31%	34%	25%	100%



Source: (TML et al, 2016)

2.5.3 Final steps related to the economic perspective to calculate impacts for the policy scenario

The following steps conclude the methodology for the overall system-level social equity analysis and were individually calculated for each household income category.

C1. Use the output of GEM-E3 model in the policy scenario (changes in income) to recalculate consumption expenditures across all COICOP categories for each EU MS up to 2050. The Classification of Individual Consumption According to Purpose shows how the disposable income of households is allocated amongst the different consumption categories. COICOP serves as a harmonized nomenclature regarding consumption expenditure in Household Budget Surveys. When COICOP expenditures are examined over different household income deciles it allows to derive useful insights regarding households' consumption patterns. In particular, the quantification with the GEM-E3 model shows what the impacts are of transport policies and regulations on households' disposable income and expenditure on cars and fuels.

C2. Finally, using the input from the methodology presented in Steps B1-B9, a welfare indicator was computed showing in monetized terms how much the different household income classes are better or worse off.

2.5.4 Sensitivity analysis

Sensitivity analysis over certain parameters was also conducted at the end of the exercise to examine the degree of change and influence of the critical parameters (e.g. depreciation over age). The results of the social equity analyses are presented in the relevant sections of Chapters 3- 6 of this report.

3 Options regarding target level and timing

3.1 Setting the level and timing for future targets

Different options were defined for the levels of the CO_2 targets and for the timing of targets. The following options have been investigated with respect to the ***timing*** of the post-2020 targets:

i. Have a new target for 2030 only;
ii. Have separate new targets for 2025 and 2030;
iii. Have annual targets (2023-2030).

Due to the PRIMES-TREMOVE model's fixed 5-year calculation intervals, the third option was only analysed from a qualitative perspective.

With respect to the ***level*** of the targets, options are defined in terms of the percentage reduction in 2030 (versus the 2020/2021 targets for cars and vans) as the new Regulation will need to be based on the new WLTP test cycle, while the exact 2021 WLTP-based targets are not yet known. A wide range of options have been considered ranging from 10% to 50% reduction of the targets by 2030. This includes options consistent with the statements made by the Commission in the Council at the time of adoption of the 2014 Regulations[5] [6].

An option with 10% reduction by 2030 was not modelled as the new baseline scenario already achieves more than 10% improvement by 2030. A summary of the range of potential CO_2 reduction trajectories is provided in Table 3.1.

The quantitative assessment of the impacts of different ambition and timing options and the subsequent recommendations for prioritisation are presented in Section 3.2 of this report.

Table 3.1: Summary of the different options for CO_2 reductions (% reduction to 2020/2021 target) assessed by modelling analysis

		Cars		LCVs	
Name	**Description**	**2025**	**2030**	**2025**	**2030**
Low (L) [20%]	**Linear 20% reduction on 2020/1 for cars and LCVs**	**9.4 %**	**20.0%**	**10.6%**	**20.0%**
Central (C) [30/25%]	**Linear 30% reduction on 2020/1 for cars; 25% for LCVs**	**14.7%**	**30.0%**	**13.4%**	**25.0%**
High (H) [40%]	**Linear 40% reduction on 2020/1 for cars and LCVs**	**20.3%**	**40.0%**	**22.5%**	**40.0%**
68g NL	Reduction by 2025 to equivalent of 68g/km / 105g/km NEDC for cars /LCVs, then linear trajectory to equivalent of 25g/km / 60g/km NEDC for cars / LCVs by 2050	28.4%	41.4%	28.6%	36.1%
Very High (V) [50%]	Linear 50% reduction on 2020/1 for cars and LCVs	26.5%	50.0%	29.3%	50.0%

5 http://register.consilium.europa.eu/doc/srv?l=EN&f=ST%206642%202014%20ADD%201%20REV%201
6 http://register.consilium.europa.eu/doc/srv?l=EN&f=ST%205584%202014%20ADD%201

3.2 Impacts of options regarding target level and timing

3.2.1 Assessing the effectiveness in reducing CO_2 emissions

3.2.1.1 TTW GHG emissions

The model, as expected, correlates tailpipe emission reductions for cars and vans with the implementation of progressively tightening targets, as illustrated in Figure 3.1 to Figure 3.3 below.

The timing of the implementation of the target is also found to drive changes in the evolution of TTW GHG emissions, i.e. the model does not simply result in a linear emission reduction trajectory in the absence of intermediate targets. The effect of intermediate 2025 targets can be seen from the comparison of the scenarios C-30-MNM (target set for 2030 only) and C-25-MNM (target set for 2025 and 2030).

The implementation of an intermediate target acts as an additional constraint on the performance of manufacturers on the pathway towards compliance with the targets of 2030. In addition, CO_2 emissions from the whole LDV fleet are found to be notably lower by 2030 in the scenario with the intermediate target – achieving 6.7% reduction versus the baseline in comparison to 5.5% without intermediate targets – see Figure 3.3. In other words, the absence of targets in 2025 risks delaying the deployment of more efficient vehicle technologies into the fleet by 2030, and consequently reducing the improvement in fleet-wide CO_2 emissions reductions (and the cumulative effects of this).

Figure 3.1: LDV TTW GHG emissions in 2030 for selected scenarios with different target levels and timing

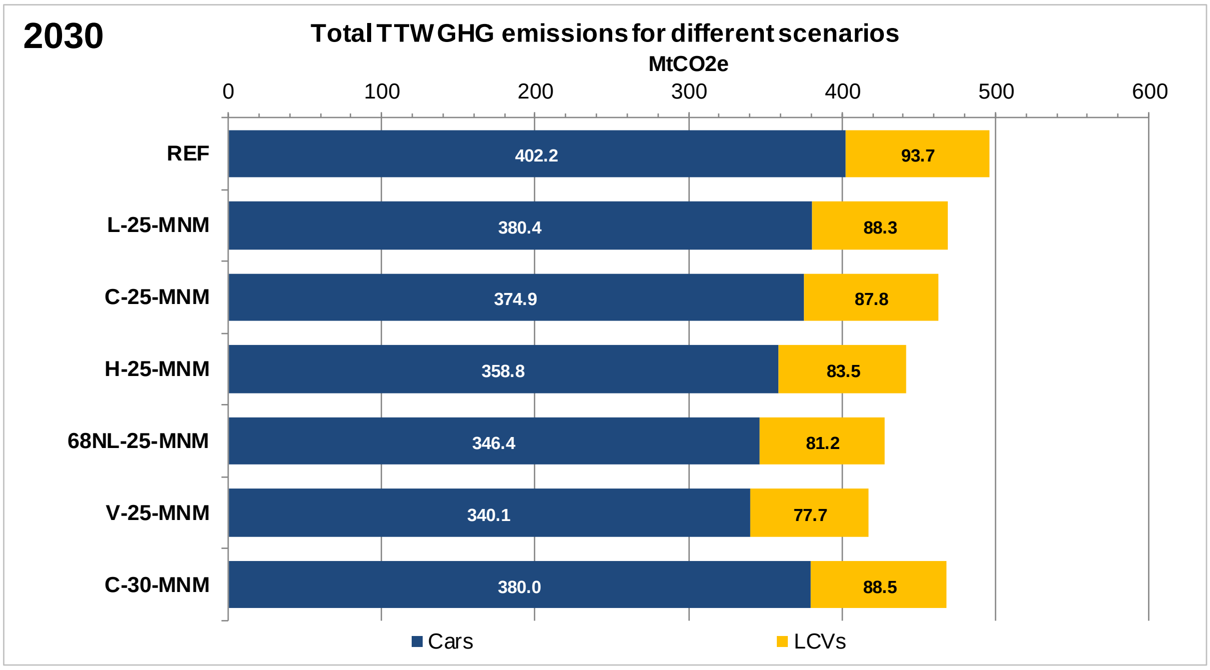
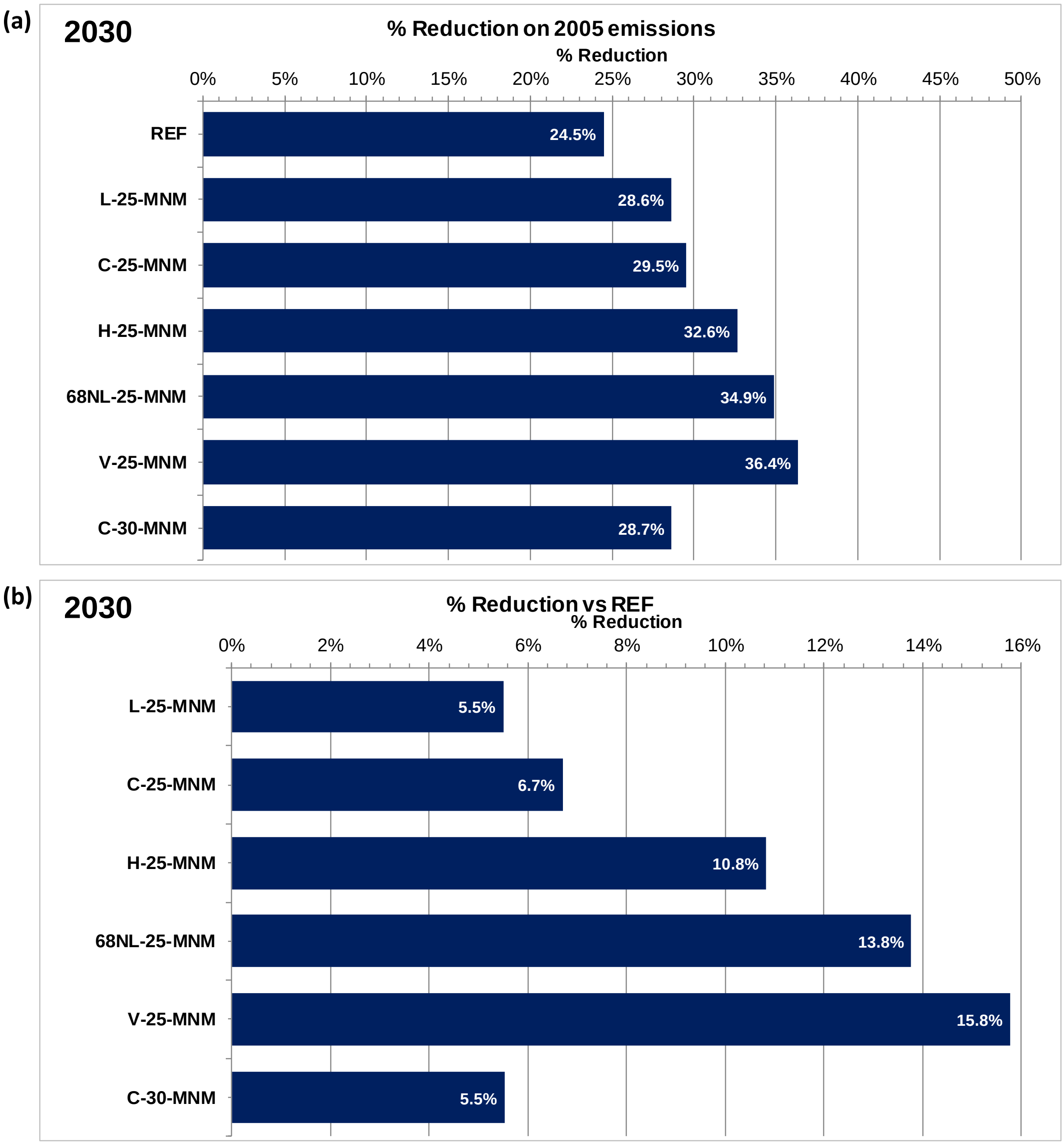


Figure 3.2 presents the same results, but expressed as emission reductions in 2030 relative to 2005. All policy scenarios considered deliver greater emission reductions compared to the Baseline scenario.

The highest emission reductions occur under the V-25-MNM scenario, i.e. 36.4% lower in 2030 relative to 2005.

Figure 3.2: LDV TTW GHG emission reduction in 2030 for selected scenarios with different target levels and timing, (a) relative to 2005, (b) relative to the baseline scenario



As a sensitivity, three scenarios were also quantified under an alternative set of cost assumptions.

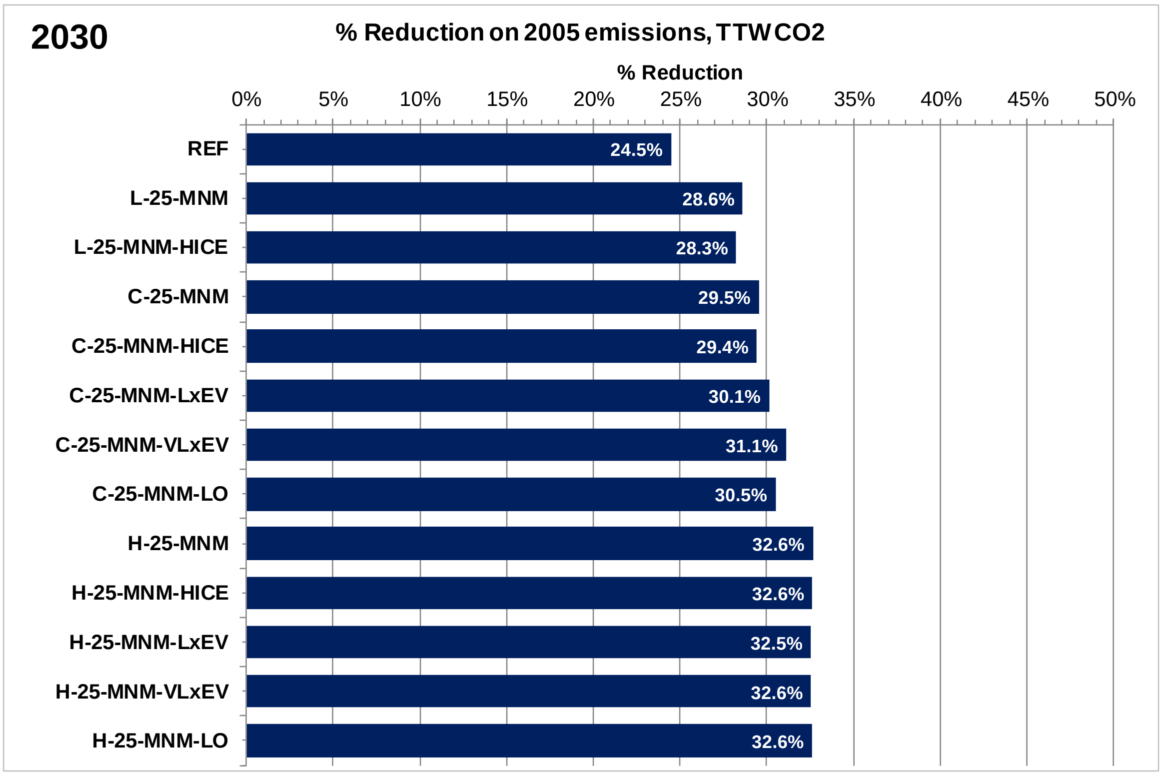
The label HICE denotes that the costs for conventional ICE (and full hybrid powertrain) are higher than in the C-25-MNM, H-25-MNM and L-25-MNM scenarios. For the -HICE scenarios, the TTW GHG emissions reduction remains relatively unchanged in case of the C-25-MNM and H-25-MNM scenarios, but for L-25-MNM the CO_2 savings are reduced as the model overachieves to a lesser extent on meeting the CO_2 reduction targets.

The scenarios termed as -LxEV (Low xEV costs) and -VLxEV (Very Low xEV costs) reflect lower future battery cost assumptions. The lower costs of xEVs will result in further emissions reductions in 2030 in case of a Central level of ambition target. This implies that the target set in the Central scenario would be overshot as a result of the increased competitive advantage of the xEVs. Such target overshooting is not the case, though, under the High Level of ambition case, where targets are costlier to achieve.

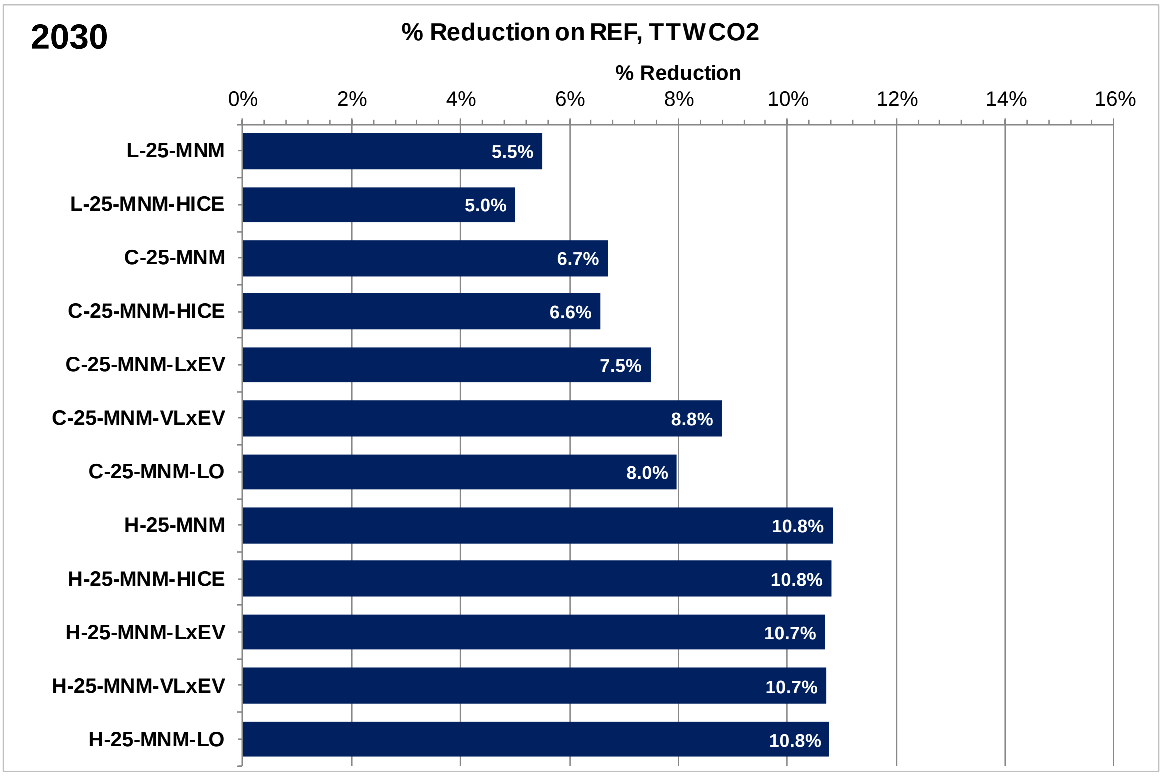
The Central and High ambition scenarios were also quantified assuming more optimistic cost assumptions for all technologies (labelled as -LO). The emission reduction in the central ambition is even higher than in the case where only the costs of batteries were more optimistic (30.5% vs 30.1% in the C-25-MNM-LxEV). Again, for the high ambition, low cost case there is little change in the GHG emissions reductions.

Figure 3.3: LDV TTW GHG emission reduction in 2030 for different ambition levels and cost technology scenarios, (a) relative to 2005, (b) relative to the baseline scenario

(a)



(b)



It is notable that the difference in overall GHG reductions is much smaller between the central (C-25-) and low (L-25-) ambition scenarios than between the central and high (H-25-) ambition equivalent scenarios. This differential appears to be due to a certain degree of over-achievement of the CO_2 target constraint for the low ambition scenario (in particular in 2025).

3.2.1.2 WTW GHG emissions

The WTW emissions for selected options with different target levels are shown in Table 3.2. WTW emissions include both the TTW (tailpipe) emissions and the WTT (upstream) emissions related to the production and distribution of transport fuels. WTT emissions for petroleum products include emissions at the refinery stage and during the extraction of crude oil. WTT emissions of electricity depend on the power generation mix and thus differ by EU Member State. WTT emission factors are derived from the PRIMES energy systems model, and were updated in this project to also include emissions from upstream processes outside the EU for conventional petroleum-based fuels (consistent with the emission factors used in the Renewable Energy Directive for the WTT and WTW emissions for fossil fuels). The TTW emissions are the largest component of the WTW emissions.

The overall WTW GHG emissions reductions increase, relative to the baseline, as the level of ambition increases from 20% (L-25-MNM) to 50% (V-25-MNM). More specifically, TTW emissions from gasoline and diesel vehicles decrease under all scenarios, while increases in the WTT emissions associated with electricity and hydrogen consumption are observed (Table 3.2). This effect is also further discussed in Section 5.3.1 for LEV incentives.

Table 3.2: WTW GHG emissions in 2030 for selected scenarios with different target levels, $ktCO_2e$

	REF	L-25-MNM	C-25-MNM	H-25-MNM	68NL-25-MNM	V-25-MNM	C-30-MNM
Total transport emissions (WTW)	**1,161,427**	**1,123,477**	**1,116,997**	**1,095,786**	**1,080,776**	**1,071,217**	**1,123,335**
of which TTW CO_2 emissions	*937,784*	*906,044*	*900,085*	*879,644*	*865,112*	*855,227*	*905,872*
Total road transport emissions (WTW)	**905,265**	**870,097**	**863,396**	**841,395**	**825,707**	**815,722**	**869,937**
Passenger cars	494,746	470,972	464,778	447,517	434,290	427,849	470,556
LCVs	114,458	108,442	107,952	103,400	101,027	97,673	108,692
Total LDV emissions by fuel (WTW)	**609,204**	**579,414**	**572,730**	**550,917**	**535,317**	**525,522**	**579,248**
LPG	22,296	23,255	23,829	24,545	25,942	25,064	23,347
Gasoline	186,572	174,739	172,504	164,880	157,910	155,398	174,595
Diesel oil	371,621	350,027	344,715	327,841	316,666	308,594	349,882
Natural gas	10,437	10,360	10,229	9,699	9,098	8,798	10,359
Electricity	6,885	6,998	7,521	9,695	11,356	12,886	7,045
Hydrogen	1,817	3,940	4,158	5,345	6,109	6,988	3,958
Biomass Diesel substitutes	7,464	7,087	6,973	6,634	6,408	6,247	7,084
Biomass Gasoline Substitutes	3,955	3,716	3,664	3,501	3,355	3,302	3,712
Biogas	121	130	128	122	118	114	130
% Diff. to REF							
Total transport		**-3.3%**	**-3.8%**	**-5.7%**	**-6.9%**	**-7.8%**	**-3.3%**
Total road		-3.9%	-4.6%	-7.1%	-8.8%	-9.9%	-3.9%
Total LDVs		-4.9%	-6.0%	-9.6%	-12.1%	-13.7%	-4.9%
Cars		-4.8%	-6.1%	-9.5%	-12.2%	-13.5%	-4.9%
LCVs		-5.3%	-5.7%	-9.7%	-11.7%	-14.7%	-5.0%

3.2.2 Assessment of other impacts

Positive externalities in terms of reduced air pollution and ambient noise occur when more ambitious targets are in place compared to the Baseline scenario. Positive externalities are mostly driven by the penetration of xEV (e.g. BEVs and FCEVs) and thus increase with increasingly ambitious target levels. (see Table 3.3). The changes in accidents and congestion costs, are due to changes in overall activity resulting on elasticities of demand with changes in transport costs in the model. The following paragraphs present the benefits and impacts by type of externality in more detail.

Table 3.3: (Change in) external costs of other impacts from transport in 2030 for scenarios differing in target levels and timing, million Euro

	REF	L-25-MNM	C-25-MNM	H-25-MNM	68NL-25-MNM	V-25-MNM	C-30-MNM
Million Euro							
Accidents	77,376	77,378	77,403	77,468	77,603	77,537	77,377
Noise	11,415	10,968	10,852	10,309	9,939	9,702	10,958
Congestion	192,233	191,943	191,928	191,942	192,172	192,022	191,924
Air Pollution	9,052	8,637	8,527	8,163	7,924	7,759	8,623
Total	**290,075**	**288,925**	**288,710**	**287,882**	**287,638**	**287,020**	**288,882**
% Difference to REF							
Accidents		0.0%	0.0%	0.1%	0.3%	0.2%	0.0%
Noise		-3.9%	-4.9%	-9.7%	-12.9%	-15.0%	-4.0%
Congestion		-0.2%	-0.2%	-0.2%	0.0%	-0.1%	-0.2%
Air Pollution		-4.6%	-5.8%	-9.8%	-12.5%	-14.3%	-4.7%
Total		**-0.4%**	**-0.5%**	**-0.8%**	**-0.8%**	**-1.1%**	**-0.4%**

The policy scenarios also lead to a reduction in the consumption of petroleum oil products in the EU transport system by 2025 and 2030. The reduction in demand for petroleum products limits the need for imported quantities of both crude oil that is refined in EU refineries and the quantities of refined petroleum products that are available for final consumption.

The vast majority of petroleum products and crude oil are imported. Hence, their substitution with other energy carriers such as electricity reduces the need for imports and thus the import dependency of the transport sector. Figure 3.4 presents the final energy demand for gasoline and diesel in the scenarios under comparison.

In addition, the EU has an energy efficiency objective to reduce energy consumption by 30% by 2030, relative to the 2007 baseline projection (European Commission, 2017) (European Commission, 2007b). The 2016 Commission Proposal for a revised Energy Efficiency Directive is currently being discussed by the European Parliament and the Council. Whilst there is no specific target/objective for transport, it is useful to assess the contribution that could be made under different post-2020 regulatory targets. Figure 3.5 shows the energy consumption reductions achieved for different options for CO_2 standards for cars and vans. Implementing more ambitious targets on LDV manufacturers leads to higher energy savings due to the penetration of less carbon intensive and more efficient technologies. The market uptake of battery electric vehicles is expected to lead to significant reductions in final energy demand compared to the conventional technologies.

Figure 3.4: Demand for gasoline and diesel from LDVs for different options for target level and timing compared to the baseline scenario

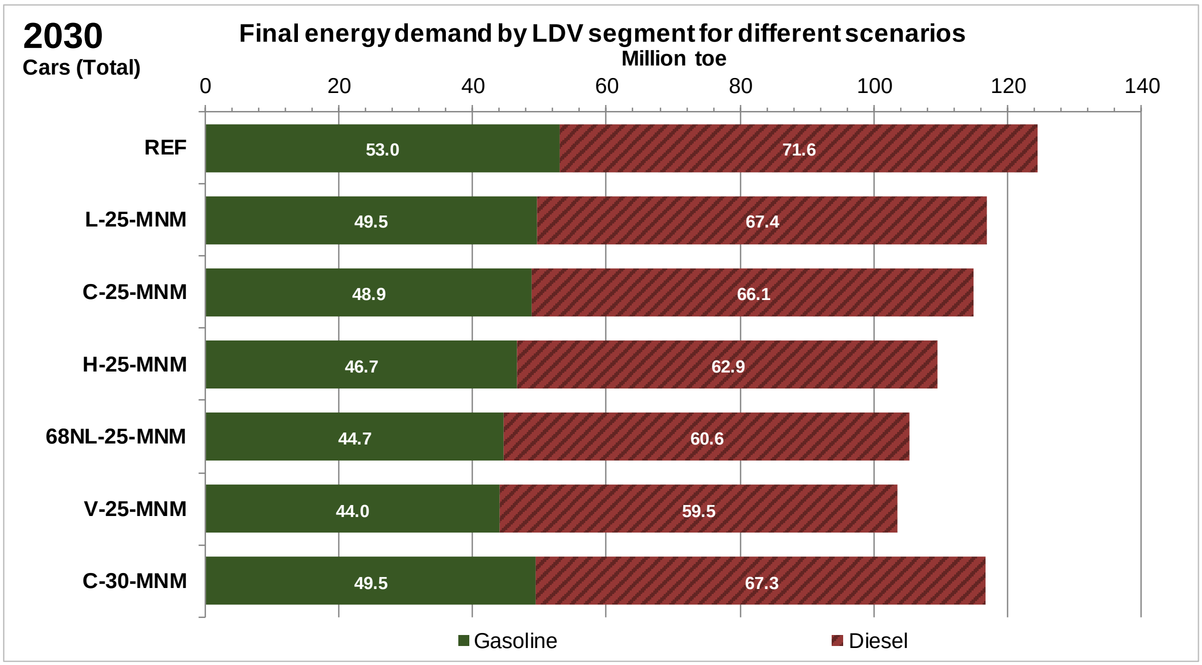
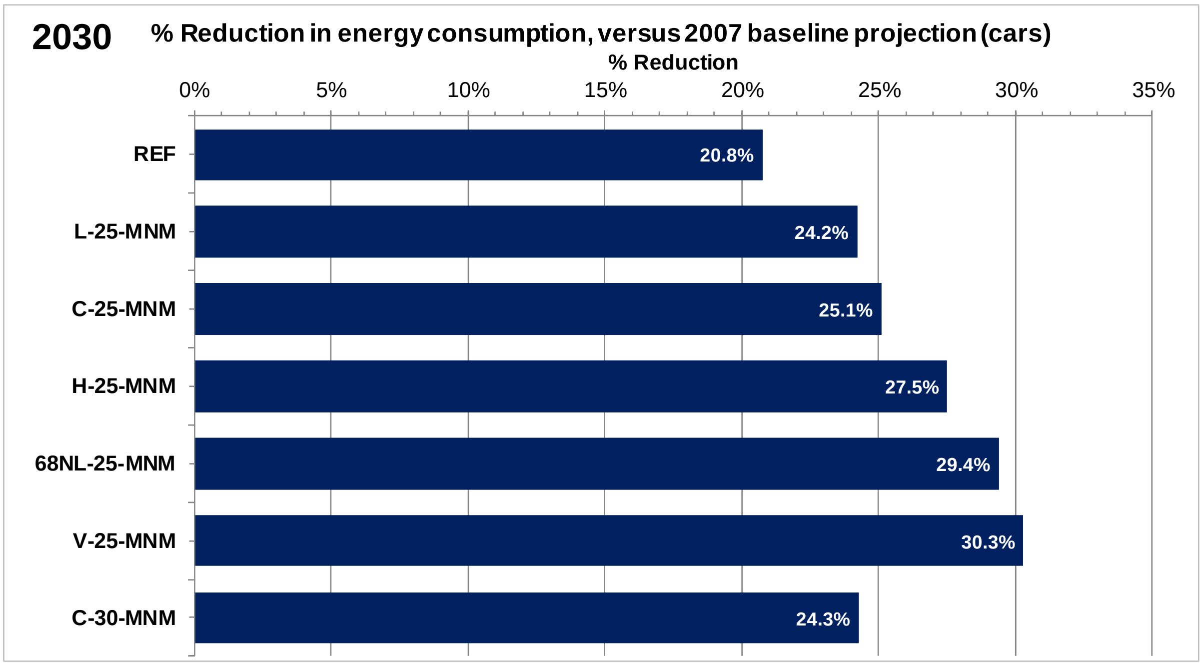


Figure 3.5: Reduction in overall energy consumption from cars in 2030 for selected scenarios with different options for target level and timing, relative to 2007 baseline projection*



3.2.2.1 Air pollutant emissions

The model identifies a positive correlation between the reduction of external costs from air pollution and the implementation of stricter CO_2 targets– see Table 3.3. External costs from air pollution depend on the actual volume of pollutants. The latter decreases with the penetration of more fuel-efficient cars but most importantly with the penetration of advanced vehicle powertrains and in particular zero emission vehicles like BEVs and FCEVs. The pollutants under consideration are mainly NOx and PM. The latter are responsible for the largest share in the overall external costs from air pollution in transport. Diesel powered cars are mainly associated with higher levels of NOx and PM emissions. This is also illustrated later for the "lower diesel share" sensitivity scenarios with significantly lower penetration of diesel cars assumed in later periods (see Section 3.2.9).

3.2.2.2 Noise

External costs from noise are also found to decrease with increasing stringency of the targets, driven mostly by the penetration of advanced powertrains– see Table 3.3. In urban areas, the reduction in the external costs from noise is higher as a result of the higher concentration of BEVs compared to other non-urban areas. However, most noise costs are due to high-speed traffic where there is little-no difference between ICEVs and BEVs (i.e. noise damage costs are dominated by tyre/road noise which is the same for both EVs and ICEVs). The external costs from transport represent 3.2% of total transport system external costs in 2030 in the C-25-MNM scenario.

3.2.2.3 Other impacts (congestion, accidents, etc.)

The implementation of new targets has not been found to have important impacts on the external costs from congestion and accidents– see Table 3.3. In fact, these externalities are not associated with the powertrain and the fuel of the vehicle, but are influenced by the level of traffic (i.e. most important for congestion but also applies to accidents) and potential improvements in the safety of vehicles (i.e. for accidents). Hence, no direct impact is associated, only second order effects.

3.2.3 Assessment of net costs for manufacturers and society

3.2.3.1 Impacts on average vehicle Total Cost of Ownership (TCO)

The average[7] total cost of ownership (TCO) for new vehicles has been calculated to assess the economic and societal impacts of different ambition levels for cars and LCVs from a societal and end-user perspective. The TCO for the second end-user also provides a useful indicator of potential impacts for social equity, as a much greater share of second-hand vehicles is purchased by lower income households according to recent analysis for the Commission (TML et al, 2016). The key assumptions used in the TCO analysis were summarised in earlier Section 2.4.

The results of this analysis, illustrated in Figure 3.6 and Figure 3.7 below for a range of ambition levels, show significant net TCO benefits (i.e. NPV cost savings excluding externalities) for societal or end-user perspectives for both cars and LCVs across most ambition levels, with the benefits for 2030 new vehicles exceeding those for 2025 new vehicles.

For passenger cars, the net savings are generally greatest for the second end-user (with potential social equity benefits), while for LCVs the greatest savings are for first end-users – which has positive implications for the initial purchasing decision (which is in most cases by businesses for LCVs). Whilst net savings are greatest for the central ambition level for cars, there are still significant net savings for the high ambition level. Net TCO savings for cars are generally significantly smaller (and even negative from the societal perspective in 2025) for the 68NL scenario, and for the very high ambition level.

When including accounting for the external costs of GHG emissions, air quality pollutant emissions and other impacts, the greatest overall (direct + externalities) cost savings in 2030 from the societal perspective are reached by the High and 68gNL scenarios, see Table 3.4 below.

For LCVs, there are substantial net TCO savings across all ambition levels and perspectives for both 2025 and 2030, with the high ambition (40% reduction) scenario showing the highest net benefits in many cases. When including externalities, the very high ambition scenario shows the greatest overall societal cost savings in 2030, as well as the highest savings for end-users, see Table 3.5.

[7] The costs for an 'average' vehicle are based on a sales weighted average of the costs calculated for different manufacturers, market segments and powertrains which were output from the DIONE modelling.

Figure 3.6: Summary of the average vehicle Total Cost of Ownership (TCO) for passenger cars registered in 2025 under different target level options compared to the baseline scenario for societal and end-user perspectives

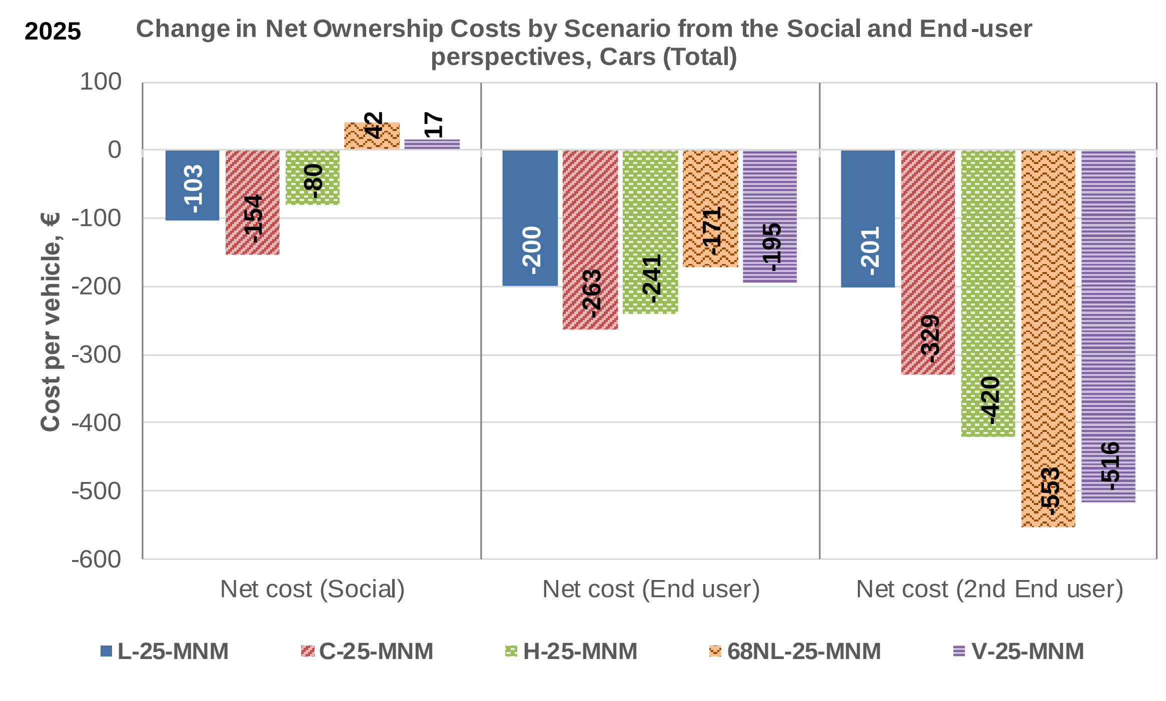


Figure 3.6: Summary of the average vehicle Total Cost of Ownership (TCO) for passenger cars registered in 2025 under different target level options compared to the baseline scenario for societal and end-user perspectives

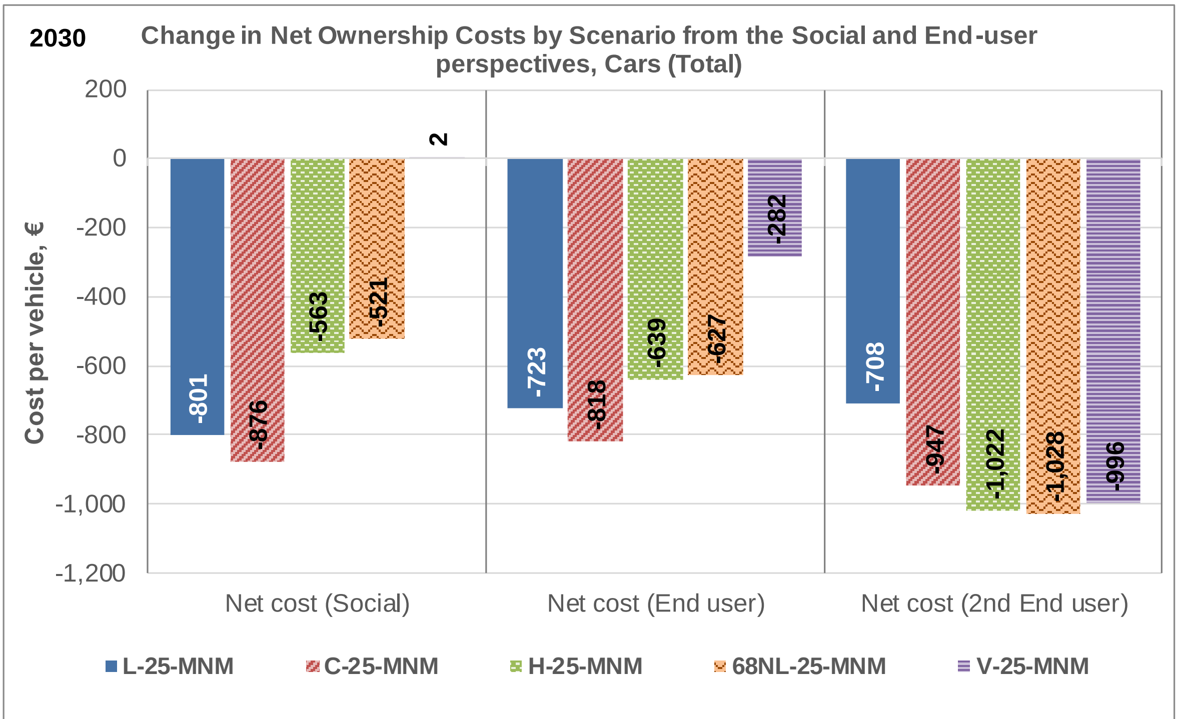
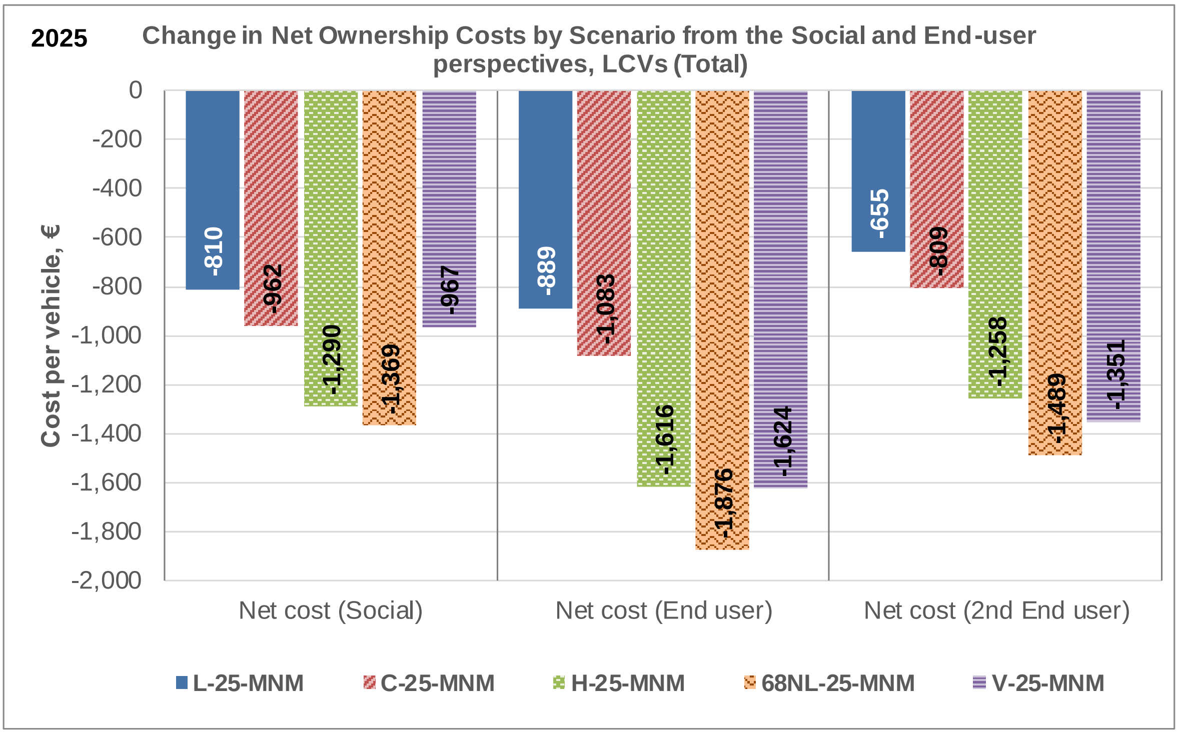


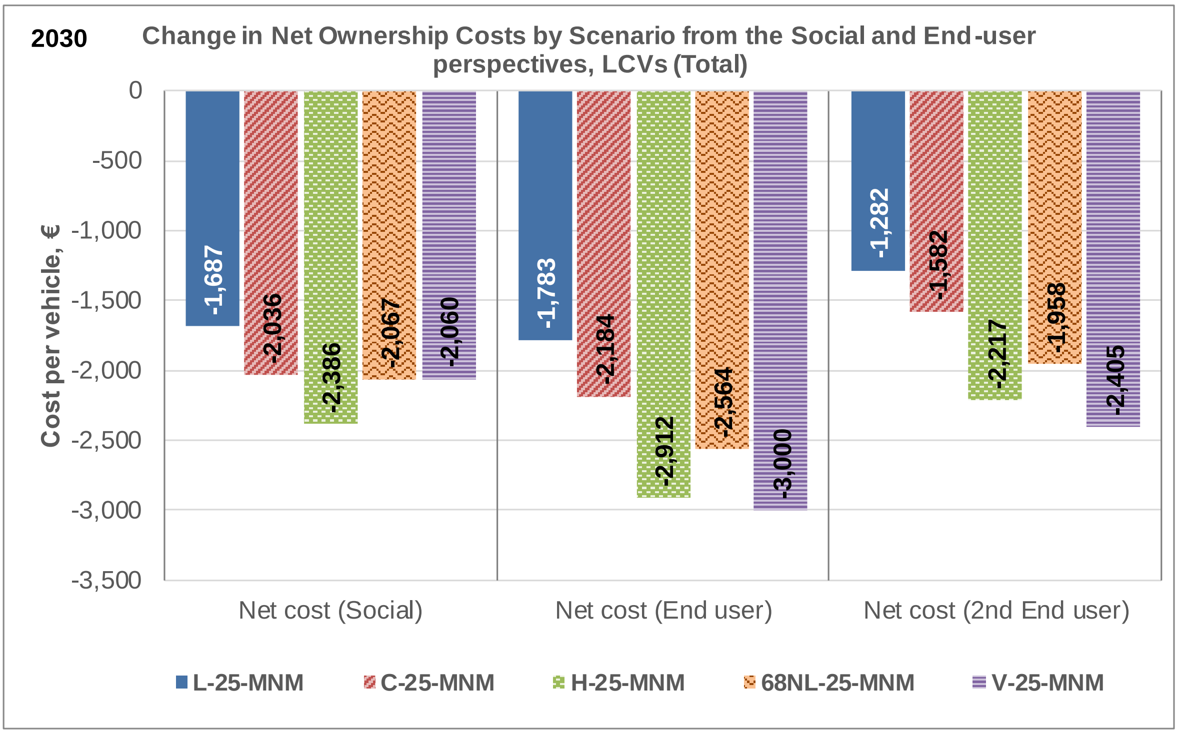
Table 3.4: Summary of the average vehicle Total Cost of Ownership (TCO) (EUR/vehicle) for new passenger cars registered in 2030 under different target level options compared to the baseline scenario for societal and end-user perspectives

	ERU/vehicle	L-25-MNM	C-25-MNM	H-25-MNM	68NL-25-MNM	V-25-MNM
Societal (Lifetime)	Manufacturing cost	419	1,020	1,812	1,861	2,752
	Fuel cost	-1,159	-1,802	-2,220	-2,214	-2,558
	O&M cost	-61	-94	-155	-168	-192
	Net cost	**-801**	**-876**	**-563**	**-521**	**2**
	WTW GHG external costs	*-622*	*-967*	*-1,281*	*-1,313*	*-1,582*
	Other external costs	*-194*	*-210*	*-268*	*-284*	*-343*
	Total Costs incl. externalities	***-1,616***	***-2,053***	***-2,111***	***-2,118***	***-1,923***
First end-user (5 yrs)	Manufacturing cost	328	799	1,419	1,456	2,154
	Fuel cost	-1,025	-1,576	-1,992	-2,012	-2,354
	O&M cost	-26	-40	-66	-71	-82
	Net cost	**-723**	**-818**	**-639**	**-627**	**-282**
Second end-user (5 yrs)	Manufacturing cost	158	385	684	702	1,039
	Fuel cost	-841	-1,292	-1,640	-1,659	-1,953
	O&M cost	-26	-40	-66	-71	-82
	Net cost	**-708**	**-947**	**-1,022**	**-1,028**	**-996**

Notes: **Societal** view = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** view = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

Figure 3.7: Summary of the average vehicle Total Cost of Ownership (TCO) of different options for LCVs compared to the baseline scenario for societal and end-user perspectives, by ambition level





Notes: **Societal** view = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** view = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

Table 3.5: Summary of the average vehicle Total Cost of Ownership (TCO) (EUR/vehicle) of different options for new LCVs registered in 2030 compared to the baseline scenario for societal and end-user perspectives, by ambition level

	EUR/vehicle	L-25-MNM	C-25-MNM	H-25-MNM	68NL-25-MNM	V-25-MNM
Societal (Lifetime)	Manufacturing cost	426	620	1,582	1,415	2,439
	Fuel cost	-2,063	-2,600	-3,827	-3,341	-4,261
	O&M cost	-50	-55	-142	-141	-239
	Net cost	**-1,687**	**-2,036**	**-2,386**	**-2,067**	**-2,060**
	WTW GHG external costs	*-1,003*	*-1,302*	*-2,047*	*-1,813*	*-2,458*
	Other external costs	*-167*	*-174*	*-389*	*-339*	*-597*
	Total Costs incl. externalities	**-2,854**	**-3,509**	**-4,817**	**-4,216**	**-5,108**
First end-user (5 yrs)	Manufacturing cost	265	386	984	879	1,516
	Fuel cost	-2,026	-2,546	-3,833	-3,382	-4,412
	O&M cost	-22	-24	-62	-61	-104
	Net cost	**-1,783**	**-2,184**	**-2,912**	**-2,564**	**-3,000**
Second end-user (5 yrs)	Manufacturing cost	128	186	474	424	731
	Fuel cost	-1,388	-1,743	-2,629	-2,321	-3,032
	O&M cost	-22	-24	-62	-61	-104
	Net cost	**-1,282**	**-1,582**	**-2,217**	**-1,958**	**-2,405**

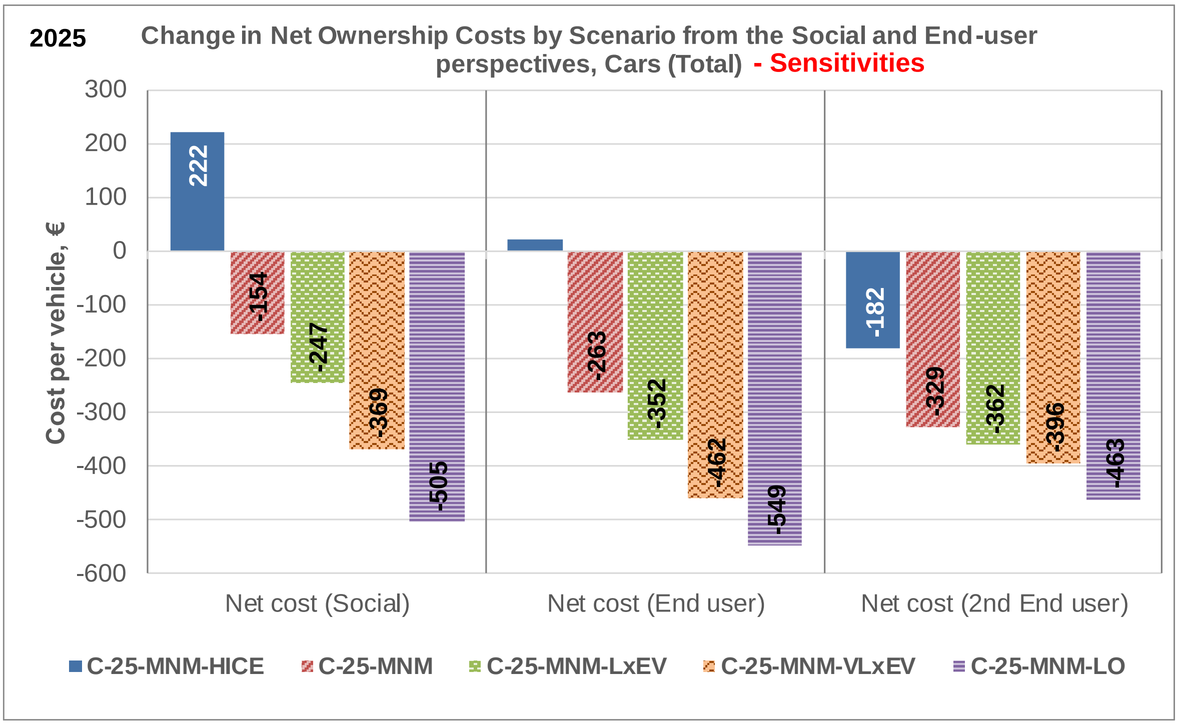
Notes: **Societal** view = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** view = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

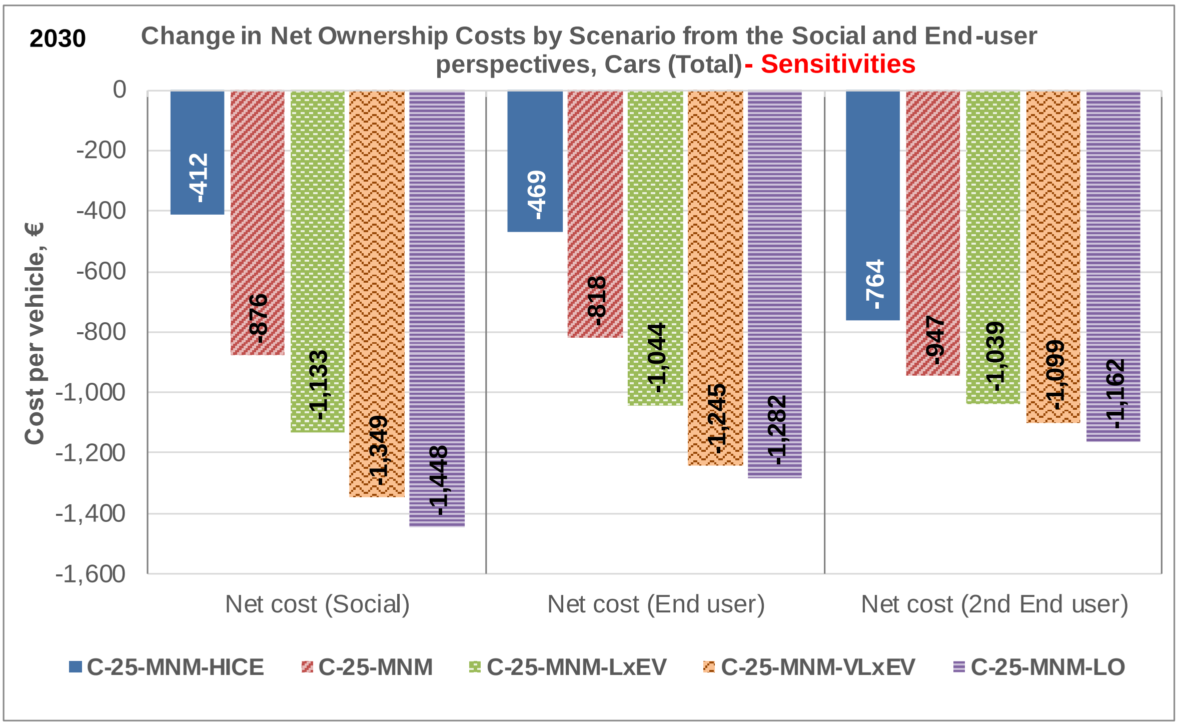
3.2.3.1.1 TCO sensitivities on technology costs

Figure 3.8 and Figure 3.9, provide a summary of the TCO results for the sensitivities using different cost-curve assumptions for the central scenario for passenger cars and for LCVs (respectively). The scenarios in these figures are presented from highest cost (-HICE) to lowest cost (-LO), as summarised in earlier Table 2.5 in Section 2.2.2.3. The results for cars show a spread in TCO of around €1000 between highest and lowest costs for the societal and end-user perspectives. On a societal perspective net costs in 2025 are higher than the baseline scenario for the highest cost (HICE) assumptions; however, these would become net savings also factoring in reductions in external costs (i.e. from reductions in GHG, air pollutant emissions, etc.). For LCVs, the spread in costs across different cost-cases is around half that of passenger cars, and there are net cost savings in all cases.

Figure 3.10 shows similar results for cars for different cost-curves for the high ambition level. Here the pattern is similar, although the spread in net costs is smaller in 2025, and higher in 2030. Again, the increase net increase in direct costs from a societal perspective in 2025 would be balanced out by even larger reductions in external costs.

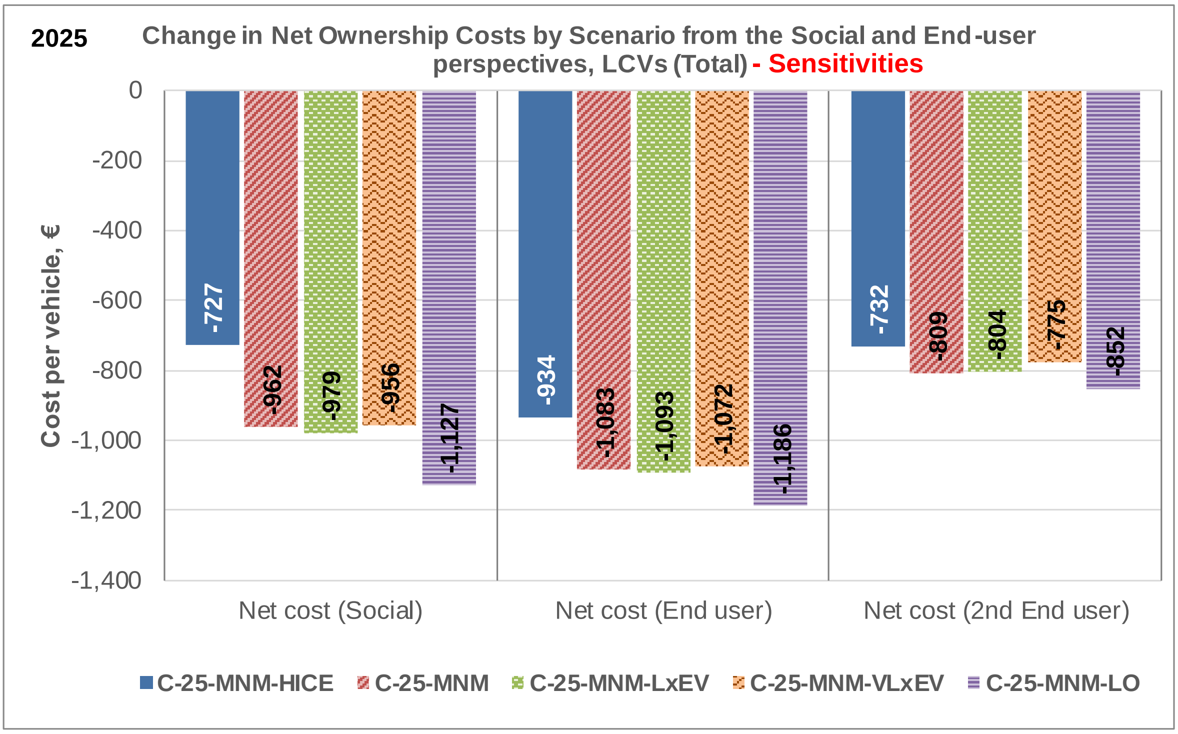
Figure 3.8: Summary of the average vehicle Total Cost of Ownership (TCO) of different options for passenger cars compared to the baseline scenario for societal and end-user perspectives, for the central ambition targets with different cost sensitivities

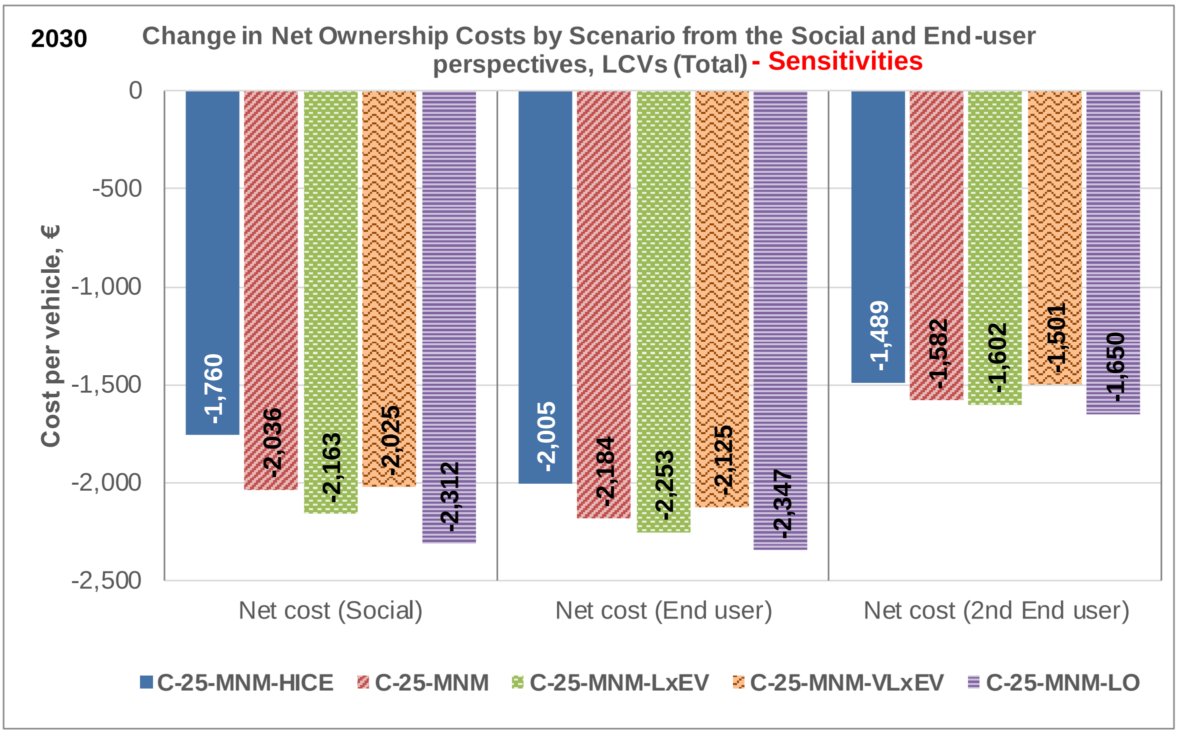




Notes: **Societal** view = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** view = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

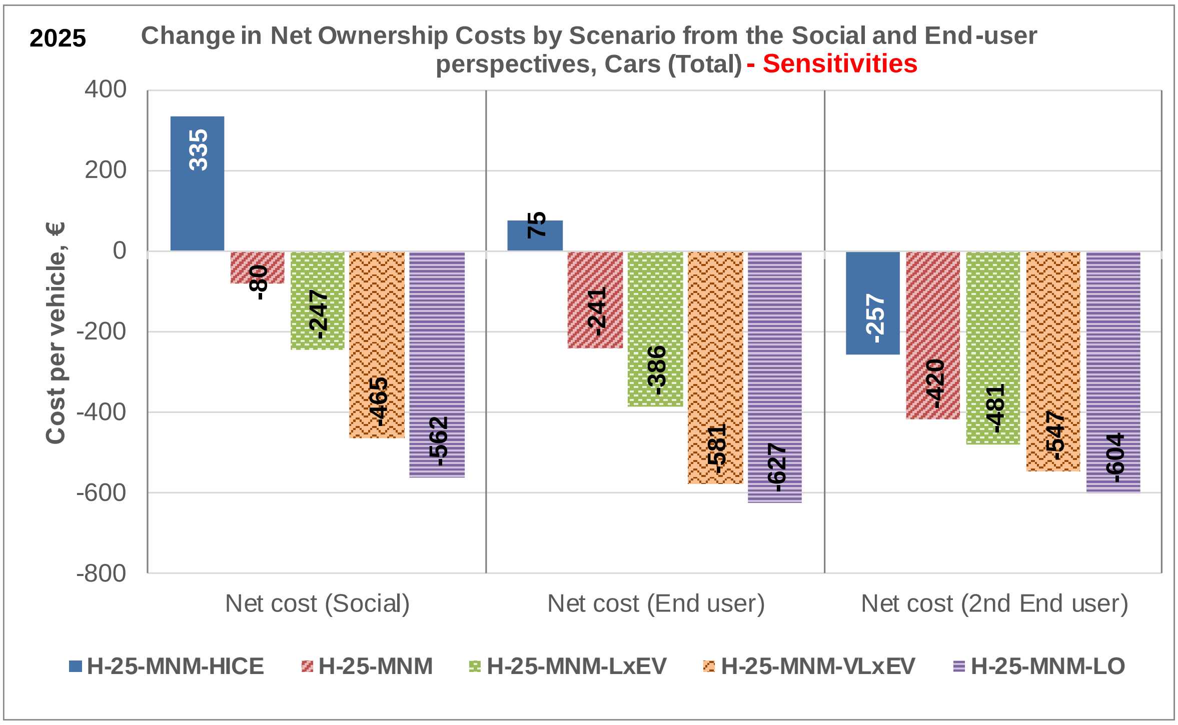
Figure 3.9: Summary of the average vehicle Total Cost of Ownership (TCO) of different options for LCVs compared to the baseline scenario for societal and end-user perspectives, for the central ambition targets with different cost sensitivities

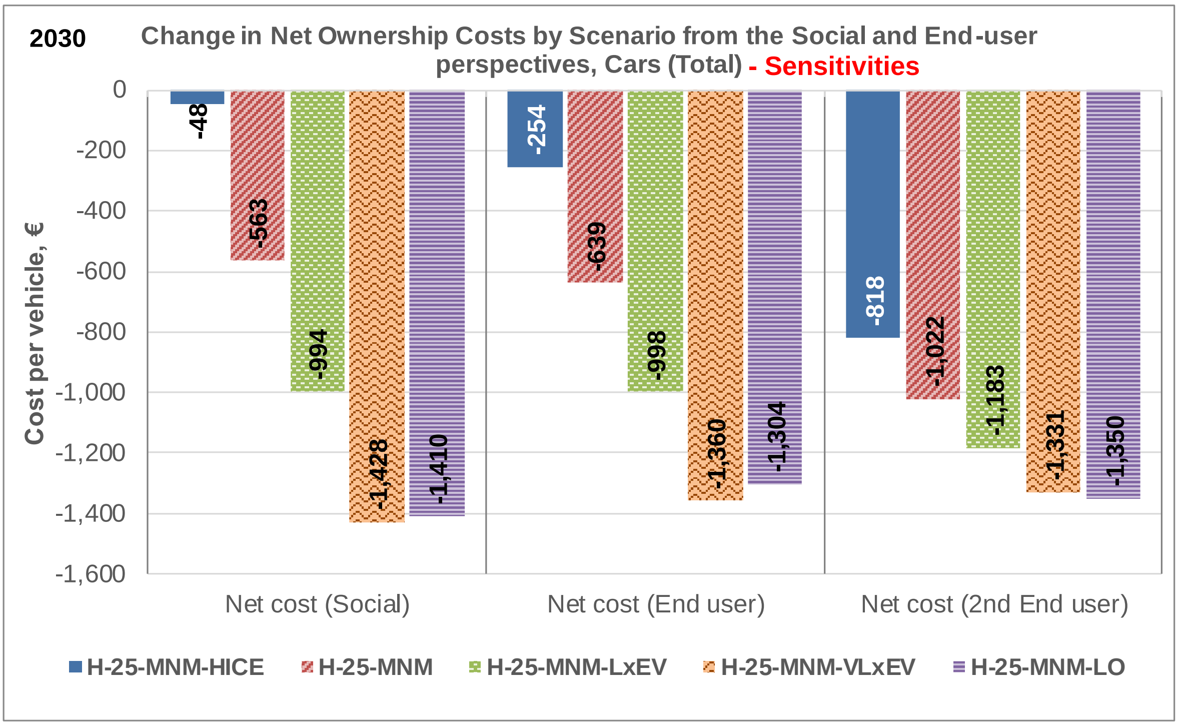




Notes: **Societal** view = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** view = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

Figure 3.10: Summary of the average vehicle Total Cost of Ownership (TCO) of different options for passenger cars compared to the baseline scenario for societal and end-user perspectives, for high ambition targets with different cost sensitivities





Notes: **Societal** view = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** view = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

3.2.3.2 Cost-benefit analysis of system-level PRIMES-TREMOVE results

PRIMES-TREMOVE provides the following fleet-level annualised cost outputs (for LDVs, and for cars and vans separately) in 5 year intervals, which were used to calculate cumulative costs for each scenario run over the 2020-2040 period:

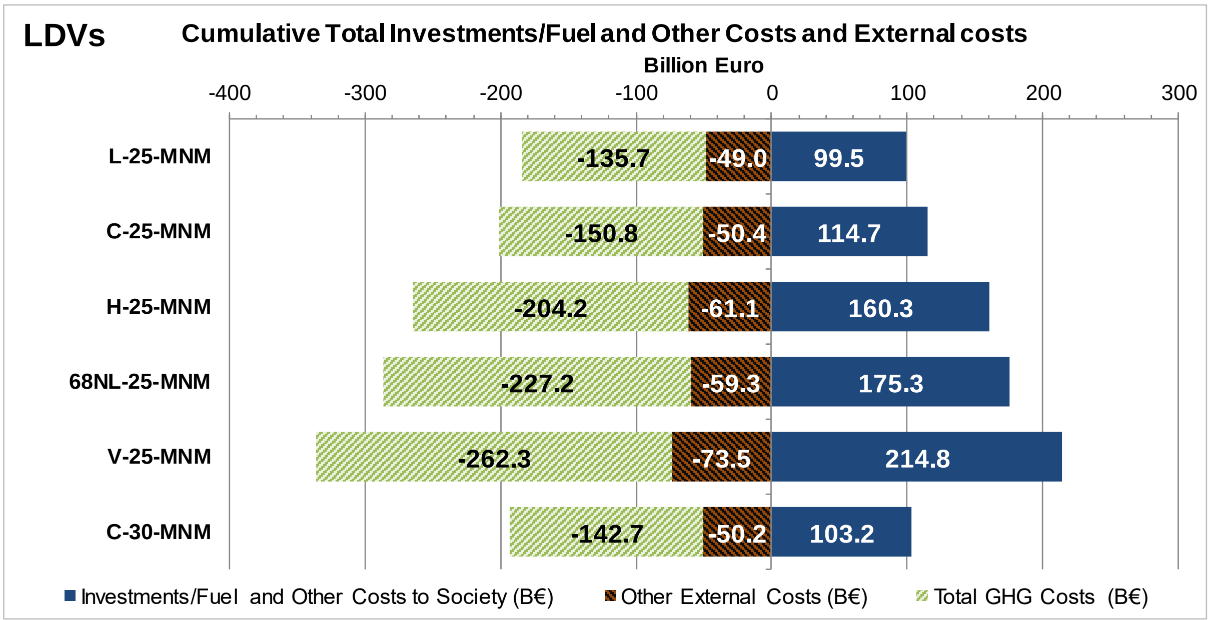
- Capital costs
- Fuel costs
- Variable non-fuel costs
- Fixed operation and maintenance costs
- Infrastructure payments (i.e. xEV charging, hydrogen, etc.).

The PRIMES-TREMOVE model outputs overall annualised direct costs (i.e. including capital, fuel, and other non-fuel costs, etc.), as well as the indirect monetised costs of air quality pollutant emissions and other externalities. These direct and indirect costs/benefits can also be combined with the monetised costs of GHG emissions to assess the net societal impacts of the different scenarios. An assessment of the cumulative impacts of the direct and indirect cost components and net societal cost-benefit analysis is presented in Figure 3.11 below (for central GHG costs) (based on (Ricardo-AEA, 2014), see also Appendix 4).

The figure shows that although the cumulative costs for the LDV vehicle parc (i.e. all stock) from PRIMES-TREMOVE increase with increasing ambition level for the CO_2 targets, the wider societal benefits due to savings in overall LDV transport externalities outweigh the direct costs. The result is that, from a societal perspective, the overall total net cost savings increase in magnitude as the ambition level increases from low to high. For LCVs only, there are net direct cost savings also.

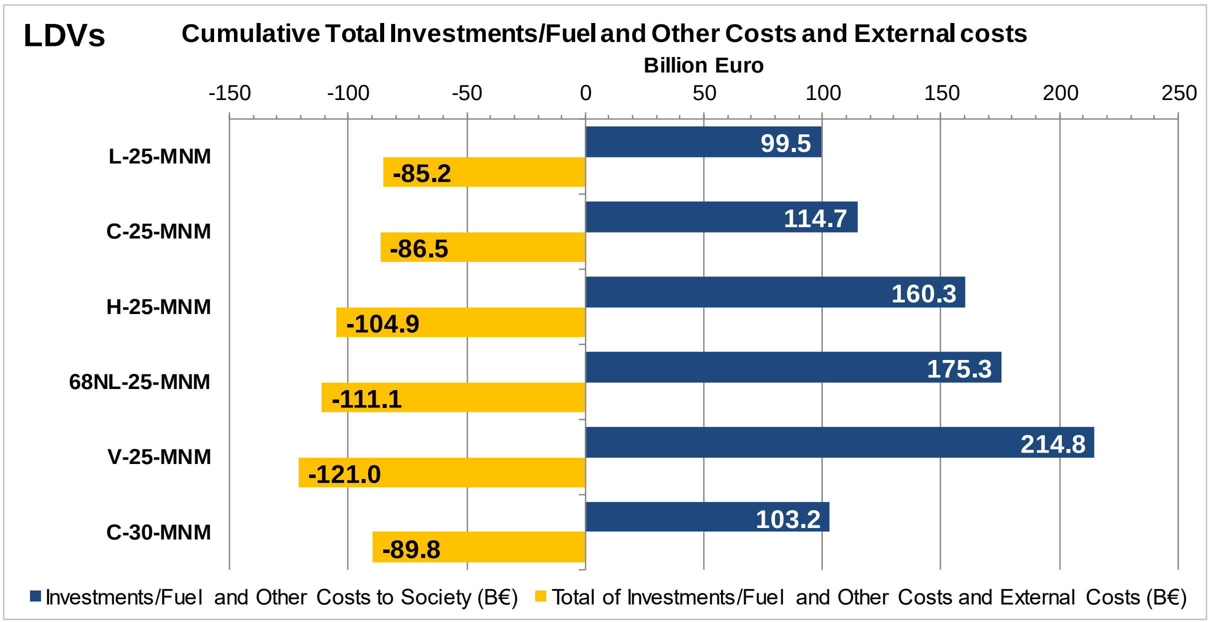
More information is provided in Appendix 4 on this methodology, together with a more detailed breakdown of the different components.

Figure 3.11: Summary of the cost-benefit analysis for different options for ambition level and timing compared to the baseline scenario (central GHG costs)



Notes: "Investments/Fuel and Other Costs" = includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

Figure 3.11: Summary of the cost-benefit analysis for different options for ambition level and timing compared to the baseline scenario (central GHG costs) (continued)



Notes: "Investments/Fuel and Other Costs" = includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

3.2.4 Assessment of impacts on competition between manufacturers

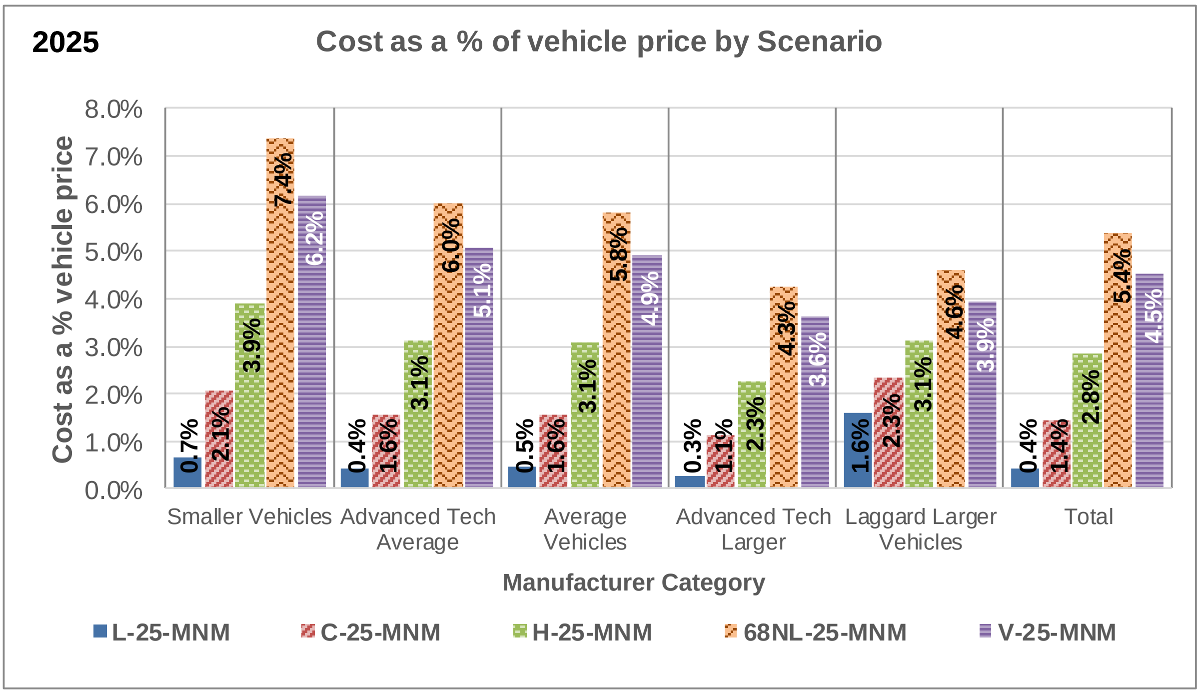
There is a general aim for the LDV CO_2 Regulations to set CO_2 emission targets in a way that is as neutral as possible from the point of view of competition. This "competitive neutrality" refers to differences in impacts between manufacturers of vehicles and components operating in the same market – i.e. competitiveness in relation to potential impacts on relative pricing for different manufacturers (Ricardo-AEA and TEPR, 2015).

The impacts on such competition between manufacturer categories were quantitatively assessed using outputs from the PRIMES-TREMOVE model and the JRC DIONE model, as summarised in Section 2.1. The principal regulatory design element that has an impact on competition between manufacturers is the mechanism for distribution of effort (DoE) between manufacturers. This element, and its impact on competition between manufacturers, is discussed in detail in Chapter 4.

A summary of the key findings relating to ambition level are also presented in the section below. The figures and tables presented below show the impact of different levels of ambition and different cost assumptions (sensitivities) on the cost increases for passenger cars and LCVs relative to their 2015 average market prices. The increases in vehicle prices across ambition levels show an overall pattern of distribution between different manufacturer categories that is broadly similar for both cars and LCVs, though the magnitude generally increases with the ambition level. Results presented for LCVs illustrate that the effort distribution between different manufacturer types is relatively independent of the selected distribution function (i.e. mass, footprint, etc. and utility slopes). For passenger cars, the distribution is less even with higher relative increases in cost (versus current average price) for manufacturers of smaller vehicles (on average) compared to those on average selling larger ones. Since the degree of this differential increases with target ambition, so do the potential negative implications for both competitive neutrality and also for social equity (though the latter is also influenced by the total cost of ownership – discussed in Section 3.2.3.1) as the prices of manufacturers of smaller vehicles increase relatively more than those of larger/heavier premium vehicles.

Figure 3.14 below also shows the cost increase (relative to current retail price) under different cost assumptions (sensitivities) for the central ambition level scenario in 2030 for cars and LCVs. This illustrates that the overall pattern of distribution between the different manufacturer types is rather independent of the cost assumptions.

Figure 3.12: The impact of different levels of ambition on relative costs for different passenger car manufacturer categories



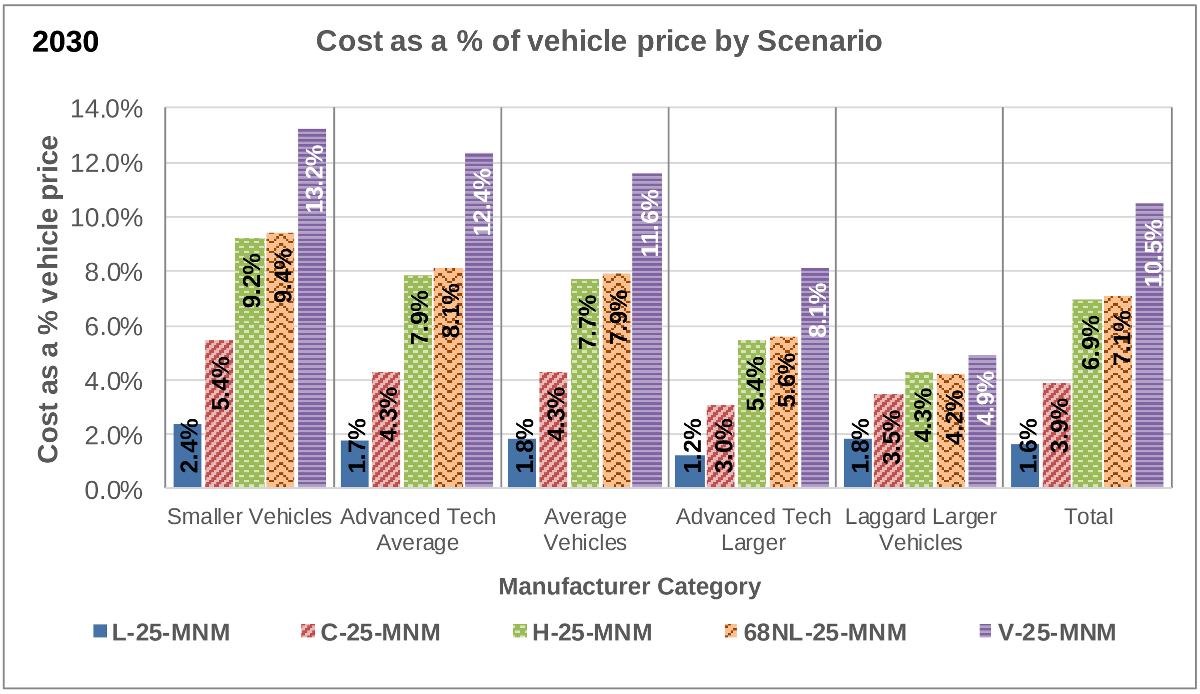


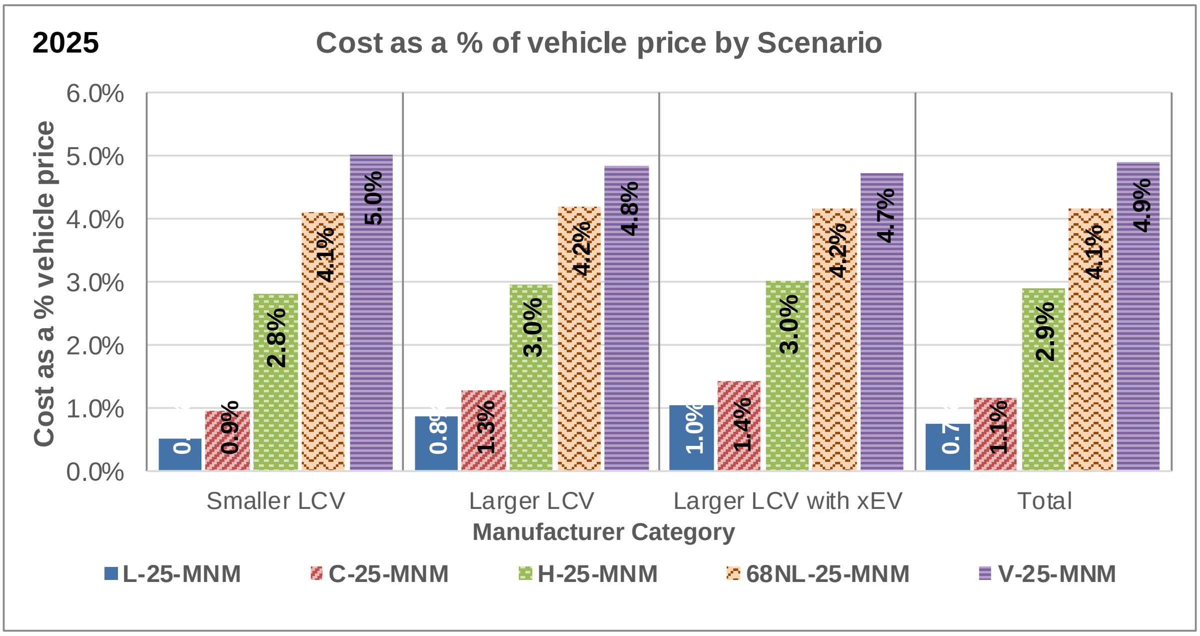
Table 3.6: Increased 2030 manufacturing costs relative to the baseline for passenger cars for different ambition levels and manufacturer categories, values presented as absolute (€) and relative (%) to average prices

2030	L-25-MNM	C-25-MNM	H-25-MNM	68NL-25-MNM	V-25-MNM
Additional manufacturing cost, € per manufacturer category					
Smaller Vehicles	417	955	1,615	1,649	2,320
Advanced Tech Average	374	928	1,689	1,743	2,660
Average Vehicles	423	995	1,771	1,814	2,672
Advanced Tech Larger	419	1,066	1,902	1,950	2,852
Laggard Larger Vehicles	1,343	2,546	3,148	3,091	3,602
Total	**421**	**1,023**	**1,807**	**1,853**	**2,724**
Additional manufacturing cost as a percentage of average vehicle price per manufacturer category					
Smaller Vehicles	2.4%	5.4%	9.2%	9.4%	13.2%
Advanced Tech Average	1.7%	4.3%	7.9%	8.1%	12.4%
Average Vehicles	1.8%	4.3%	7.7%	7.9%	11.6%
Advanced Tech Larger	1.2%	3.0%	5.4%	5.6%	8.1%
Laggard Larger Vehicles	1.8%	3.5%	4.3%	4.2%	4.9%
Total	**1.6%**	**3.9%**	**6.9%**	**7.1%**	**10.5%**

Table 3.7: Increased 2030 manufacturing costs relative to the baseline for LCVs for different ambition levels and manufacturer categories, values presented as absolute (€) and relative (%) to average prices

2030	L-25-MNM	C-25-MNM	H-25-MNM	68NL-25-MNM	V-25-MNM
Additional manufacturing cost, € per manufacturer category					
Smaller LCV	324	492	1,362	1,229	2,179
Larger LCV	479	689	1,702	1,510	2,572
Larger LCV with xEV	568	798	1,890	1,673	2,807
Total	**428**	**622**	**1,588**	**1,417**	**2,445**
Additional manufacturing cost as a percentage of average vehicle price per manufacturer category					
Smaller LCV	1.3%	1.9%	5.4%	4.9%	8.6%
Larger LCV	1.5%	2.1%	5.3%	4.7%	8.0%
Larger LCV with xEV	1.5%	2.1%	5.1%	4.5%	7.5%
Total	**1.4%**	**2.0%**	**5.3%**	**4.7%**	**8.2%**

Figure 3.13: The impact of different levels of ambition on relative costs for different LCV manufacturer categories



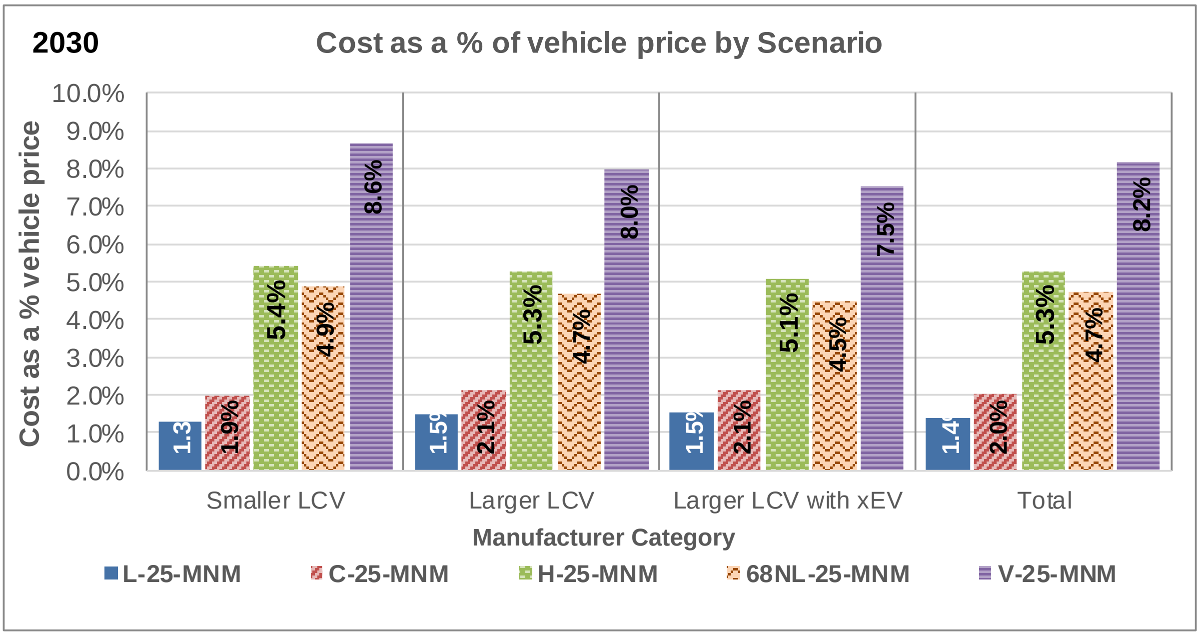
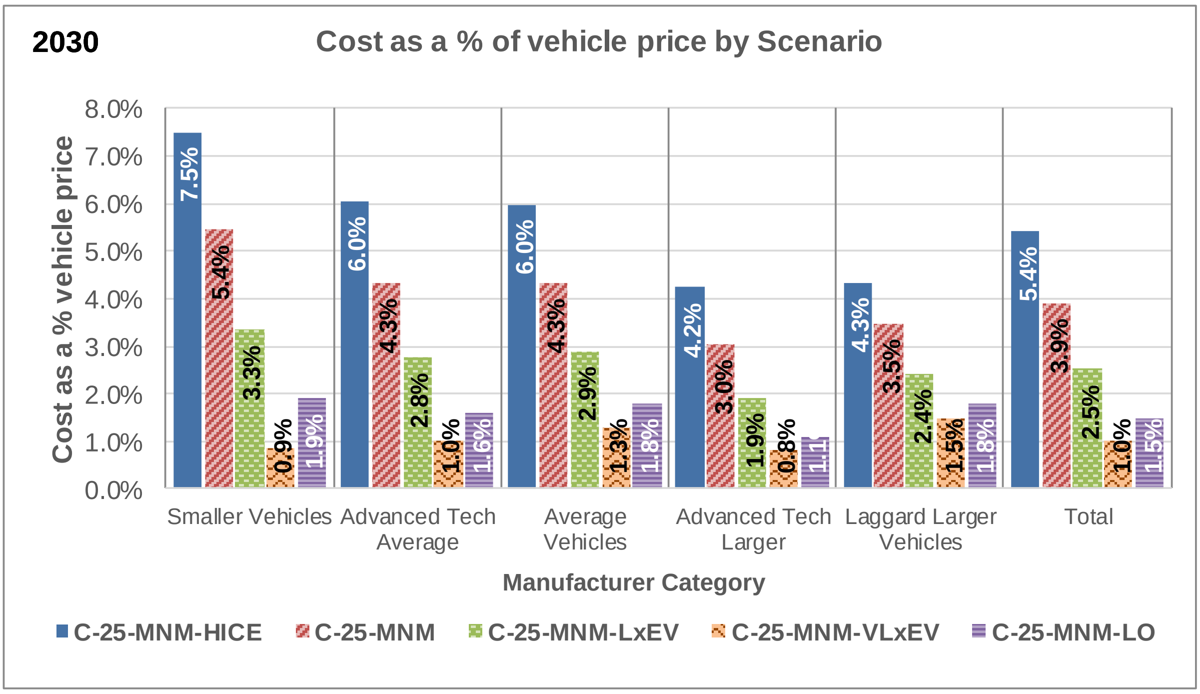
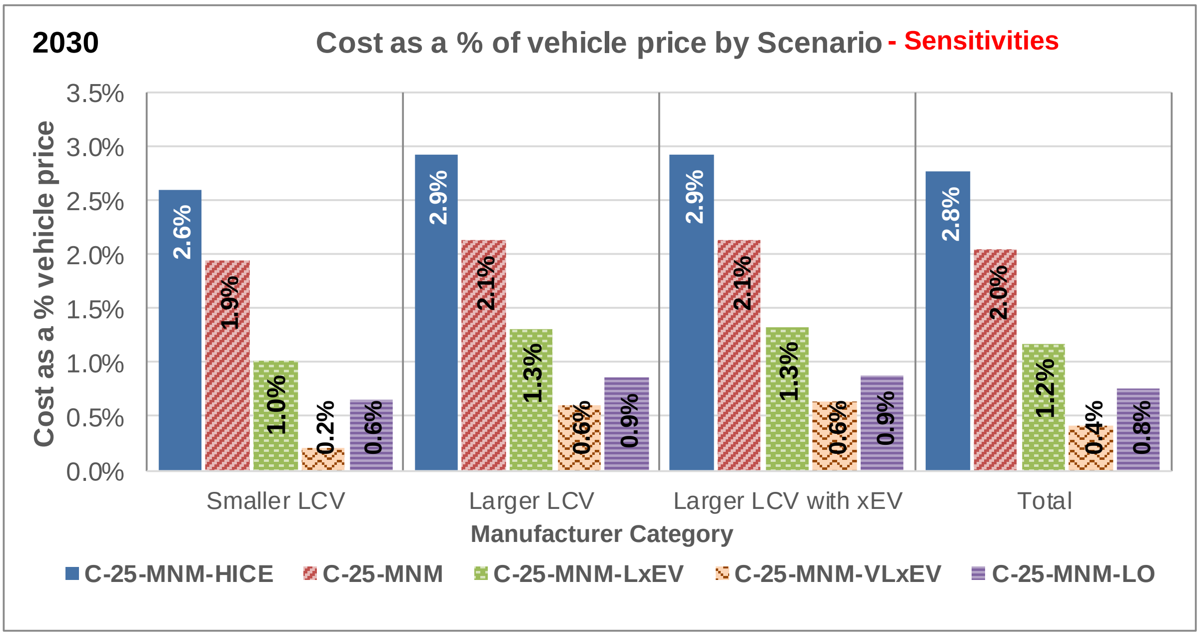


Figure 3.14: The impact of different cost cases for the central ambition scenario on relative costs in 2030 for different passenger car and LCV manufacturer categories - Sensitivities





3.2.5 Distribution of impacts across income groups (social equity)

A post-modelling analysis has been employed to assess the distribution of impacts across income groups, as outlined in Section 2.5. The analysis incorporates the impacts of the second-hand car market and draws from outputs from the baseline and the C-25-MNM scenarios quantified using the PRIMES-TREMOVE transport model.

The analysis restricts itself to the assessment of the relative repercussions of the policy options to the various income classes (five classes have been considered depending on the household income per capita). The analysis considers the impacts of the second-hand car market, especially as reflected differently on the various household income categories.

The analysis in the previous section has shown that the cost of the average new vehicle increases in the policy scenarios compared to the baseline scenario. At the same time, new vehicles exhibit a reduction in tailpipe CO_2 emissions and specific fuel consumption compared to the average new vehicle in the Baseline scenario. Hence, consumers purchasing the new vehicles with lower tailpipe CO_2 emissions enjoy a reduction in their annual fuel expenditures.

The second-hand car market holds a significant portion of the EU market for vehicle sales. This means that a vehicle purchased new, is likely to be sold again within the lifetime of the car. As shown in Figure 2.6 (TML et al, 2016), those who purchase older second-hand cars are usually medium to low income households.

To compare the impacts, we calculate the annual expenditures related to the purchasing and the operation of the vehicle. For the operation of the vehicle, we multiply the average specific fuel consumption of the average vehicle for each time-period and age cohort times the average energy price and the annual mileage of the vehicle. As regards the purchasing cost of the vehicle, we calculate the annuity payment for capital for the purchasing of the vehicle. In this way, the accounting of the capital expenditures is comparable with the annual expenditures for fuel purchases. For the calculation of the annuity payment, we multiply the purchasing price of the vehicle times the capital recovery factor that converts the present value of the purchasing price of the vehicle into a stream of equal annual payments over a specified time-period (economic lifetime: years n) at a specified discount rate (δ). It has been well documented in economic literature the fact that the individual discount rates decrease as income rises. For the purposes of this analysis, we have assumed five different discount rates applying to the various income categories. The assumptions are based on expert judgment. We have undertaken further sensitivity analysis on the values of discount rates to assess their impact on the results – some of these (on discount and depreciation rates) are presented in Appendix 5 of this report. On the assumptions on the economic lifetime, we have also undertaken a number of sensitivity runs for various time-periods.

For the analysis, we have split EU28 households into five quintiles. The reason for doing so, was to be able to draw data and assumptions, regarding the distribution of vehicle ownership over the various households and age of vehicles, from the TML study which features the same segmentation of EU households.

Each household class is assumed to purchase vehicle following a specific frequency regarding the age of the vehicles purchased. According to the TML study, low-income households purchase mostly used cars over 10 years old. On the contrary, newly registered vehicles are allocated to high-income classes. Given the above, the present analysis aims to assess whether the implementation of policy bears positive or negative impacts across the household classes.

The assessment draws from the comparison between the C-25-MNM scenario against the baseline scenario. Assuming that each household class purchases vehicles with a certain frequency, we quantify the net impact of the different vehicles purchased under the policy scenario compared to baseline. In other words, the comparison assesses whether the fuel savings of the vehicles marketed under the more ambitious targets on cars are enough to outweigh the higher purchasing prices. We validate that as the vehicle age increases and its market price decreases in the second-hand car market, the fuel savings outweigh the increased vehicle price. On the contrary, high-income households, which usually purchase new or newer second-hand cars sustain the negative impact of the higher vehicle purchasing prices. We have assumed that the average cost of a second-hand car aged between 0-5 years has depreciated to 80% of its original market value when new. The average depreciation of the original prices of vehicles aged between 5-10 and >10 years have been assumed equal to 65% and 15%, respectively. Values draw from assumptions from PRIMES-TREMOVE, but are broadly consistent with the depreciation profile used in the TCO analysis (see earlier Figure 2.5). We provide additional sensitivity analysis over the assumptions on depreciation rates in Appendix 5 (Section A5.3).

Below, we present the results of the analysis differentiating the economic lifetime of the cars and the discount rates that influence the annuity payment for the capital cost of the vehicle. The analysis presents the savings or the additional costs (in Euro/vehicle) that are incurred per household category in the C-25-MNM scenario relative to the baseline (REF).

3.2.5.1 Sensitivity analysis over the duration of the economic lifetime

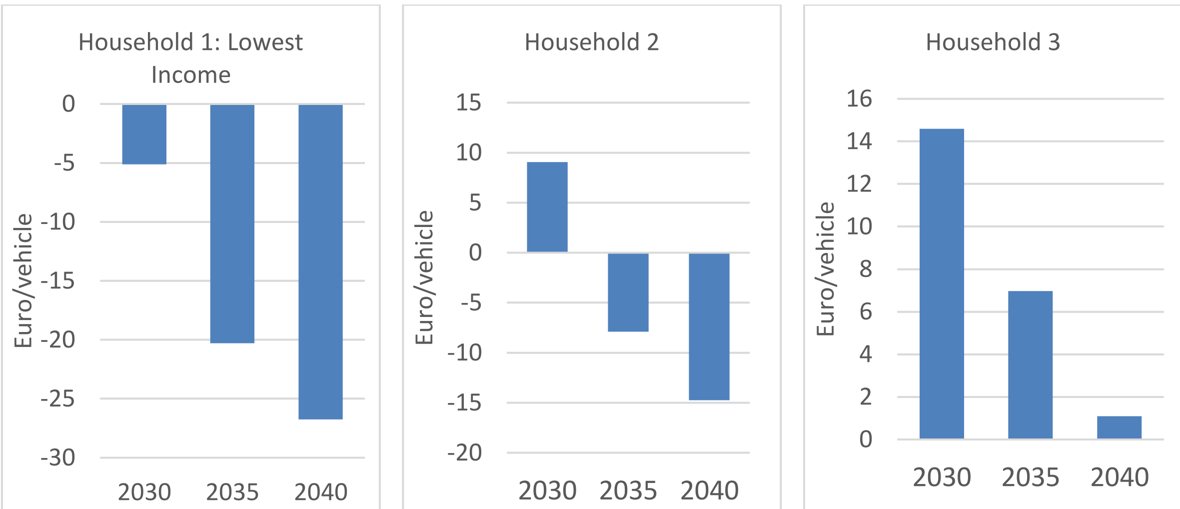
To assess the impact of the duration of the economic lifetime, we repeat the calculations in the post-processing analysis by varying the economic lifetime of the payment of the purchasing price of the vehicle. The discount rates remain unchanged in all these cases to allow comparability.

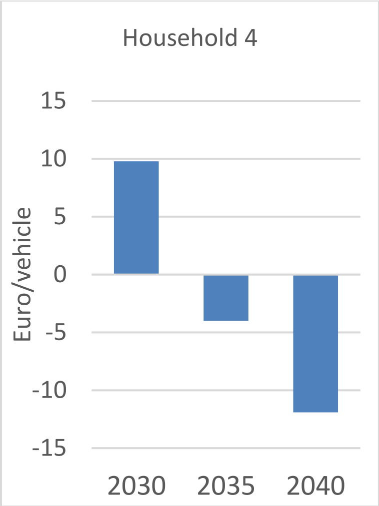
Table 3.8: Assumed discount rates by household class for the sensitivity runs over the duration of the economic lifetime of cars

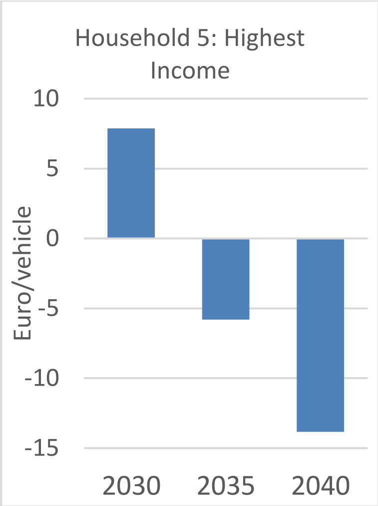
Household Income class	Discount rate
Household 1: Lowest Income	23%
Household 2	20%
Household 3	17%
Household 4	13%
Household 5: Highest Income	10%

The higher the economic lifetime used to calculate the annuity payment for the vehicle price, the lower the annual payment for capital. In that case, the fuel savings matter more when compared to the annual payment for the vehicle price. According to the calculations, using a 10-year economic lifetime, the lowest income category exhibits the highest annual savings, given that fuel savings outweigh the payment for the vehicle acquisition, despite the higher discount rates of this household class. Benefits are also apparent for other household classes, albeit to a lower extent.

Figure 3.15: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 10 years







Using an economic lifetime of 7 years, the lowest household income class is the only category that exhibits net savings in the policy scenario compared to the baseline (detailed figures in Appendix 5). The highest losses are found to take place on the household categories 3, 4 and 5. The higher savings take place beyond 2030 (i.e. as new vehicles also work their way through to the second-hand market) driven also by the fact that the steadily increasing energy prices widen the gap in the annual fuel expenditures between the policy and the baseline scenario. The results go in the same direction when assuming a short duration for paying the vehicle price (e.g. 5 and 4 years, also presented in Appendix 5). Under these conditions, all household categories exhibit annual losses in the policy scenario compared to the baseline scenario. The analysis finds that the highest impacts are on the higher-income household classes. Again, the lowest income category experiences the lowest impacts.

3.2.5.2 Implications on income inequality measured through a modified Gini coefficient

This section aims to complement the analysis presented in the previous subsection and examines whether the purchasing of new vehicles and their subsequent trade in secondary market results in a transfer of income among household of different income classes. The implications on income inequality are measured through a modified Gini coefficient[8].

The Gini coefficient is calculated as part of the post-processing analysis at the end of the calculations presented in the previous subsection. The changes in consumption patterns implied by the scenario and the various sensitivities are allocated to changes in expenditures for different household income groups. To translate these different expenditures into income transfers, we first calculate the additional expenditure over and above the baseline scenario expenditures on new vehicles and the trade in the second-hand market for each household. The gains from savings due to improved fuel efficiency of cars are calculated for each household. It is assumed that the net effect of higher purchasing cost and lower running costs implicitly affect the household disposable income (as low-income households save income and high-income households spend more income to meet their transport needs in the C-25-MNM scenario). To proxy this, we subtract the net expenditures on transport from household disposable income of each household.

The perfect equality line corresponds to the case that each household has the same proportion to the total income. However, in the Baseline scenario, low-income households hold disproportionally lower share of the total income relative to their proportion in total households. The dotted line represents the baseline scenario. When approaching the “perfect equality” line, the income distribution would become fairer.

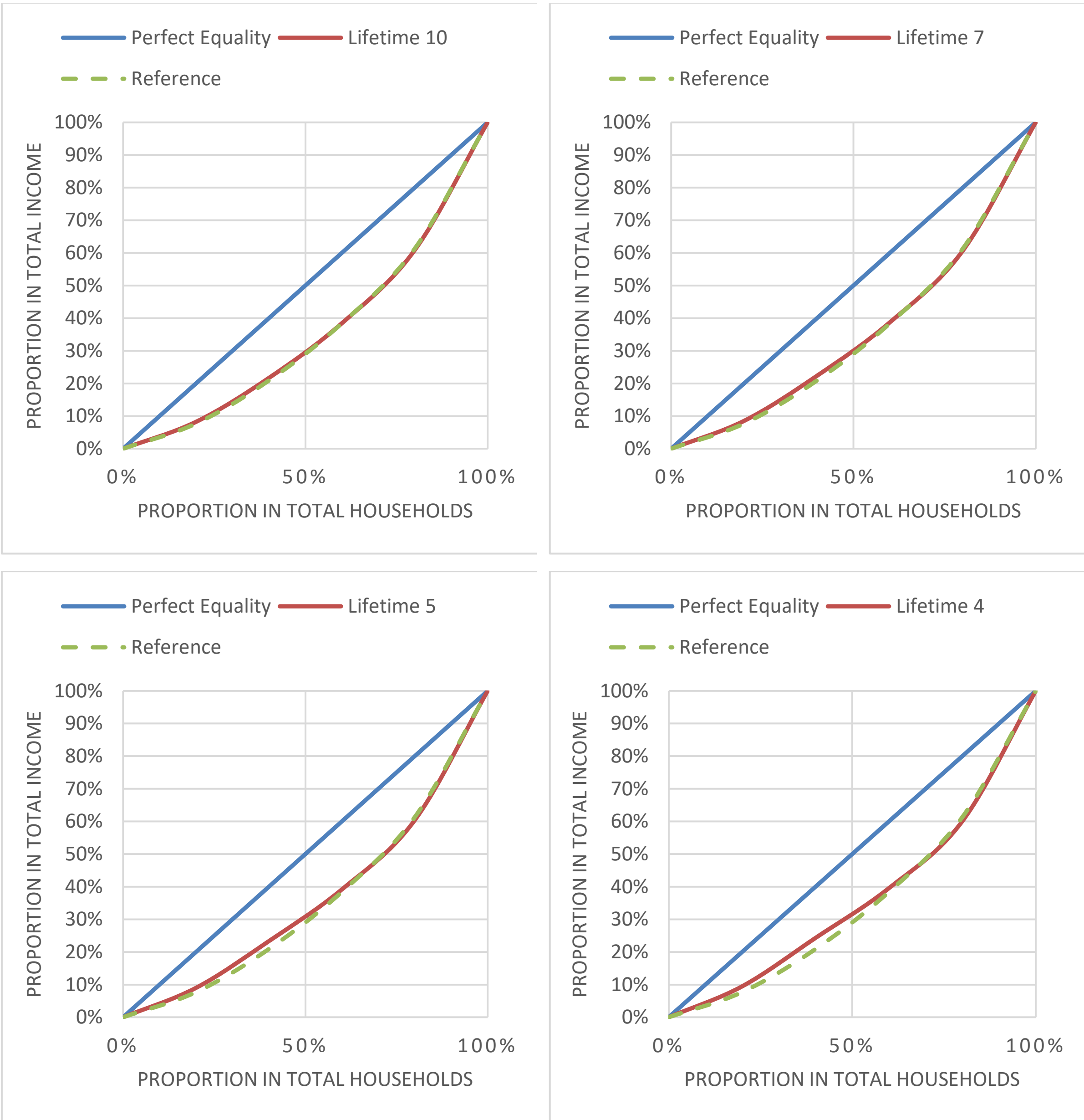
Over the previous subsection, we found that the lower income households benefit from the more optimistic targets on cars relative to Baseline. The benefit translates either as savings in total annual

[8] Gini coefficient is a statistical measure intended to represent the income or wealth distribution of a nation's residents, and is the most commonly used measure of inequality. The Gini coefficient ranges from 0 (perfect equality, i.e. same income for all households) to 1 (perfect inequality, i.e. one household has all the income).

costs or as lower expenditures compared to households with higher income. This finding was confirmed after a number of sensitivity analyses over key variables.

The analysis using the Gini coefficient also confirms the conclusion that lower income households benefit compared to higher-income households. Looking at Figure 3.16, the C-25-MNM scenario line slightly deviates from the dotted line of the Baseline scenario. A marginal trend towards the "perfect equality" line is observed, which is small in magnitude though. This takes place for all the variants considered. With regard to Figure 3.16, the highest impact takes place under a short economic lifetime (though shorter economic lifetimes pose negative impacts - higher annual costs relative to baseline - to all households). The Gini coefficient shows that eventually low-income households end in being in a better position than higher-income households, simply because the latter face higher expenditures.

Figure 3.16: Gini coefficient of the C-25-MNM scenario relative to Baseline: variants over the economic lifetime of the annuity payment



3.2.5.3 The impact of varying the target level

The analysis in the previous subsections 3.2.5.1 and 3.2.5.2 assessed the distribution of impacts across the income groups when comparing the Central level of ambition against the baseline scenario. The analysis has considered a number of sensitivity analyses to assess the robustness of the results, with further details also provided also in Appendix 5.

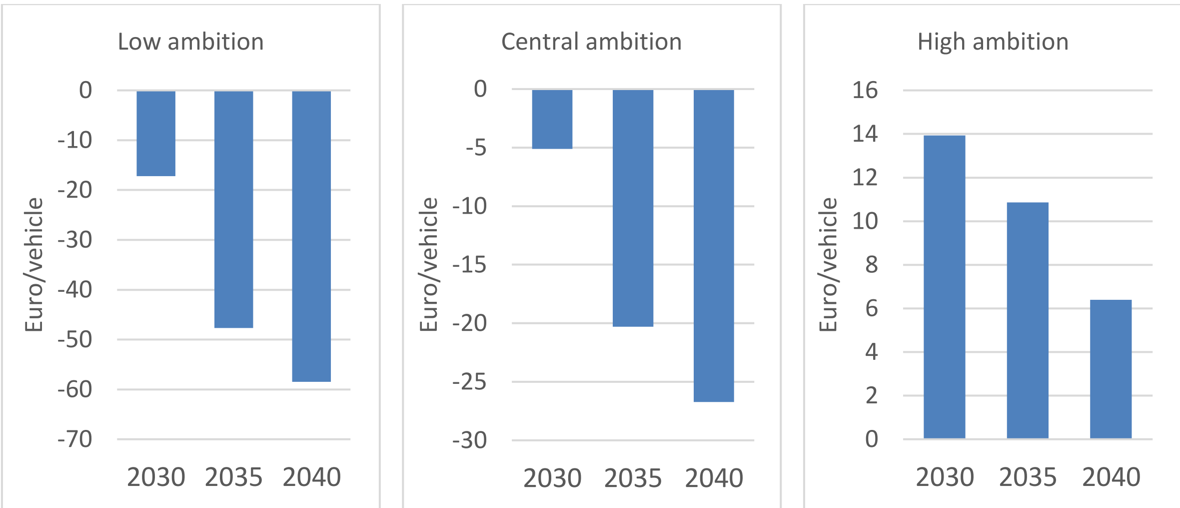
In this section impacts of differentiating the level of ambition of the options is explored. The analysis compares the H-25-MNM, the L-25-MNM and the C-25-MNM scenarios. Again, the impacts are drawn from the savings/ additional costs per household category in the above-mentioned scenario relative to the baseline scenario.

The comparison of the different levels of ambition is based on an economic vehicle lifetime of 10 years, central discount rates and central depreciation. The additional cost for the average new vehicle in 2025 and 2030 has been assumed to be €110 and €423 respectively in the Low ambition scenario. The additional costs in the High ambition scenario in this analysis were assumed to be €704 and €1771 in 2025 and 2030 respectively. The assumptions are based on the output from the JRC DIONE analysis.

Figure 3.17-Figure 3.18 provide the comparison among the three levels of ambition for each type of household. Our analysis consistently finds that under the Low ambition scenario, all the household income classes exhibit savings compared to the Baseline. This contrasts the High ambition scenario, where the opposite takes place; all household income categories end up to face additional costs compared to the baseline scenario.

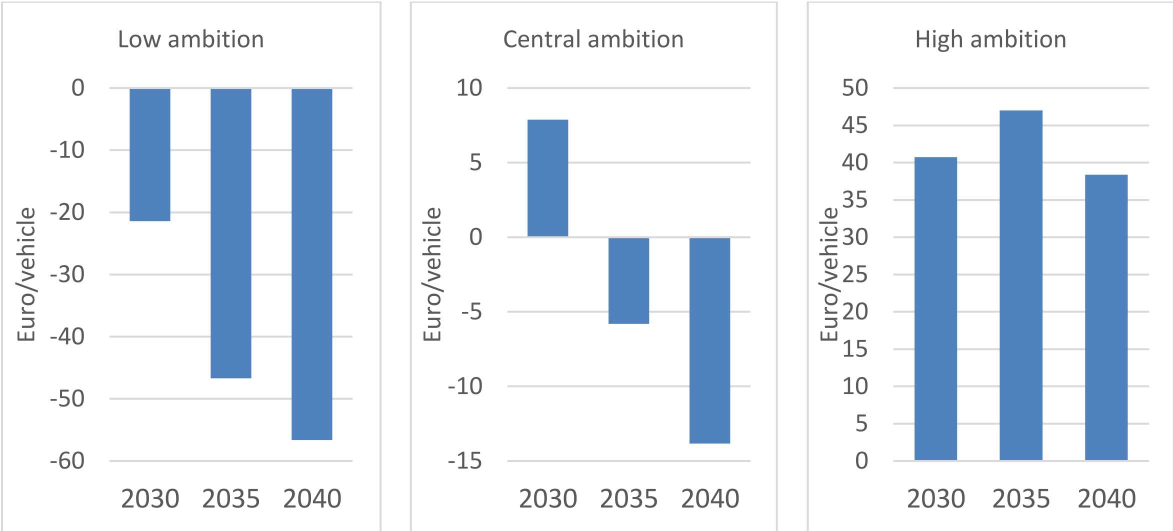
The lowest household income class exhibits gains under both the Low and the Central ambition scenarios throughout the period 2020-2040. However, under the High ambition scenario, this household class exhibits additional cost relative to the Baseline scenario.

Figure 3.17: Savings/Additional cost for the "Household 1: Lowest Income" category in the L-25-MNM, C-25-MNM and H-25-MNM scenarios relative to Baseline ("-" means savings): Economic lifetime assumed 10 years, Central discount rates, Central Depreciation



The picture remains consistent when comparing the remaining household categories (Figure 3.18 shows highest income class household, the rest of the income classes are presented in Appendix 5). All household classes exhibit savings under the Low ambition scenario, while they face additional costs under the High ambition scenario. The additional costs that the household classes face in the High ambition scenario differ by class category. In particular, the lowest income class faces the lowest addition costs (ranging from 6-14 euros/vehicle/annum) compared to the rest of household classes.

Figure 3.18: Savings/Additional cost for the "Household 5: Highest Income" category in the L-25-MNM, C-25-MNM and H-25-MNM scenarios relative to Baseline ("-" means savings): Economic lifetime assumed 10 years, Central discount rates, Central Depreciation

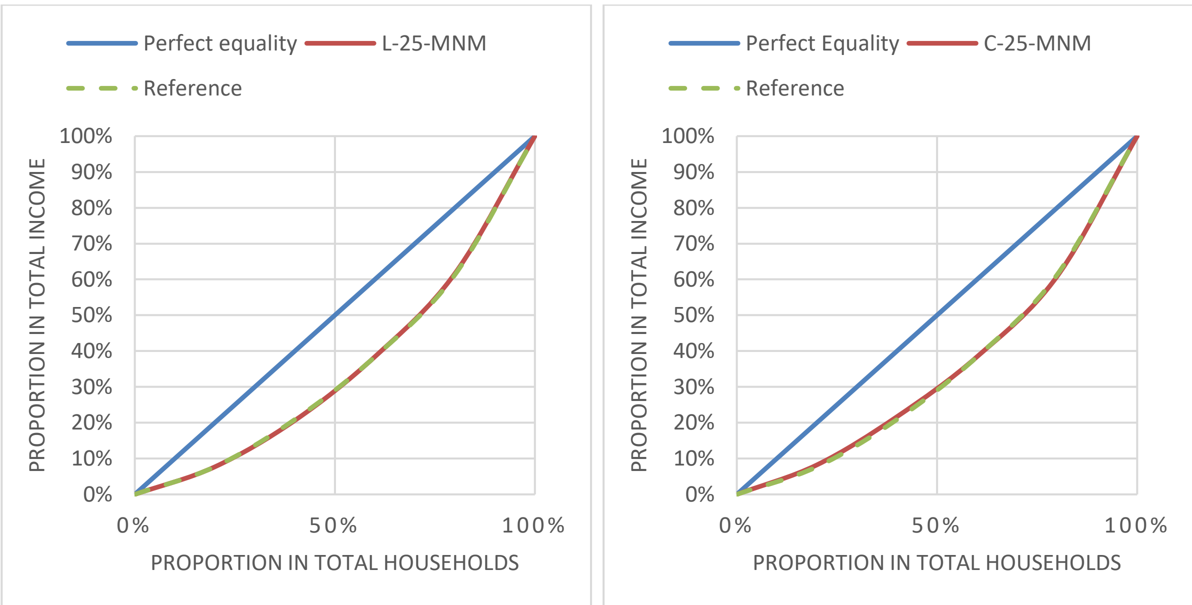


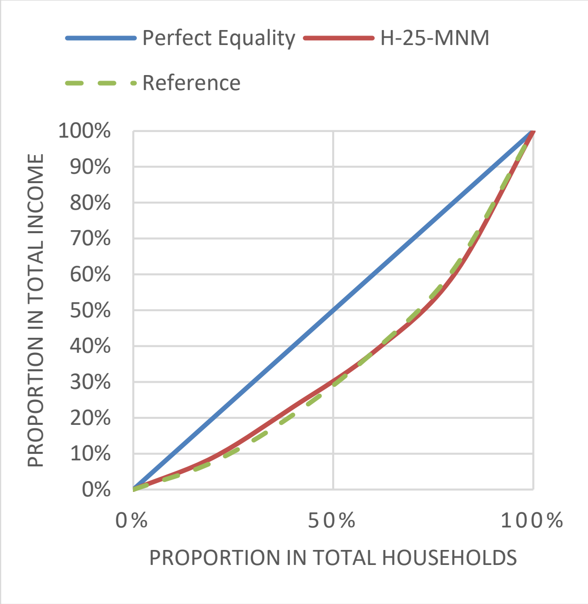
When increasing the level of ambition, the benefits from the derived annual fuel savings are outweighed by the higher costs for the purchasing of the vehicles.

The increase in the additional costs and the relative improvement of vehicles' efficiency exhibit increasing returns to scale in the Low ambition scenario. Beyond the Low ambition scenario, the marginal costs (additional costs) are becoming increasingly higher compared to the efficiency gains that the consumers enjoy. Hence, the High ambition scenario exhibits diminishing returns to scale.

We conclude the analysis over the impacts of the three levels of ambition by utilizing the Gini coefficient. Looking at Figure 3.19, the High Ambition scenario shows a higher trend towards the "perfect equality" line for the low-income households because the remaining household classes face higher expenditures. This contrasts the case of the Low ambition scenario where the changes are the marginal and lowest compared to the Central and High cases. Under the Low ambition scenario, all income classes considered in this analysis end in the same position as they would be in the Baseline scenario.

Figure 3.19: Gini coefficient of the C-25-MNM, L-25-MNM and H-25-MNM scenarios relative to Baseline





3.2.5.4 Overall conclusions for the social equity analysis

The implementation of more ambitious targets relative to the baseline, drives in the market vehicle options that are less expensive to use, but more capital intensive. High-income classes, that are more likely to purchase new cars, face higher upfront cost, whilst enjoying lower fuel costs. The analysis finds that the implementation of more ambitious targets yields increasingly positive impacts on the lower-income households, compared to the baseline (i.e. positive impacts for high > central > low ambition). The households that purchase vehicles in the second-hand car market (i.e. mostly those in low and medium income classes) benefit from annual fuel savings by only paying a fraction of the additional cost that higher income classes pay. This finding is confirmed under a number of assumptions over a range of discount rates and economic lifetimes of vehicles. The result is confirmed also for the higher ambition case, where lower income categories end up in a better position relative to the high-income households. In the case of low ambition, the analysis shows that the household classes remain only at a similar position as in the baseline case.

3.2.6 Impact on competitiveness

The GEM-E3 dynamic computable general equilibrium model has been used to quantify a series of options for regulating the CO_2 emissions performance of LDVs in the period post 2020. The model calculates the impact of these regulations on the EU economy, sectoral production and employment. The scenarios simulated with the GEM-E3 model are the: i) Central (30%/25% reduction) ambition (C-25-MNM), ii) High (40%) ambition (H-25-MNM) and iii) Low (20%) ambition (L-25-MNM). These scenarios are then compared against the baseline scenario.

The model has a separate representation for the manufacturing of conventional and electric vehicles. Each sector's production structure in terms of capital, labour and material requirements is derived from the Input Output table data and from satellite statistics where required. In the baseline production structure, the manufacturing of electric vehicles has lower direct requirements for labour than conventional vehicles. In our baseline scenario, it is assumed that the batteries required for the electric vehicles manufactured in the EU are mainly produced in the EU and are not imported. Four variants of the central scenario have been examined with alternative labour requirements in the electric vehicles industry.

3.2.6.1 GDP impacts

In the Central scenario, it is assumed that the transport sector, alone, undergoes changes as driven by the CO_2 targets, while all the other sectors of the economy remain in a "reference/baseline context[9]". This means that in this particular scenario, the other sectors do not undertake efforts to reduce GHG emissions. The variants of the Central scenario can be grouped to the following categories:

- **Loan based scenarios**: agents receive a 10-year loan to purchase the advanced vehicles that are more expensive when compared to the baseline. Within this period, agents fully pay back capital and interest. The loan interest rate is 2%. Loans received after 2040 are partly paid back within the simulation period.
- **Self-financing**: agents cover the additional expenses for purchasing more expensive transport equipment using own funds.

The implementation of the targets on CO_2 emissions reduces gasoline and diesel consumption, commodities upon which taxes are levied in all member states, as the share of ICE running on gasoline and diesel shrinks. This leads to lower government revenues than the baseline scenario, in the absence of any compensating measures. Governments increase general taxation to maintain **budget neutrality**

The naming of the scenarios quantified is the following:

- **REF_C_25_MNM_self_neutral:** Central scenario simulated in a baseline context with self-based financing option and with neutrality on public budget
- **REF_C_25_MNM_loan_neutral:** Central scenario simulated in a baseline context with loan-based financing option[10] and with neutrality on public budget

Table presents the macroeconomic impacts in terms of GDP, of the central scenario for alternative financing schemes. The loan-based scenarios present positive effects on GDP (when compared to the baseline scenario) that diminishes over time as the investment and expenditure for new advanced vehicles is reduced and loans starts to be paid back. In the self-financing scenarios, the crowding out effect is dominant and GDP is marginal negative as compared to the baseline scenario. The imposition of additional taxes (by governments) to maintain budget neutrality increases the distortion on the economy affecting negatively the GDP. The slightly positive impacts in the short term are mostly driven by the additional than the baseline investments that take place. In particular, the possibility for firms and households to finance their purchases through loans stimulates aggregate demand without crowding out other investments. The aggregate impact from fuel savings becomes gradually important over time as the stock of more efficient vehicles builds up.

Table 3.9: GDP impacts on self and loan based financial variant in the central ambition scenario

GDP [in m.€ 2013] and percentage difference from the baseline						
	2025	2030	2035	2040	2045	2050
Baseline	15,564,081	16,654,923	17,941,843	19,388,241	20,873,370	22,467,063
Central self-based	-0.014%	-0.014%	-0.024%	-0.040%	-0.069%	-0.096%
Central loan-based	0.016%	0.053%	0.066%	0.041%	0.004%	-0.025%

Source: GEM-E3

3.2.6.2 Adopting different degree of optimism: Comparison of High, Central and Low options against the Baseline case

In addition to the Central scenario two scenarios with different targets for CO_2 emissions have been quantified with the GEM-E3 model:

[9] The comparison of the central scenario (under the EUCO30 policy context) with the Baseline is presented in the Annex.
[10] In the scenarios that are simulated under the loan-based financing option it is assumed that until the year 2040 the agents receive a loan to cover the 90% of the additional than the reference expenditures and the remaining 10% is self-financed. In the post-2040 the share of self-financing increases to 30%.

- **REF_L_25_MNM_loan_neutral:** Low ambition option scenario simulated in a baseline context with loan-based financing option and with neutrality on public budget (less ambitious CO_2 targets than in the central scenario)
- **REF_H_25_MNM_loan_neutral:** High ambition option scenario simulated in a baseline context with loan-based financing option and with neutrality on public budget (more ambitious CO_2 targets than central)

Table 3.10 presents the change in percentage of GDP of the capital costs, associated with the purchasing of vehicles, in the two options examined (high, low) compared to the central one. These yield from the PRIMES-TREMOVE model and are very small when compared to the size of the economy (ranges from -0.03% to 0.1% of GDP). Following the small initial change in vehicles expenditure, the GEM-E3 model shows that the impacts of the High and Low ambition options relative to the central one are marginal.

Table 3.10: Change of EU28 capital cost for purchases of vehicles in the High and Low scenarios relative to Central (as % of GDP)

Scenario	2025	2030	2035	2040	2045	2050
High	0.02%	0.08%	0.10%	0.09%	0.05%	0.02%
Low	0.00%	-0.01%	-0.03%	-0.02%	-0.01%	0.00%

Source: PRIMES-TREMOVE

Table 3.11 presents the macroeconomic impacts in terms of GDP, for the variants of the central, low and high ambition scenarios. In the high ambition scenario, where CO_2 target are more ambitious than the central scenario, consumers increase their purchases of advanced vehicles (plug-in-hybrid and electric) hence facing higher purchasing and lower operating vehicle costs. Higher expenditures increase GDP as long as agents contract loans to cover their additional expenses relative to baseline vehicle purchases. In the low ambition scenario, where CO_2 target are less ambitious than the central scenario, the results follow the opposite direction (compared to the high ambition case), but they are of lower magnitude in terms of deviation from the central case. In the low case, the positive impact on GDP driven by the investments required to attain the emission target is higher than the baseline but lower than the central scenario.

Table 3.11: GDP impacts on loan based financial variant in the central, low and high ambition scenario

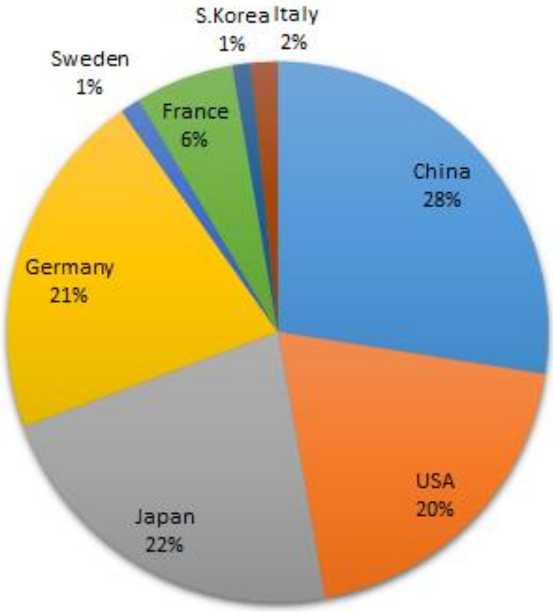
	GDP percentage difference from baseline					
	2025	2030	2035	2040	2045	2050
Baseline [in m.€ 2013]	15,564,081	16,654,923	17,941,843	19,388,241	20,873,370	22,467,063
Low loan-based	0.015%	0.045%	0.044%	0.021%	-0.003%	-0.028%
Central loan-based	0.016%	0.053%	0.066%	0.041%	0.004%	-0.025%
High loan-based	0.021%	0.110%	0.169%	0.108%	0.042%	-0.010%

Source: GEM-E3

3.2.6.3 Sectoral and employment impacts

The electric vehicles market is currently a niche market where manufacturers compete both at cost and quality. Today, EU holds nearly 30% of the global market of electric and plug-in hybrid vehicles (Figure 3.20). The post-2020 targets in the Central scenario lead to increased domestic production of electric vehicles and of biofuels (the latter due to the inclusion in the transport side of coordination policies that lead to an uptake of advance biofuels for the decarbonisation of the transport sector). Electric vehicles almost double in 2030 compared to the baseline, but still their production is a small share of the overall LDV market. The targets on CO_2 emissions from LDV send a signal to increase production of electric vehicles not only to EU manufacturers, but also to non-EU ones. Hence the additional demand for electric vehicles is met by both EU and non-EU manufacturers.

Figure 3.20: Country shares in the global market for electric and plug-in hybrid vehicles in 2015



Source: "R&D and technology spill-overs of Clean Energy technologies". European Commission, Directorate-General for Energy, 2017.

In the C-25-MNM scenario, no additional energy and climate policies for non-EU regions are imposed compared to the baseline. The cost reductions in vehicle production achieved in the EU are not sufficient to render EU domestically produced advanced vehicles directly competitive with conventional vehicles outside the EU. It is assumed that conventional vehicles will continue to remain the main vehicles in demand outside the EU under a business-as-usual case for the rest of the world. Therefore, exports of electric cars outside the EU increase only marginally relative to the baseline in 2030 (increase of exports to non-EU countries grows by 0.1% compared to the baseline). If the whole world adopts additional standards on new vehicle emissions, then the demand for electric vehicles produced in EU is likely to increase.

At a sectoral level[11] the sectors which are mostly affected from the increase in the ambition of the CO_2 regulation targets, are the manufacturing of vehicles (electric and conventional), the electrical equipment sector[12], fossil fuels and the power generation.

Table 3.12: EU28 production by sector (in % change from Baseline)

Sectors	Scenario	2025	2030	2040	2050
Electric vehicles	Low Ambition	47.2	40.9	49.6	52.8
	Central Ambition	49.8	57.4	53.7	52.8
	High Ambition	93.1	165.9	94.2	55.8
Conventional vehicles	Low Ambition	-0.8	-1.3	-2.4	-3.8
	Central Ambition	-0.9	-1.9	-2.4	-3.8
	High Ambition	-1.6	-5.6	-4.2	-4.0
Electrical equipment (including batteries)	Low Ambition	0.3	0.4	0.7	0.8
	Central Ambition	0.3	0.6	0.7	0.8
	High Ambition	0.6	1.8	1.3	0.8

[11] Detail description of the sectors used in the GEM-E3 model is presented in the Annex.
[12] In the present version of GEM-E3 the manufacturing of batteries is not represented as a separate sector but it is assumed to be part of the electrical equipment sector.

Sectors	Scenario	2025	2030	2040	2050
Fossil Fuels	Low Ambition	-0.2	-0.4	-0.8	-1.9
	Central Ambition	-0.2	-0.5	-1.0	-1.9
	High Ambition	-0.3	-1.3	-1.9	-2.5
Electricity	Low Ambition	0.2	0.4	1.1	2.6
	Central Ambition	0.2	0.5	1.2	2.7
	High Ambition	0.3	1.2	2.3	3.4
Other Sectors	Low Ambition	0.02	0.03	0.00	-0.08
	Central Ambition	0.02	0.04	0.01	-0.08
	High Ambition	0.02	0.05	0.02	-0.08

Source: GEM-E3

Table 3.13 presents the employment impacts, for the economic variants of the central, low and high ambition scenarios. Total employment increases as compared to the baseline scenario in all scenarios examined. The net jobs created (i.e. jobs generated minus jobs lost) in the transport manufacturing industry are driven from the manufacturers of electric vehicles. The scale on the net employment depends on the labour intensity of the different sectors which benefit from the policies assumed in the central scenario. These are the sectors of advanced vehicles manufacturing, batteries production, and electrical equipment. Increasing EU demand for these products does not necessarily imply more jobs as this depends on where production takes place (domestically or at non – EU countries). Table 3.14 presents the employment impacts by sector.

Table 3.13: Employment impacts on loan based financial variant in the central, low and high ambition scenario

	N of jobs [in 000s] and percentage difference from the baseline					
	2025	2030	2035	2040	2045	2050
Baseline	218,609	216,367	214,265	212,852	210,513	208,414
Low loan-based	0.01%	0.01%	0.02%	0.01%	0.02%	0.02%
Central loan-based	0.01%	0.02%	0.02%	0.02%	0.02%	0.03%
High loan-based	0.01%	0.04%	0.05%	0.04%	0.04%	0.04%

Source: GEM-E3

Table 3.14: Employment impacts by sector on loan based financial variant in the central, low and high ambition scenario (in % change from Baseline)

Sectors	Scenario	2025	2030	2040	2050
Electric vehicles	Low Ambition	47.1	38.3	48.6	52.5
	Central Ambition	49.8	55.6	51.1	52.5
	High Ambition	93.8	159.8	85.6	54.2
Conventional vehicles	Low Ambition	-0.9	-1.4	-2.5	-3.9
	Central Ambition	-0.9	-2.0	-2.5	-3.9
	High Ambition	-1.6	-5.8	-4.3	-4.1
Electrical equipment goods (including batteries)	Low Ambition	0.3	0.4	0.7	0.8
	Central Ambition	0.3	0.6	0.7	0.8
	High Ambition	0.5	1.7	1.2	0.8
Fossil Fuels	Low Ambition	-0.1	-0.1	-0.2	-0.6
	Central Ambition	-0.1	-0.2	-0.2	-0.6
	High Ambition	-0.1	-0.5	-0.6	-0.9

Sectors	Scenario	2025	2030	2040	2050
Electricity	Low Ambition	0.2	0.4	1.1	2.5
	Central Ambition	0.2	0.5	1.2	2.6
	High Ambition	0.3	1.2	2.3	3.2
Other Sectors	Low Ambition	0.00	0.00	-0.02	-0.04
	Central Ambition	0.00	-0.01	-0.02	-0.04
	High Ambition	-0.01	-0.03	-0.03	-0.04

Source: GEM-E3

3.2.6.4 Variants of the central scenario regarding labour intensity of electric vehicles and regional location of battery manufacturers.

Many studies report that the labour intensity (in terms of direct job requirements) of electric vehicles (IEA, 2017)[13] is lower than conventional vehicles if the manufacturing of batteries is excluded (i.e. if it is not performed by the EV industry but it is outsourced). For the GEM-E3 model, the direct job requirements for the conventional, electric vehicles and battery manufacturing are presented in Table 3.15 below. In order to test for the importance of labour intensity[14] in determining the overall employment impacts, the following variants have been considered:

- *Central:* In the default case, manufacturing of electric vehicles has lower direct requirements for labour than conventional vehicles and the batteries are manufactured in the EU.
- *SameEVCV:* In this variant, manufacturing electric vehicles and conventional vehicles has the same direct requirements for labour and the batteries are manufactured in the EU.
- *EVhighCV:* In this variant manufacturing of electric vehicles has higher direct requirements for labour than conventional and the batteries are manufactured in the EU.

Table 3.15: Direct labour Intensities used in GEM-E3[15] for vehicle manufacturing (in persons / m.€)

Sector	Scenario	2020	2030	2040	2050
Conventional vehicles	Central	3.4	2.9	2.5	2.2
	SameEVCV	3.4	2.9	2.5	2.2
	EVhighCV	3.4	2.9	2.5	2.2
Electric vehicles	Central	2.7	2.3	2.0	1.8
	SameEVCV	3.4	2.9	2.5	2.2
	EVhighCV	4.3	3.8	3.3	2.8
Batteries	Central	3.6	3.1	2.6	2.2
	SameEVCV	3.6	3.1	2.6	2.2
	EVhighCV	3.6	3.1	2.6	2.2

Source: GEM-E3

[13] (IEA, 2017) "It seems likely that the main employment impact of a switch to EVs would be associated with the production and installation of the electric drivetrain, including the battery, compared to an internal combustion engine. Producing internal combustion engines involves complex supply chains and requires more engineering resources than making an electric motor, but this difference may be offset by higher employment in *battery manufacturing".*

[14] Labour intensity is considered as a number of persons per unit of output (this is the direct requirements for labour). Labour intensity should not be mixed with the employment multiplier. Type I employment effect multiplier shows the direct and indirect impact upon employment throughout the economy arising from a change in final demand for output of 1 unit of an industry, whereas the type II includes also the induced effects (income effects). To clarify to what the direct labour intensities refer to the following example is provided: The electric vehicles industry will need to employ 2.3 persons to meet a demand of 1m €. As batteries represent roughly the 20% of total electric vehicles production cost there will be a demand of 200000 € for batteries. This demand will create 0.06 jobs (0.2*3.1=0.06).

[15] Labour intensities for 2015 were calculated by dividing the full time jobs by the value of production of each sector. The economic and employment data are from the Eurostat database. Labour intensity projections are based on the results of the GEM-E3 that includes sectoral production and employment by 5year period until 2050.

The scenarios Central, SameEVCV and EVhighCV were simulated under two labour market regimes: i) Flexible wages: Increasing demand for labour that increase wages and employment. Employment increases but not at its full potential as wages will moderate demand and ii) Sticky wages: Additional labour is available at baseline scenario wages.

Increasing the labour intensity of EV does not increase necessarily proportionally employment. In the flexible wages regime, additional demand for labour will increase average wage rates resulting a slight increase in total employment. In the sticky wages regime, where there is no pressure in the labour market, the increase in total employment for each scenario simulated (Central, SameEVCV, EVhighCV) is higher than those in the flexible wages regime. The results on employment of these sensitivities are also illustrated in below.

Table 3.16: Employment impacts of the alternative labour intensity scenarios

		Percentage difference from the respective[16] baseline			
Scenario	**Wage regime**	**2025**	**2030**	**2040**	**2050**
Central	Flexible	0.009%	0.019%	0.020%	0.025%
SameEVCV	Flexible	0.009%	0.020%	0.022%	0.028%
EVhighCV	Flexible	0.012%	0.026%	0.026%	0.032%
Central	Sticky	0.020%	0.044%	0.070%	0.083%
SameEVCV	Sticky	0.024%	0.051%	0.078%	0.093%
EVhighCV	Sticky	0.032%	0.068%	0.094%	0.109%

Source: GEM-E3

An additional case has been examined where battery manufacturing is outsourced and performed outside the EU. In the Central scenario, it is estimated, that the market value of batteries (that is additional to the Baseline scenario) is 6.1 billion € in 2030. In the case where batteries are manufactured exclusively outside EU the number of jobs lost is 23.6 thousand persons or 0.011% change from the baseline in the central scenario with sticky wage regime. This number includes the direct and indirect jobs lost from relocating battery manufacturing and calculated through the multiplier of the type I employment effects as derived in 2030. To capture the induced effects (that includes the income effects), the multiplier of the type II employment effects has been used. The type II employment effects were found to be 5.6 and the total impact on employment is 34.5 thousand persons or 0.016% change from the baseline in the central scenario with sticky wage regime.

3.2.7 Sensitivity: Evolution of the assumed gap between WLTP test cycle and real-world emissions performance

3.2.7.1 Definition of the sensitivity scenario on the WLTP-RW gap

There has been a difference between test-cycle and real-world CO_2/fuel consumption performance and this difference has been significantly increasing over time due to a combination of effects that have been explored in detail (e.g. in (JRC, 2016), (TNO et al., 2012a)). The introduction of WLTP is anticipated to considerably reduce this gap. For the analysis, a series of NEDC-WLTP and WLTP-RW factors have been implemented in the updated PRIMES-TREMOVE model. The default assumption/setting in this analysis is for the WTLP-RW gap to remain constant from 2020 for a given powertrain type and segment (the average gap may change due to shifts in the mix of powertrains).

[16] To ensure the comparability among the alternative scenarios regarding the labour intensity, the respective baselines have been simulated: (i) **Base_int**: Baseline scenario results with labour intensity equal between conventional and electric vehicles, neutrality on public budget and flexible wages, (ii) **Base_int_High**: Baseline scenario results where EV labour intensity is higher than CV, neutrality on public budget and flexible wages, (iii) **Base_int_fix**: Baseline scenario results with labour intensity equal between conventional and electric vehicle manufacture, neutrality on public budget and sticky wages (equal to the baseline case) and (iv) **Base_int_High_fix**: Baseline scenario results where EV labour intensity is higher than CV, neutrality on public budget and sticky wages (equal to the baseline case). Each alternative scenario should be compared by its respective baseline in order to be able to distinguish between the effect of the different labour intensity and the effect of the policies in the scenarios.

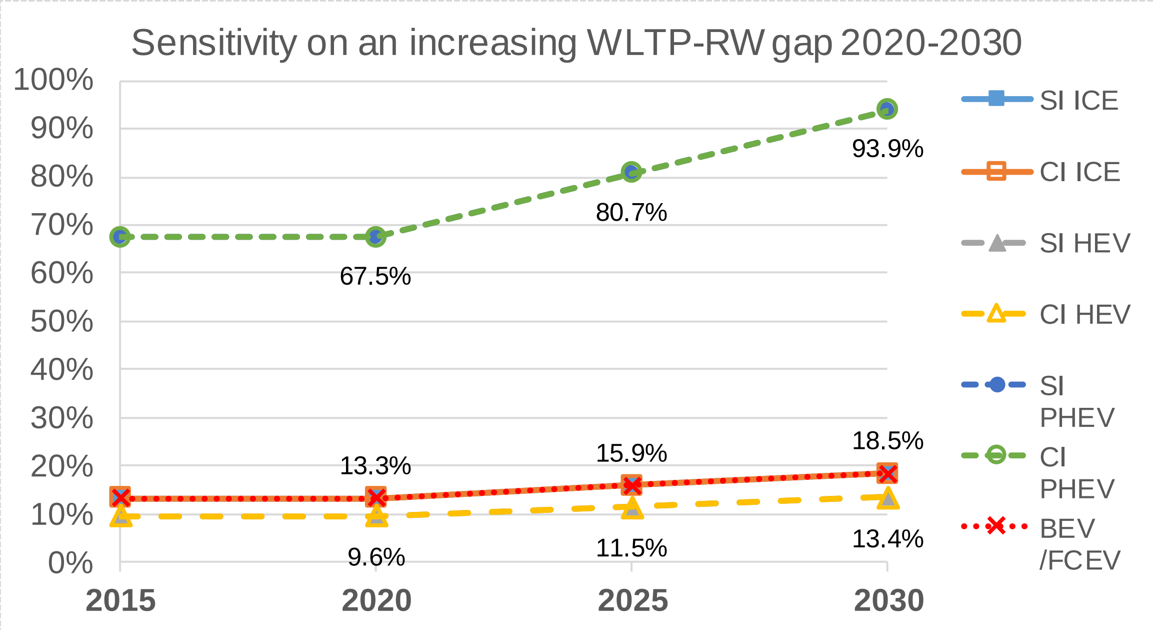
However, it was also deemed important to investigate the degree to which this WLTP-RW gap might increase in the future.

Ricardo and TU Graz evaluated the available evidence to explore the degree to which the WLTP-RW gap could be different to the default scenario assumptions in order to characterise a sensitivity. There have been some recent analyses of the potential size of the WLTP-RW gap and the factors that could lead to this gap increasing over time, most significantly by (JRC, 2016) and by (ICCT/Element Energy, 2015). TU Graz also carried out an assessment of the information provided in (JRC, 2016) on the elements that might further increase the WLTP-RW gap to 2030, including the following:

- Extra load
- Trailer towing
- Technology optimisation to WLTC
- Cycle length
- Auxiliaries
- Roof boxes, open windows, etc.
- Rain, snow
- Different driving cycle and gear shifts (and impact of future move to AMTs optimised to WLTC)
- Road surface

A linear WLTP-RW increase between 2020-2030 as summarised in Figure 3.21 below was used as a sensitivity on the WLTP-RW gap. The full details of the assumptions used are provided in Appendix 2 of this report.

Figure 3.21: Sensitivity on the WLTP to Real-World (RW) gap from 2020-2030 for different powertrain types

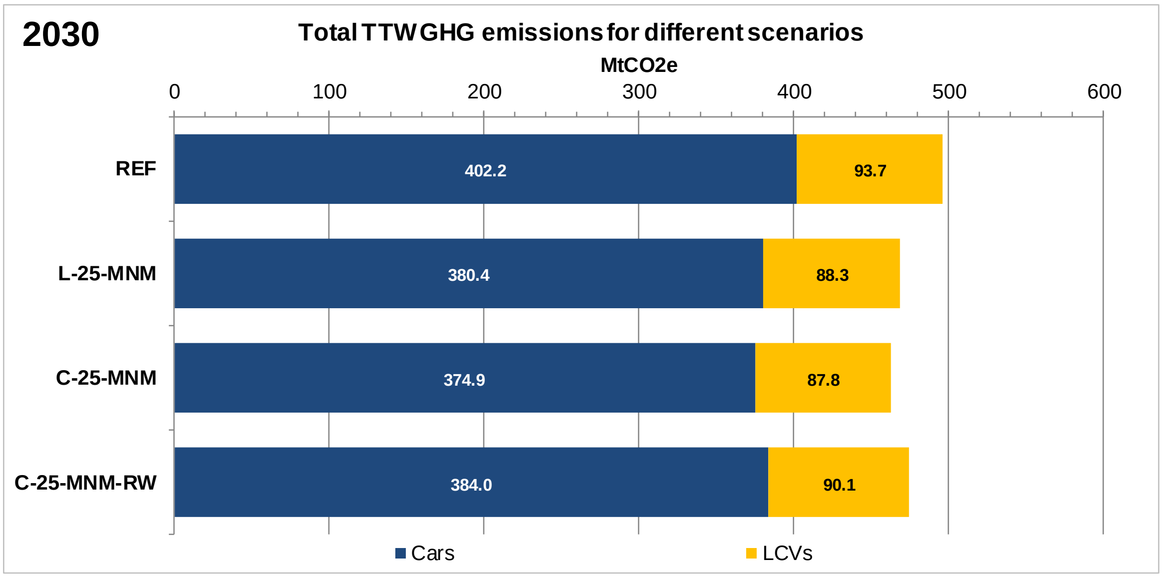


For the purposes of the modelling exercises, the model parameters of PRIMES-TREMOVE were accordingly modified, for the scenario where the impacts of alternative assumptions on the future evolution of the WLTP-RW gap was examined.

3.2.7.2 Assessing the effectiveness in reducing TTW and WTW emissions of CO_2

The impacts of the sensitivity for an increasing real-world gap (scenario C-25-MNM-RW) are straightforward when assessing the evolution of TTW CO_2 emissions in transport by 2030. As expected, an increase in the WLTP to RW gap would effectively lead to increases in CO_2 emissions from transport. Despite the higher gap assumed in the C-25-MNM-RW scenario, CO_2 emissions are still well below the baseline. This is a clear sign that the regulation, when effectively implemented, will lead to an emission reduction, though the sensitivity does show significant potential for undermining the achieved savings.

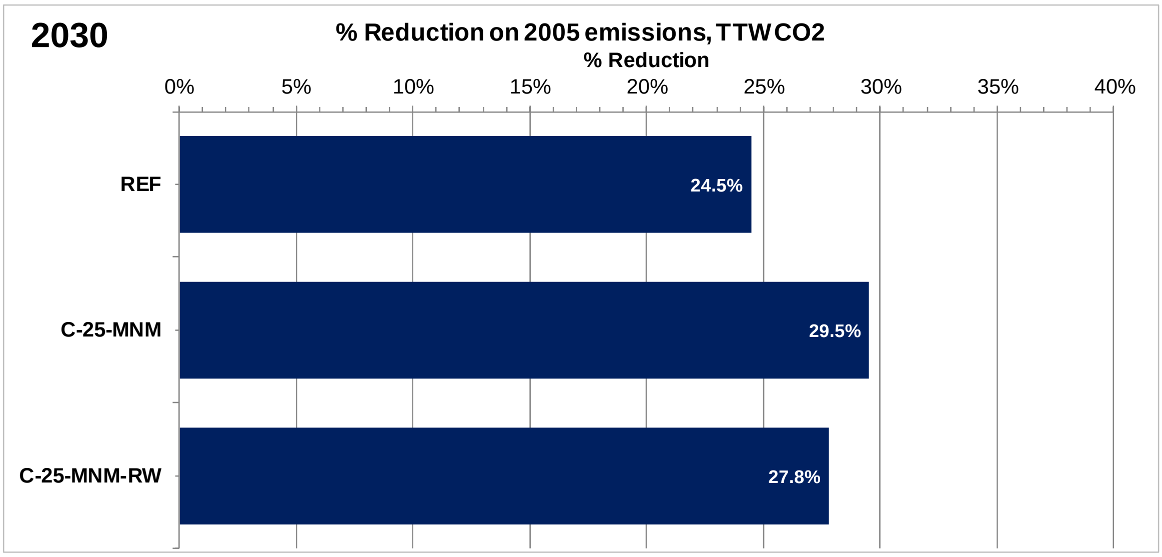
Figure 3.22: TTW CO_2 emissions from transport – sensitivity on the WLTP-RW gap



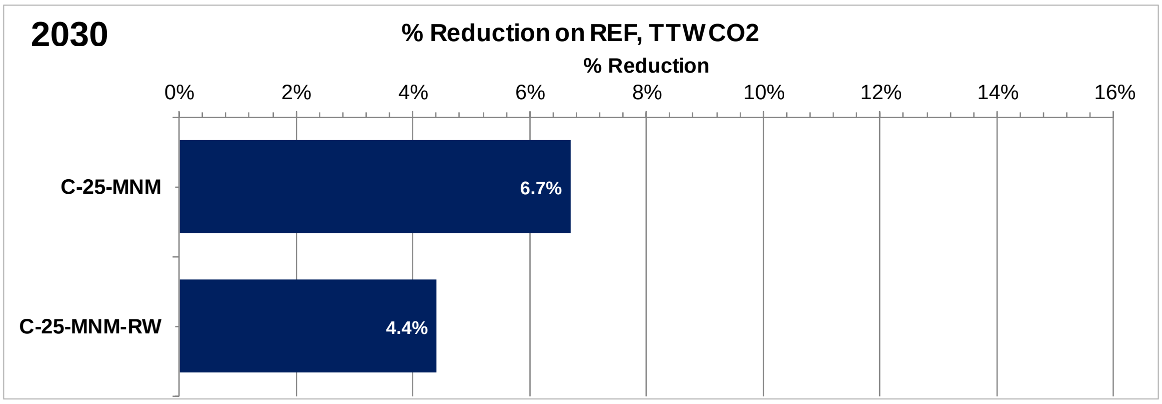
In particular, CO_2 emissions in transport in the C-25-MNM-RW scenario are found to decrease by 27.8% relative to 2005 levels, which is 1.7 percentage points (p.p.) lower than under C-25-MNM and even 0.8 p.p. lower than under the lower ambition L-25-MNM scenario. The baseline presents a reduction of 24.5% during the same timeframe. Relative to the baseline scenario, the resulting TTW CO_2 savings for C-25-MNM-RW scenario are reduced by around a third compared to the C-25-MNM scenario to around 4.4%.

Figure 3.23: TTW CO_2 emission reduction from LDVs – sensitivity on the WLTP-RW gap, (a) relative to 2005, (b) relative to the baseline scenario

(a)

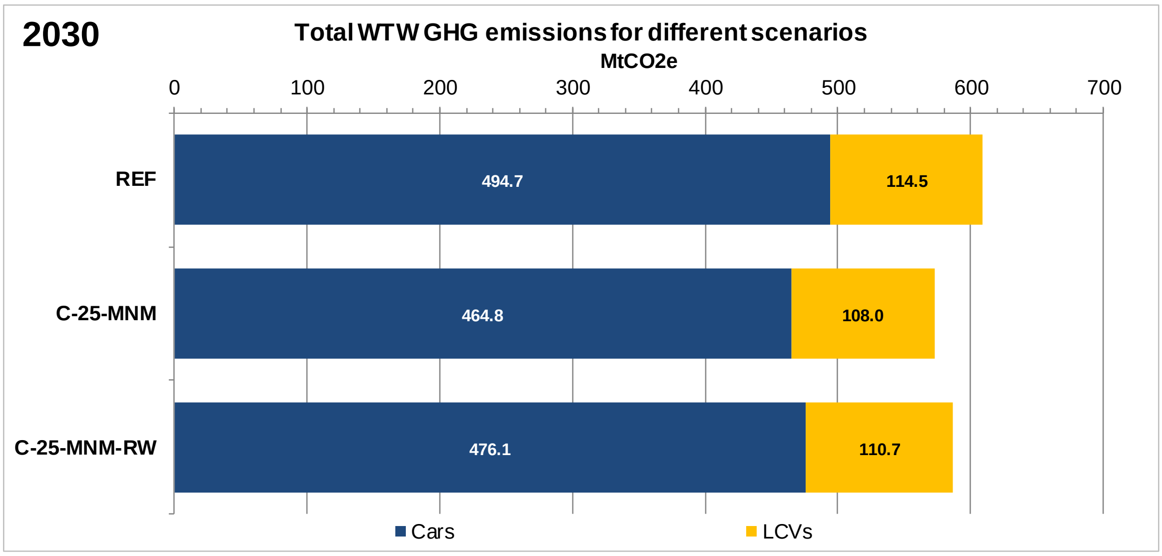


(b)



Regarding WTW emissions, the picture is quite similar to TTW emissions. The resulting increase in energy consumption on a real-world basis drives an increase in upstream WTT emissions. The contribution by vehicle segment on the marginal emissions (i.e. the additional emissions induced by the change in the gap) is found to be uniform.

Figure 3.24: WTW emissions – sensitivity on the WLTP-RW gap



3.2.7.3 Assessment of other impacts

The increased gap between WLTP and RW performance of cars is found to yield some minor positive externalities, which are likely to be mainly due to slightly reduced activity levels (from higher fuel costs).

Table 3.17: (Change in) external costs from transport in 2030 – sensitivity on the WLTP-RW gap, million Euro

	REF	C-25-MNM	C-25-MNM-RW
Million Euro			
Accidents	77,376	77,403	77,208
Noise	11,415	10,852	10,822
Congestion	192,233	191,928	191,423
Air Pollution	9,052	8,527	8,536
Total	**290,075**	**288,710**	**287,990**

	REF	C-25-MNM	C-25-MNM-RW
% Difference to REF			
Accidents		0.0%	-0.2%
Noise		-4.9%	-5.2%
Congestion		-0.2%	-0.4%
Air Pollution		-5.8%	-5.7%
Total		**-0.5%**	**-0.7%**

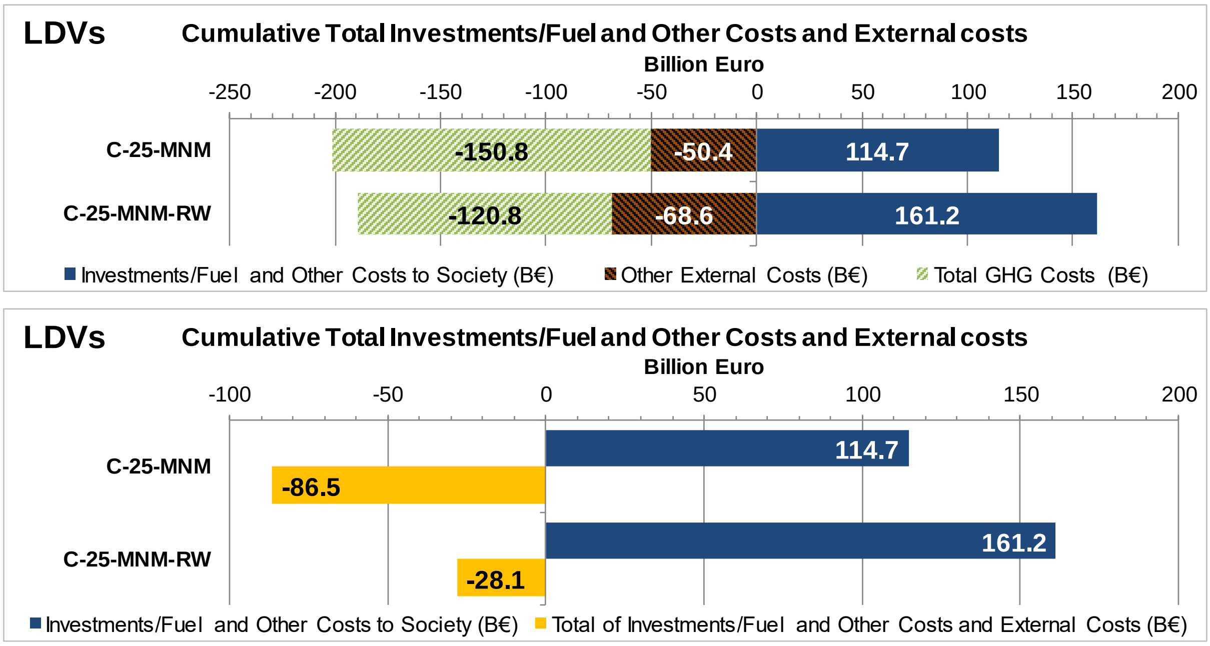
3.2.7.4 Cost-benefit analysis of system-level PRIMES-TREMOVE results

An assessment of the cumulative impacts of the direct and indirect cost components and net societal cost-benefit analysis is presented in Figure 3.25 below (for central GHG costs) (based on (Ricardo-AEA, 2014), see also Appendix 4).

The figure shows that an increase in the WLTP-RW gap could significantly increase the direct system costs (and reducing also overall cost-effectiveness, due to lower fuel cost savings) as well as savings in externalities, leading a significantly reduction in net benefits from a societal perspective (i.e. direct costs plus externalities) – by over two-thirds.

More information is provided in Appendix 4 on this methodology, together with a more detailed breakdown of the different components.

Figure 3.25: Summary of the cost-benefit analysis for the central ambition scenario and WLTP to real-world gap sensitivity compared to the baseline scenario (central GHG costs)



Notes: "Investments/Fuel and Other Costs" = includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

3.2.7.5 Conclusions for the sensitivity on potential impacts of an increasing WLTP-RW gap

The sensitivity run assuming an increasing WLTP-RW gap from 2020-2030 illustrates the potential for significant weakening of the GHG reduction effectiveness of the post-2020 targets and the end-user benefits in terms of reduced fuel costs.

3.2.8 Sensitivity: Lower fuel prices

3.2.8.1 Definition of the sensitivity scenario

Further model runs allowed to assess the potential impacts of alternative assumptions regarding the evolution of fuel prices. For this, the Baseline scenario and three policy scenarios (C-25-MNM, H-25-MNM and L-25-MNM) were run in a lower fuel price context. The price assumptions derive from the IEA's Low Oil Price Scenario (IEA, 2015), by using the rate of change between the "low oil price scenario" and the "current policies scenario" and applying it to the prices of the baseline scenario. Figure 3.26 provides a comparison of the default and low fuel price scenarios.

New, updated, IEA low oil price scenario data (IEA, 2017a) became available too late in the project to be factored directly into the modelling analysis presented analysis here. A comparison of this data with the earlier IEA figures is provided in Figure 3.27, which show the prices fall intermediate between the baseline case and the analysis based on the earlier (IEA, 2015) set.

The new IEA fuel price projections show higher projected price than the Low Oil Price Scenario developed in 2015. Therefore, the results of the sensitivity presented here may be too negative as a result of the very low oil prices used.

Figure 3.26: Fuel price trajectories for the standard scenario runs and the low fuel price sensitivities

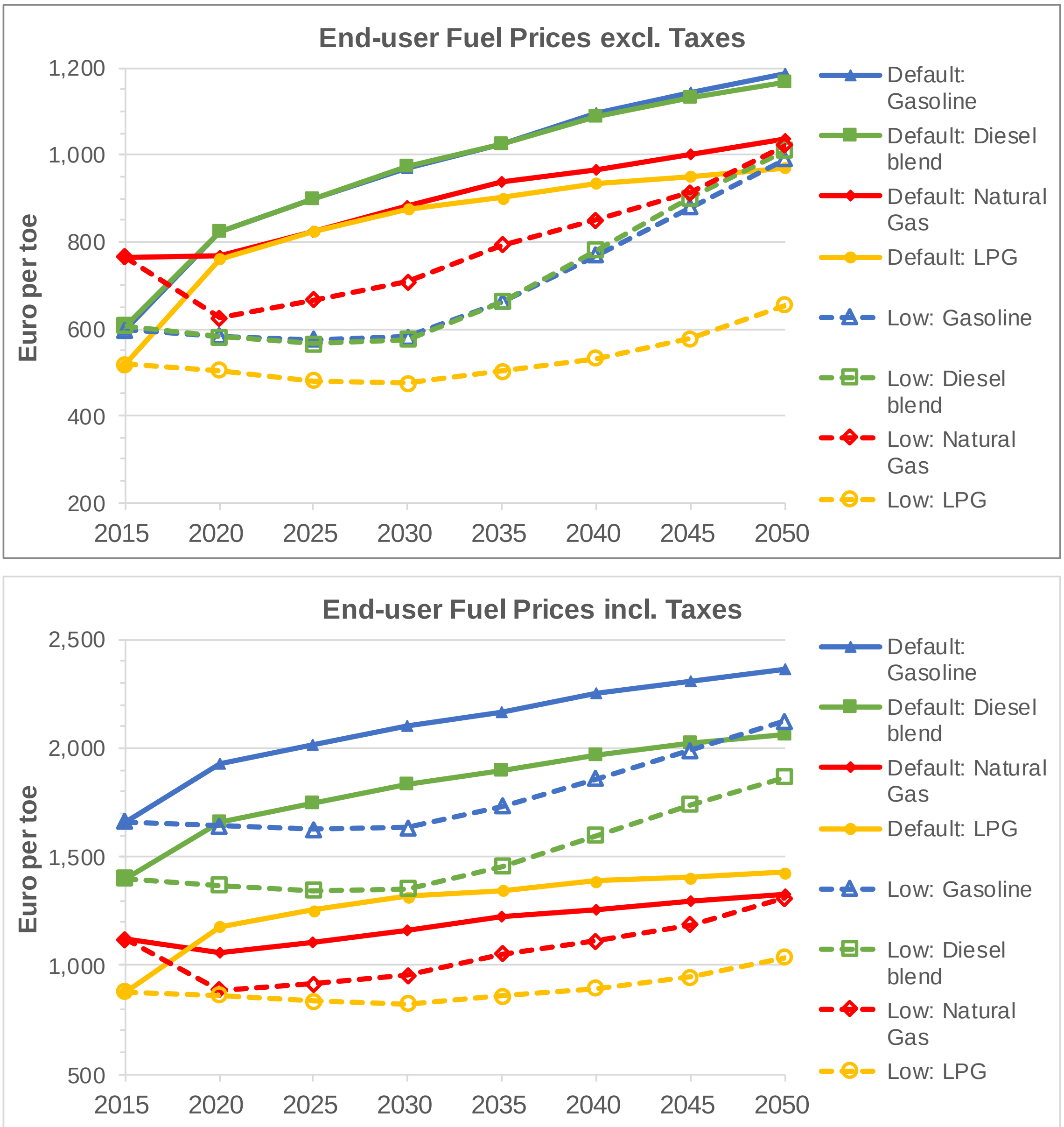
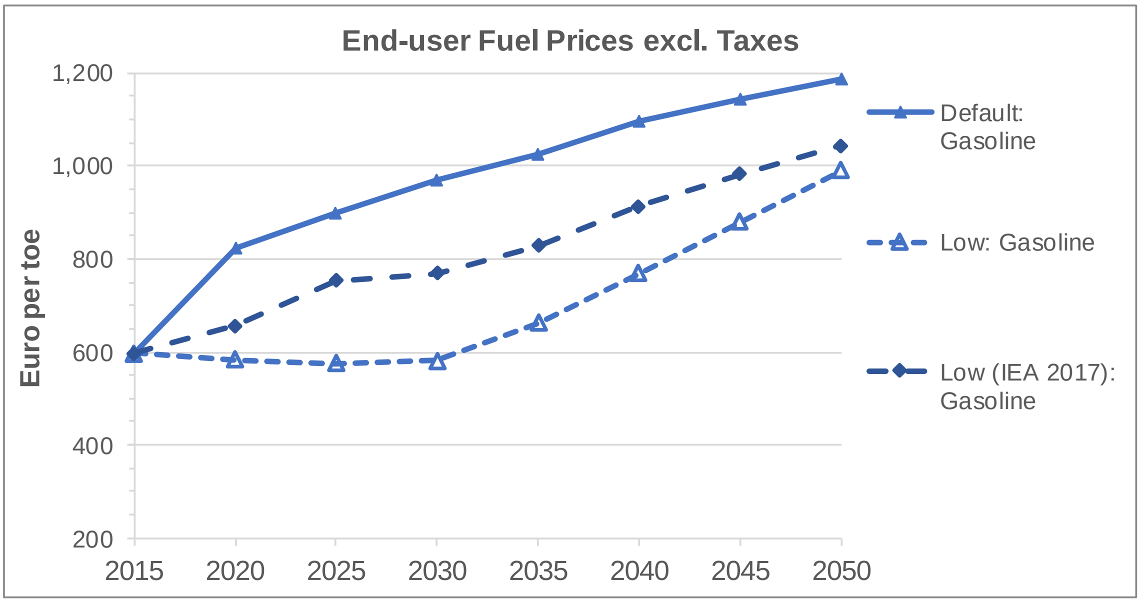


Figure 3.27: Comparison of gasoline fuel price trajectories (excluding taxes) for the standard scenario runs, and alternative low fuel price sensitivities

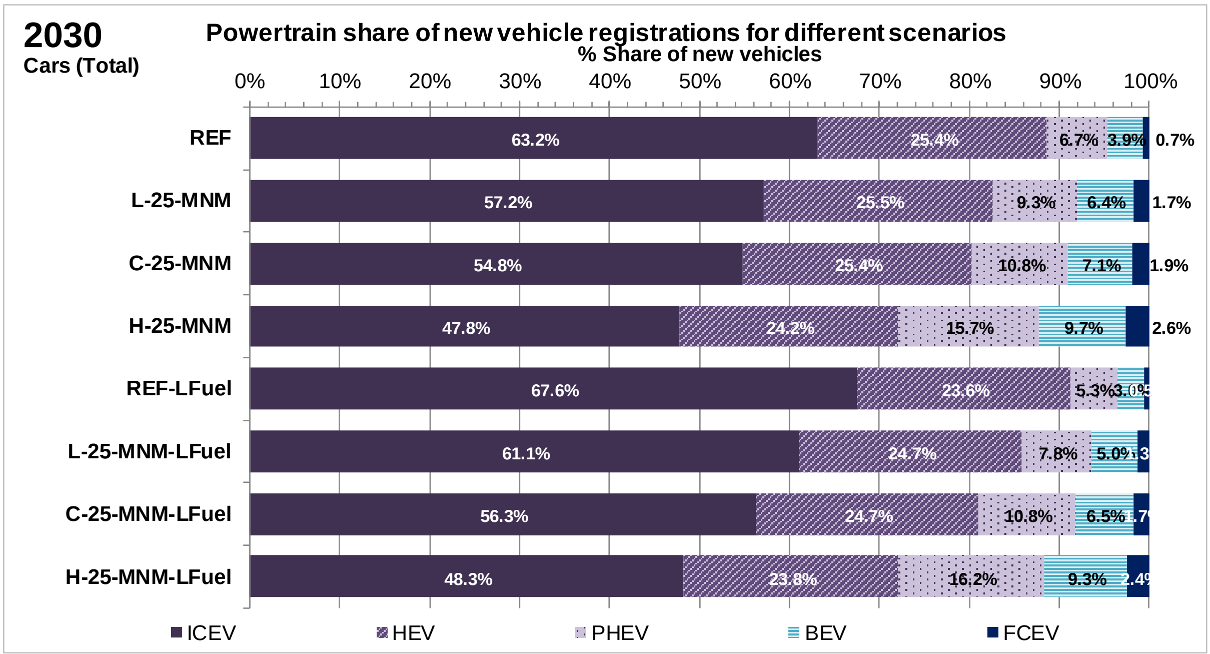


3.2.8.2 Assessing the effectiveness in reducing TTW and WTW emissions of CO_2

The market shares of advanced powertrains increase in 2030 as the ambition of the target increases also in case of lower international fuel prices.

The lower oil prices result in decreased gasoline and diesel end user prices which increase the competitive advantage of the conventional powertrains compared to advanced powertrains. According to the model results, the market shares of BEVs are found to decrease by 1.3pp (percentage points), 0.6pp and 0.5pp between the L-25-MNM and L-25-MNM-LFuel, the C-25-MNM and C-25-MNM-LFuel, and the H-25-MNM and the H-25-MNM-LFuel scenarios in 2030, respectively. The market share of PHEVs is found to slightly increase under the H-25-MNM-LFuel scenario compared to the H-25-MNM scenario in 2030. In this particular case, PHEVs benefit from the lower fuel prices compared to the BEV powertrains.

Figure 3.28: Powertrain shares of new passenger cars in 2030, low fuel price sensitivities



Lower fuel prices leading to an increase in TTW CO_2 emissions in the REF-LFuel scenario in 2030 compared to the REF scenario. The increase in emissions is driven by the increase in passenger and freight transport activity due to the lower prices of transport fuels. TTW CO_2 emissions in the REF-LFuel (low fuel price baseline) scenario decrease by 19% in 2030 relative to 2005, while the REF (baseline) scenario decreases by 24.5%.

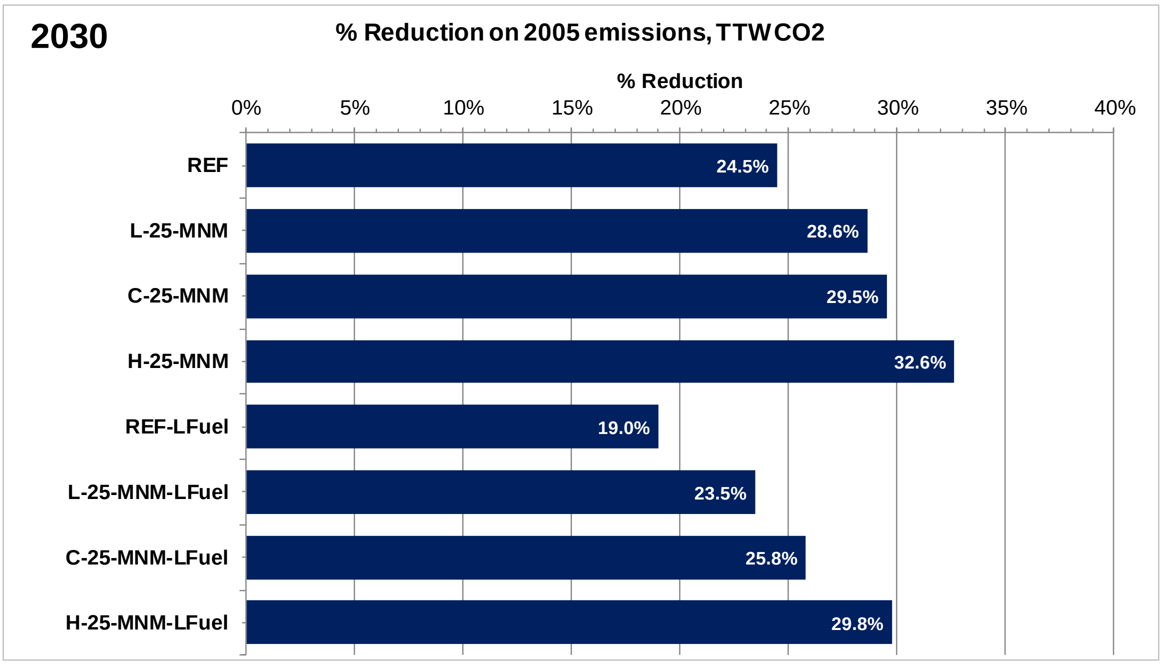
The model runs show that more ambitious targets will lead to further emission reductions. However, the emission reduction under the variants with low fuel prices is less than that of the corresponding scenarios with default prices:

- 25.8% TTW CO_2 emission reduction in the C-25-MNM-LFuel in 2030 compared to 2005, and 8.4% reduction on the low fuel price baseline;
- 29.5% TTW reduction on 2005, and 6.7% reduction on the default fuel price baseline, for the C-25-MNM scenario.

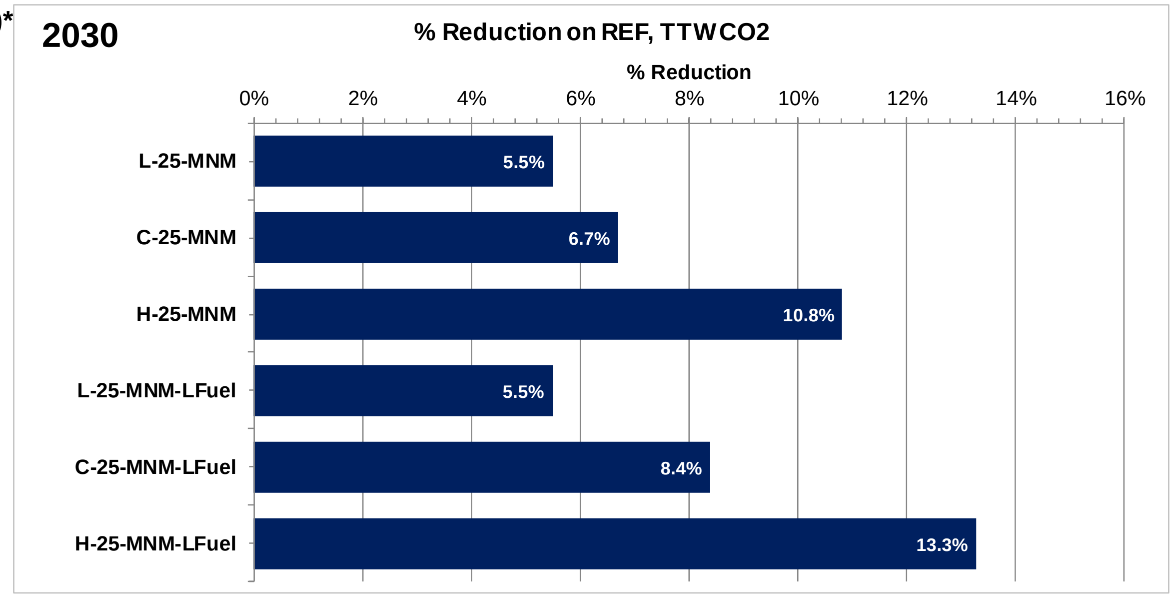
The difference in emission reduction between the C-25-MNM-LFuel (-8.4% vs baseline) and the L-25-MNM-LFuel (-5.5% vs baseline) scenarios is more pronounced compared to the C-25-MNM (-6.7% vs baseline) and the L-25-MNM (-5.5% vs baseline) scenarios. The lower fuel prices in the relevant variants favour the conventional vehicle technologies that are powered on petroleum products. According to the model, the lower fuel prices reduce some of the autonomous progress that would take place in the L-25-MNM scenario (either through a shift towards a more advanced powertrain or to a more fuel efficient conventional powertrain option). The difference in the emission reduction between the C-25-MNM and the H-25-MNM scenarios remains relatively unchanged regardless of the assumptions on the fuel prices.

Figure 3.29: TTW CO_2 emissions from LDVs for central and lower fuel price sensitivities, (a) relative to 2005, (b) relative to the baseline scenario

(a)



(b)*



Notes: * CO_2 emissions reductions for the "-LFuel" scenarios are compared to the REF-LFuel scenario baseline.

3.2.8.3 Assessment of other impacts

As shown in Table 3.18, the REF-LFuel scenario presents an increase in the external costs in transport in 2030 relative to the REF scenario. All types of externalities intensify because of an increase in transport activity.

Under the Central scenario with lower fuel prices (C-25-MNM-LFuel) total transport external costs reduce by around 0.6% in 2030 relative to the REF-LFuel scenario. This change is similar to the change between the C-25-MNM and the baseline scenario (REF) (0.5% reduction in 2030, see Table 3.18). The picture remains relatively unchanged as regards the changes by type of externality when comparing the Central scenario against the baseline scenario on the two alternative fuel price frameworks.

Model results indicate that the implementation of more ambitious targets in 2030 will result in a higher reduction in the total transport externalities. The latter decrease by 1.1% in the H-25-MNM-LFuel scenario relative to the REF-LFuel scenario in 2030. This finding is in line with the findings under the default fuel price analysis, presented previously in the report. On the contrary, the L-25-MNM-LFuel scenario exhibits the lowest reduction in external costs by 2030.

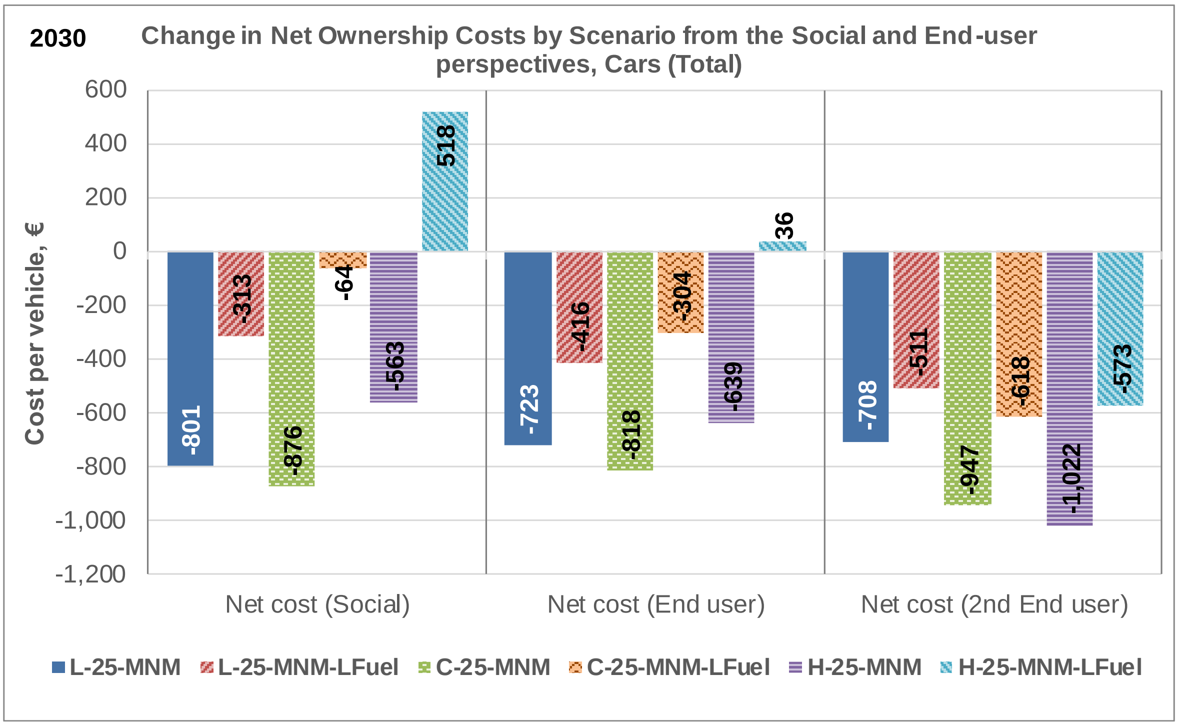
Table 3.18: (Change in) external costs from transport in 2030 – low fuel price sensitivities, million Euro

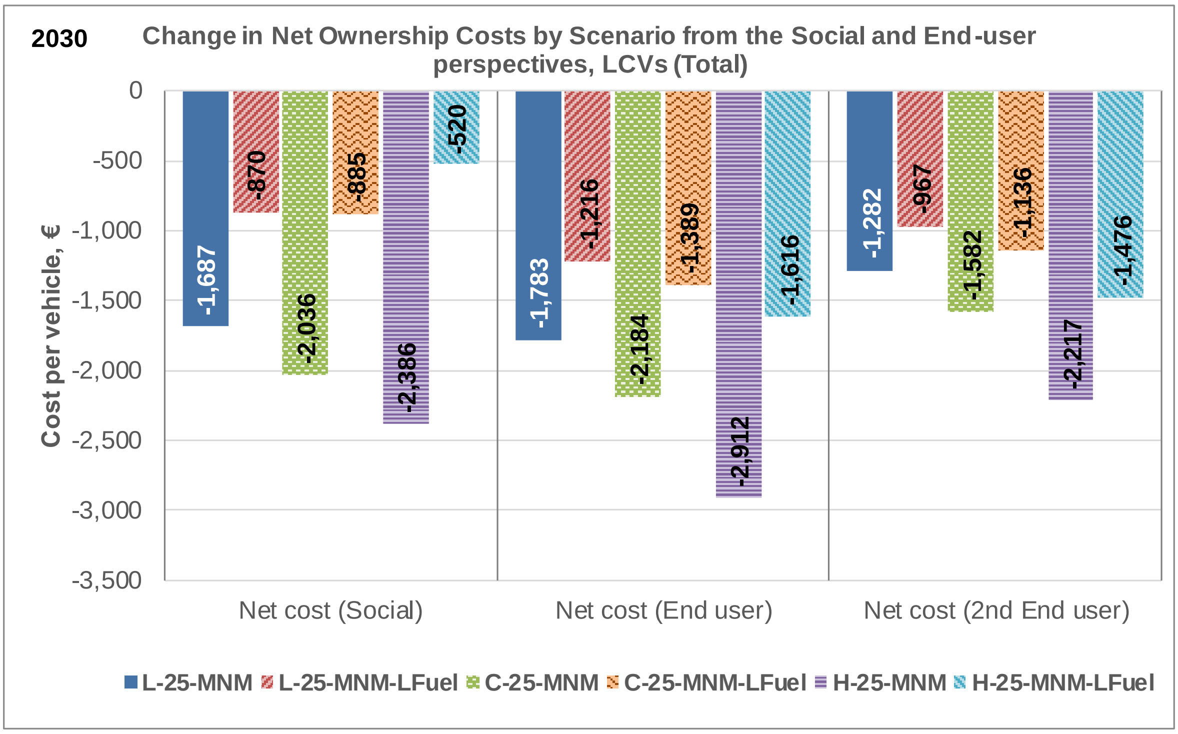
	REF	C-25-MNM	REF-LFuel	C-25-MNM-LFuel	L-25-MNM-LFuel	H-25-MNM-LFuel
Million Euro			***Million Euro***			
Accidents	77,376	77,403	80,332	80,304	80,257	80,286
Noise	11,415	10,852	12,199	11,411	11,759	10,755
Congestion	192,233	191,928	199,244	198,813	198,834	198,638
Air Pollution	9,052	8,527	9,775	9,097	9,345	8,627
Total	**290,075**	**288,710**	**301,550**	**299,625**	**300,195**	**298,306**
% Difference to REF			***% Difference to REF-LFuel***			
Accidents		0.0%		0.0%	-0.1%	-0.1%
Noise		-4.9%		-6.5%	-3.6%	-11.8%
Congestion		-0.2%		-0.2%	-0.2%	-0.3%
Air Pollution		-5.8%		-6.9%	-4.4%	-11.7%
Total		**-0.5%**		**-0.6%**	**-0.4%**	**-1.1%**

3.2.8.4 Impacts on average vehicle Total Cost of Ownership (TCO)

Figure 3.30 illustrates the impact of lower fuel costs on the average total cost of ownership for the societal and end-user perspectives in 2030 for cars and LCVs, relative to the default fuel price assumptions. The results show a significant reduction in the average net cost savings to end-users in all cases. In the high ambition case for cars the result changes from net savings to net costs for the societal perspective. However, including also reductions in external costs (for GHG, air quality pollutants, etc.) in the accounting would still lead to significant net savings in all cases.

Figure 3.30: Impact of lower fuel costs on the average vehicle Total Cost of Ownership (TCO) of different options for passenger cars compared to the baseline scenario for societal and end-user perspectives, by ambition level





Notes: **Societal** perspective = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** perspective = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

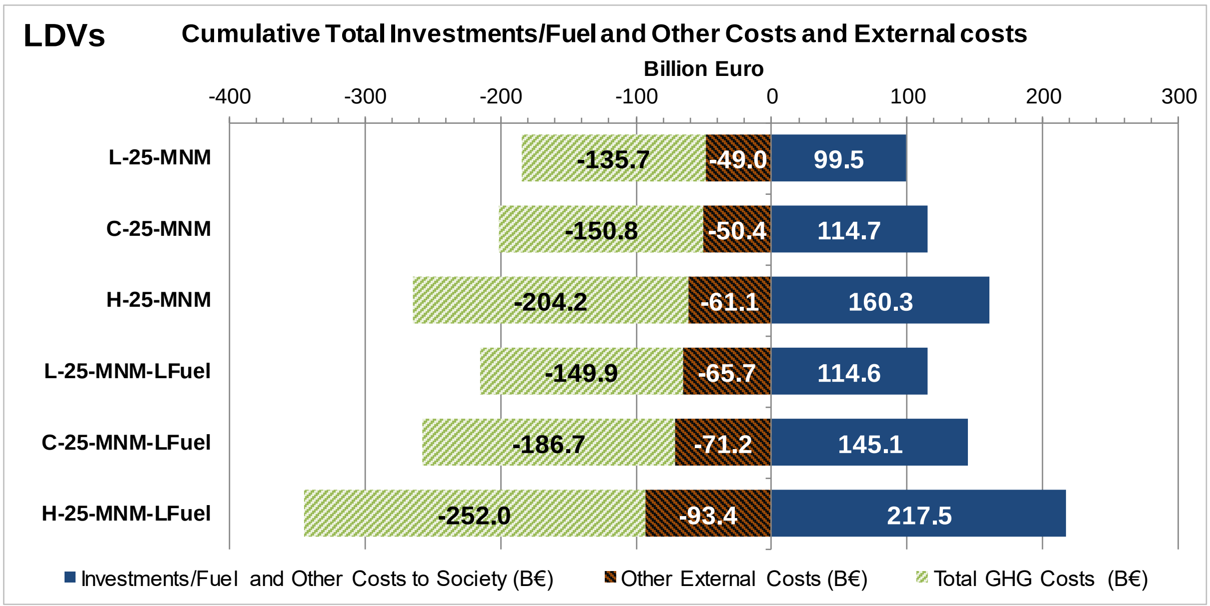
3.2.8.5 Cost-benefit analysis of system-level PRIMES-TREMOVE results

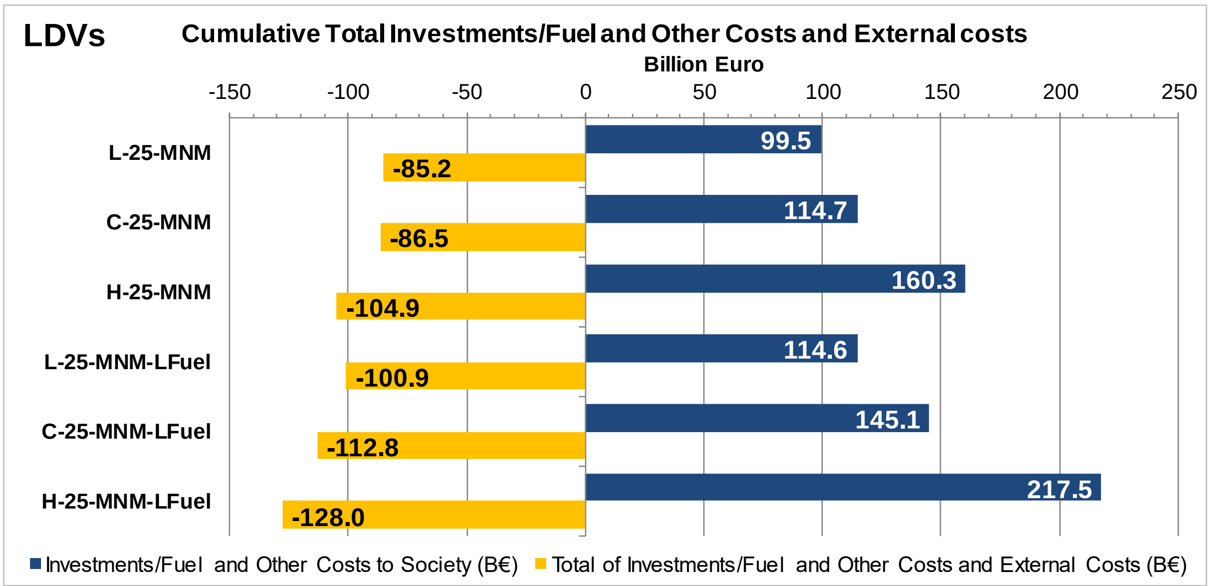
An assessment of the cumulative impacts of the direct and indirect cost components and net societal cost-benefit analysis is presented in Figure 3.31 below (for central GHG costs) (based on (Ricardo-AEA, 2014), see also Appendix 4).

The figure shows that although total direct system costs increase in a low fuel price scenario for all ambition levels, reducing the cost-effectiveness of GHG reductions (in €/tCO_2), these increases in direct costs are outweighed by the more significant reductions in externalities from a societal perspective, when also assuming a low fuel price for the baseline scenario case.

More information is provided in Appendix 4 on this methodology, together with a more detailed breakdown of the different components.

Figure 3.31: Summary of the cost-benefit analysis for the sensitivity on low fuel prices compared to the baseline scenario (central GHG costs)





Notes: "Investments/Fuel and Other Costs" = includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

3.2.8.6 Distribution of impacts across income groups (social equity)

The social equity analysis presented in Section 3.2.5 finds that the low-income classes will benefit from the purchasing of second hand cars that offer significant annual fuel savings. However, in the case of low fuel prices, the annual fuel savings will decrease which will offset the benefits observed in the analysis in the previous section. In such case, the low-income households will not benefit to the same extent as in the case of higher fuel prices.

3.2.8.7 Conclusions for the sensitivity on potential impacts of lower fuel prices

The lower fuel prices will result in higher TTW CO_2 emissions in the transport sector until 2030, due to the increase in transport activity.

The key risks of lower fuel prices include, a reduction in the net cost benefits of the regulatory targets, and *also* in their effectiveness in reducing GHG emissions.

Lower fuel prices would lead to lower benefits in terms of total cost of ownership. The effect is more outspoken for the higher target ambition levels.

Lower fuel prices risk lowering the effectiveness of the regulations in reducing GHG emissions through two key mechanisms. First, there is a risk of increased light duty vehicle activity from lower fuel prices; this has been assessed at as much as 3.5%, . Second, the reduced fuel savings of more efficient vehicles are likely to reduce the attractiveness to consumers of potentially more expensive efficient models.

Under lower fuel price assumptions, the benefits of other impacts (i.e. air pollution, noise, etc.) increase slightly as there are fewer improvements in the baseline. However, the societal benefits will also be lower as fuel cost savings will be less.

3.2.9 Sensitivity: Lower diesel share scenario

3.2.9.1 Definition of the sensitivity scenarios

Over the last two decades there has been a significant shift in market share from petrol- to diesel-fuelled passenger cars, driven at least in part by CO_2 reduction objectives, peaking in 2011 at ~55% (FT, 2016). One of the consequences of the 'dieselgate' emission scandal revealed in 2015, in combination with an increasing emphasis on reducing urban NO_x emissions due to ongoing air quality limit exceedances in European cities, is a shift back towards petrol-fuelled vehicles (and to other powertrain types). This change is also being influenced by a range of other factors (e.g. public perception, introduction of RDE, costs, improvements to petrol engine technologies, etc.). To understand what the potential implications of a substantial shift away from diesel might be (on emissions, costs, other impacts), two sensitivity scenarios were developed:

1. *C-25-MNM-DSL*: 'Low diesel' scenario, characterised as a significant reduction in the market share of diesel conventional and full hybrid cars in 2030, with a 40% reduction in diesel share for small cars, and 30% reduction for medium and large cars.
2. *C-25-MNM-DSL2*: 'Very low diesel' scenario, characterised as a very high reduction in the market share of diesel conventional and full hybrid cars in 2030, with an 80% reduction in diesel share for small cars, and 60% reduction for medium and large cars.

3.2.9.2 Assessing the effectiveness in reducing TTW and WTW emissions of CO_2

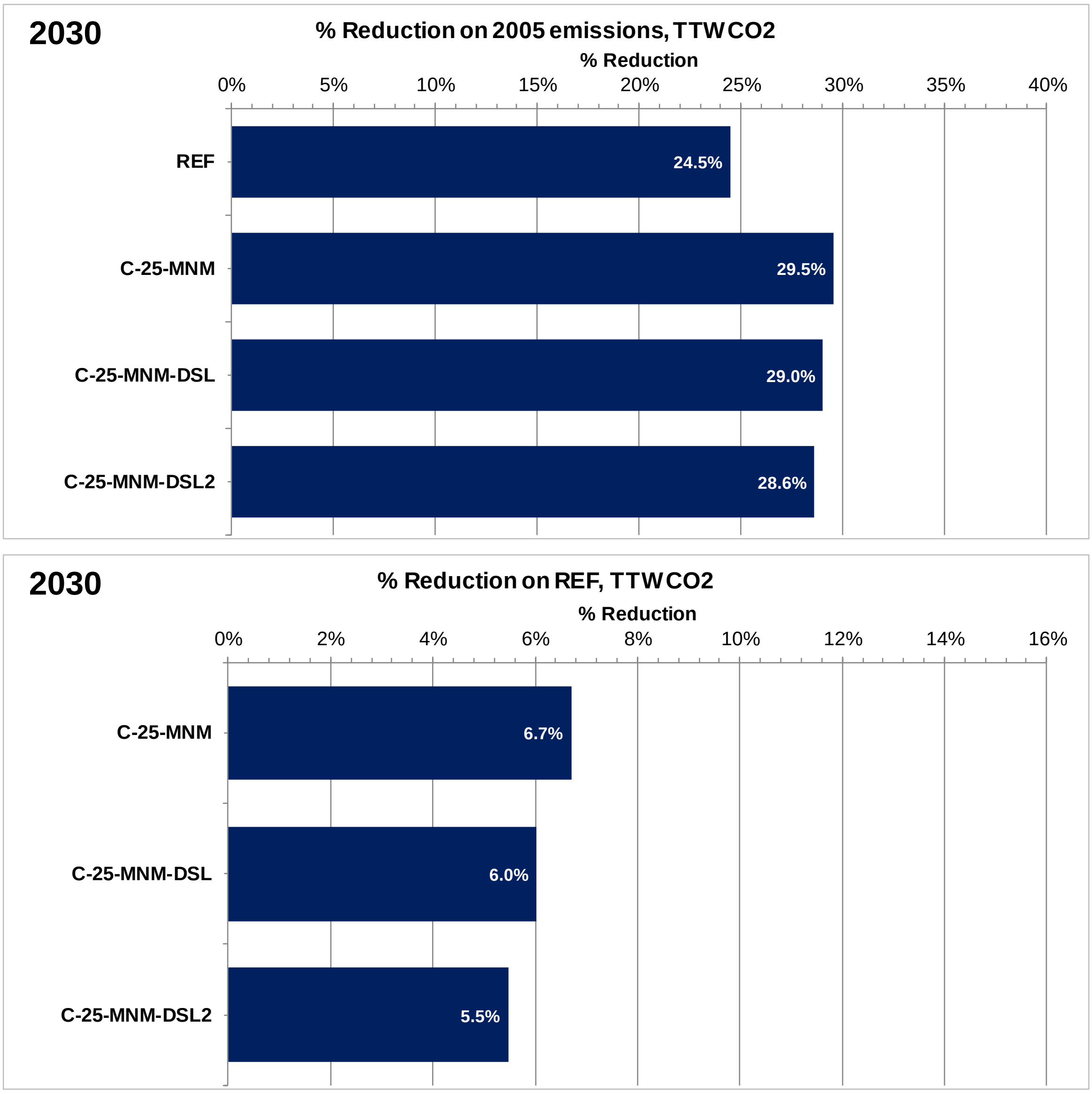
Two scenario runs have been quantified which explore two alternative evolution pathways of diesel powered cars in the market. The first scenario called (C-25-MNM-DSL) assumes a higher share of diesel cars than in the more "extreme" scenario called (C-25-MNM-DSL2).

The lower market shares of diesel cars in the market are mainly compensated by a higher uptake of gasoline powered ones, with a relatively small increase in xEVs (1.3-3% percentage points by 2030 for new cars). With regards to the evolution of the TTW GHG emissions, the model shows a marginal increase in emissions as the market share of diesel cars decreases, as illustrated in Figure 3.23. In the most extreme case this reduces the effectiveness of the CO_2 reductions by over 18%, from 6.7% to 5.5% reduction, a 1% increase in comparison to the REF scenario. This is because the gap between WLTP and the real-world performance of gasoline cars is greater than that of the equivalent diesel cars.

Reductions in the WTW CO_2 emissions at 2030 for the two lower diesel share sensitivities are also similar in magnitude.

Figure 3.32: TTW CO_2 emission reduction from LDVs, lower diesel share scenarios, (a) relative to 2005, (b) relative to the baseline scenario

(a)



3.2.9.3 Assessment of other impacts

The shift from diesel cars towards gasoline ones causes a decrease in pollutant emissions and especially NOx emissions. The highest reduction in NOx emissions takes place in the C-25-MNM-DSL2 scenario (16.1% reduction compared to baseline in 2030) as this has the lowest penetration of diesel cars. The C-25-MNM-DSL scenario shows a reduction of 9.2% in 2030 compared to the baseline scenario. This contrasts the case of the C-25-MNM scenario which shows a 4% reduction relative to the baseline.

The external costs from transport are found to decrease in both sensitivity scenarios relative to the baseline and the C-25-MNM scenario. The reduction is driven by the reduction in the external costs from air pollution. Even though the external costs from air pollution decrease considerably (around 30% in the C-25-MNM-DSL2 scenario compared to the baseline), the overall external costs in transport decrease by 1.5% between the two abovementioned scenarios as the external costs from air pollution represent the lowest part of the overall external costs in transport.

Table 3.19: (Change in) external costs of other impacts from transport – lower diesel share scenarios, million Euro

	REF	C-25-MNM	C-25-MNM-DSL	C-25-MNM-DSL2
			Costs, million Euro	
Accidents	77,376	77,403	77,259	77,266
Noise	11,415	10,852	10,667	10,463
Congestion	192,233	191,928	191,912	191,708
Air Pollution	9,052	8,527	7,552	6,339
Total	**290,075**	**288,710**	**287,390**	**285,775**
			% Difference to REF	
Accidents		0.0%	-0.2%	-0.1%
Noise		-4.9%	-6.6%	-8.3%
Congestion		-0.2%	-0.2%	-0.3%
Air Pollution		-5.8%	-16.6%	-30.0%
Total		**-0.5%**	**-0.9%**	**-1.5%**

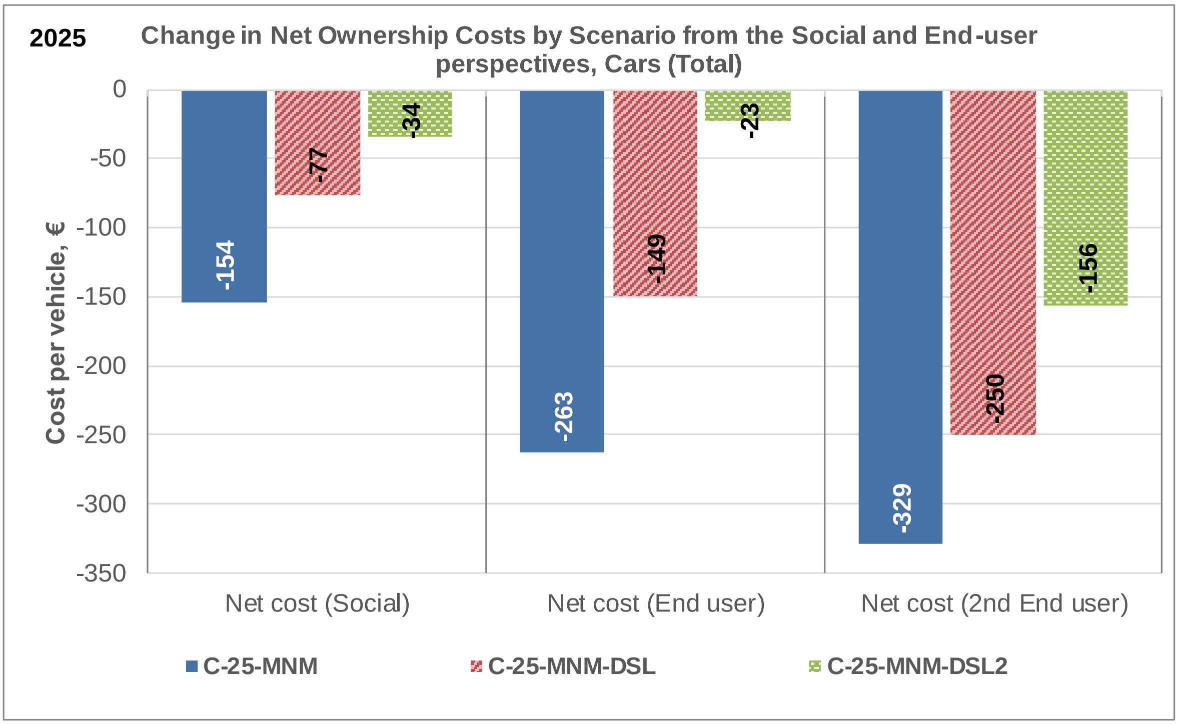
3.2.9.4 Impacts on average vehicle Total Cost of Ownership (TCO)

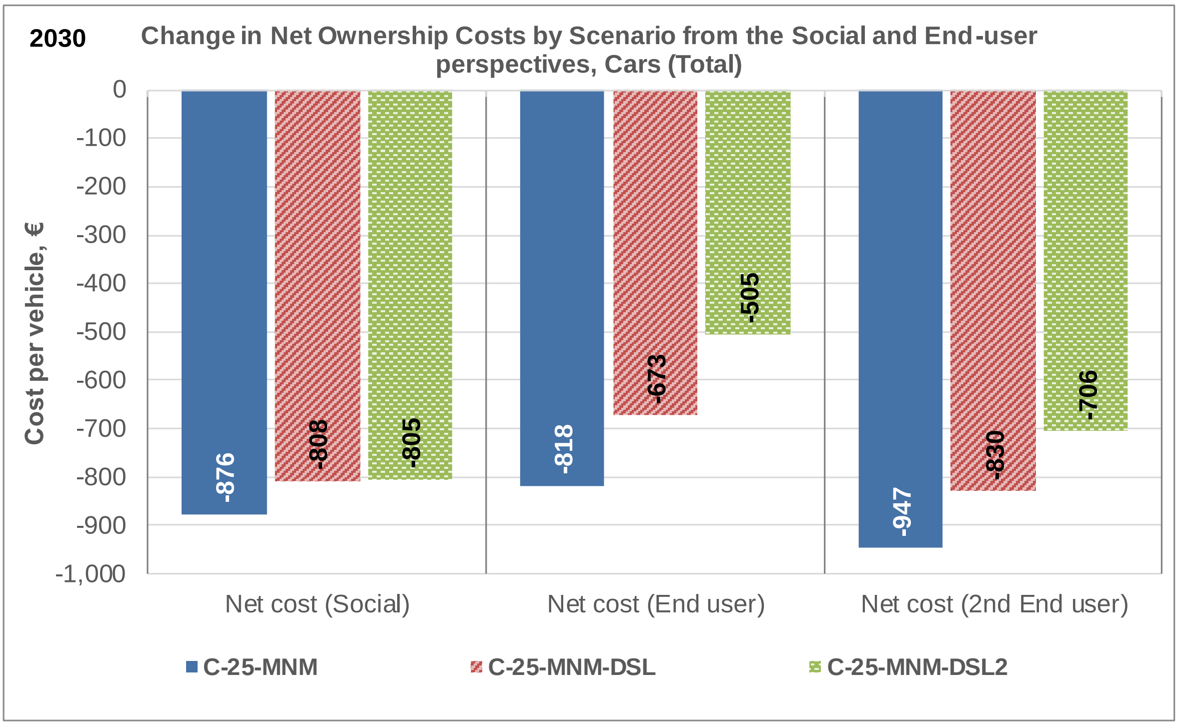
Figure 3.33 illustrates the impact on TCO for the two lower diesel share scenarios. The figure shows greater, and significant, impacts on net savings in 2025 for both the societal perspective and end-user perspectives. By 2030, impacts are relatively low (maximum ~€70 worsening) for the societal perspective, but greater for end-users, reducing benefits by as much as €240 for second end-users in the most extreme case; net cost savings are still significant, however.

Since manufacturing cost changes resulting from a net shift to petrol vehicles from diesel vehicles is not captured in the TCO analysis, the overall impacts may not be so significant: as indicated in the previous subsection, the fleet-level analysis from PRIMES-TREMOVE shows a net *decrease* in costs for the two lower diesel share scenarios, which is ascribed to this effect.

No changes to LCV diesel shares were assumed in these sensitivity scenarios.

Figure 3.33: Potential impacts of lower diesel share on the average TCO for passenger cars for the central ambition scenario, on a societal and end-user basis - Sensitivities





Notes: **Societal** perspective = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** perspective = Total NPV over 5 years of ownership (first, second user), with a 11% discount rate for cars and accounting for the remaining vehicle residual value at the end of each period.

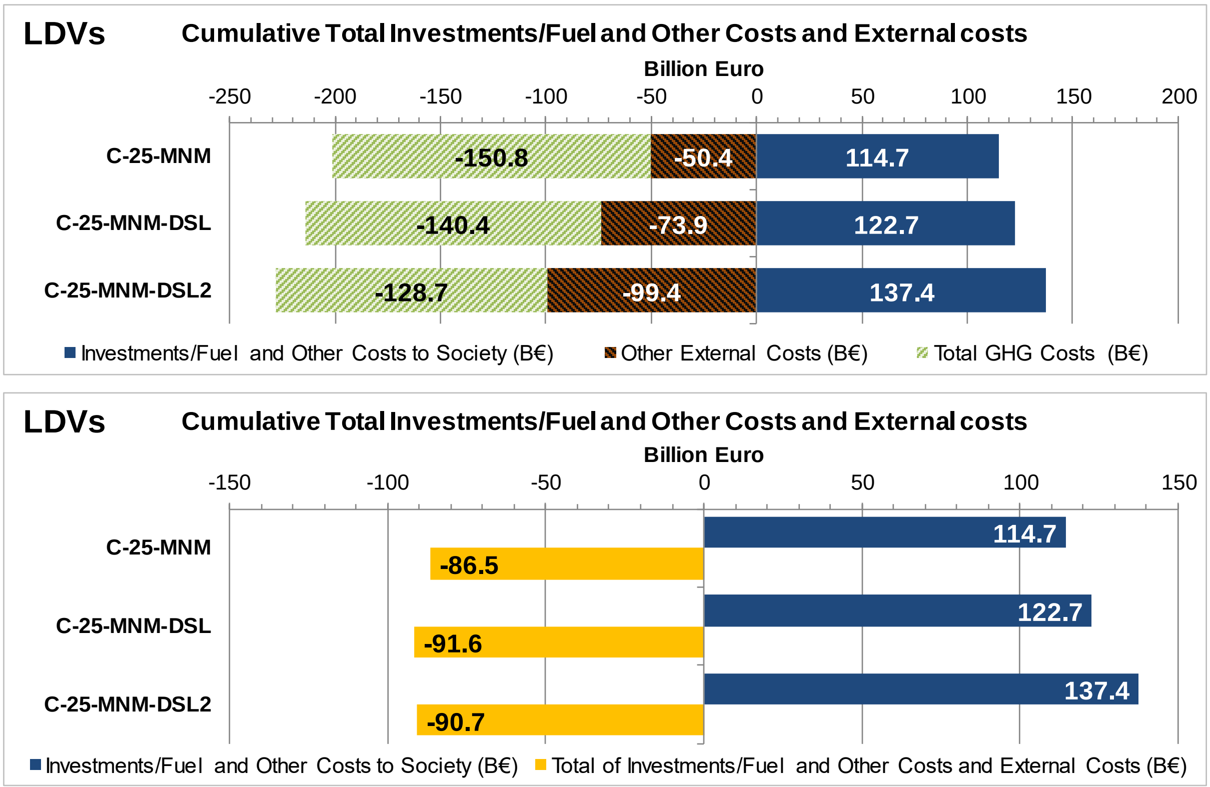
3.2.9.5 Cost-benefit analysis of system-level PRIMES-TREMOVE results

An assessment of the cumulative impacts of the direct and indirect cost components and net societal cost-benefit analysis is presented in Figure 3.34 below (for central GHG costs) (based on (Ricardo-AEA, 2014), see also Appendix 4).

The figure shows that whilst the overall direct system costs increase (and cost-effectiveness, in €/tCO_2 decreases) for the two ‘low diesel share’ sensitivities, from a societal perspective the net benefits increase over the central scenario when the externalities are included. Despite a reduction in GHG external cost savings (due to a shift to gasoline vehicles with a higher WLTP-RW gap), increases in other external cost savings outweigh these – principally relating to air pollutant emissions reductions with a shift away from diesel.

More information is provided in Appendix 4 on this methodology, together with a more detailed breakdown of the different components.

Figure 3.34: Summary of the cost-benefit analysis for the central ambition scenario and low diesel share sensitivities compared to the baseline scenario (central GHG costs)

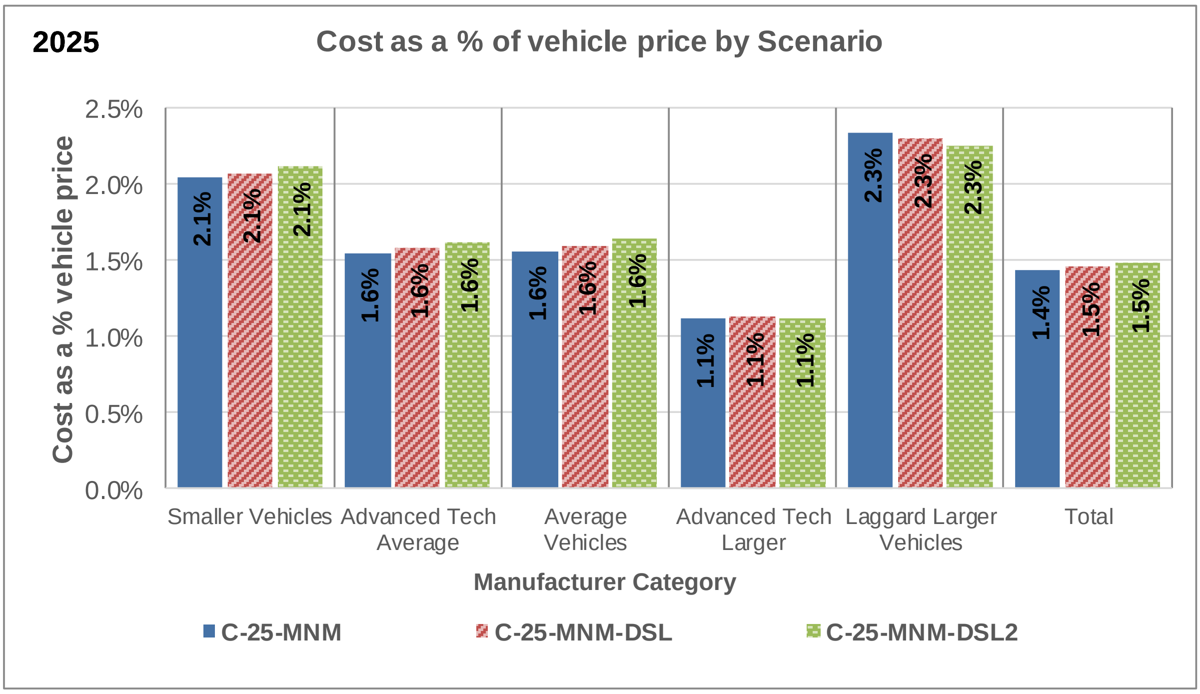


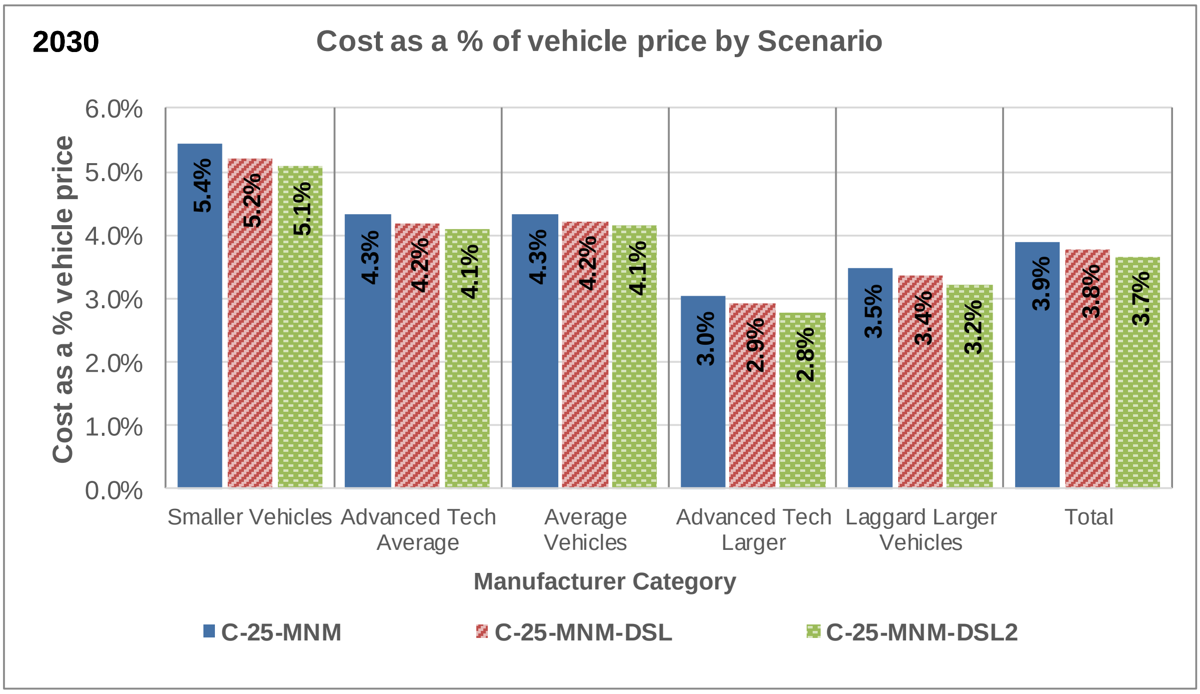
Notes: “Investments/Fuel and Other Costs” = includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. “Other External Costs” includes air quality pollutant emissions, noise, accidents and congestion.

3.2.9.6 Assessment of impacts on competition between manufacturers

The following Figure 3.35 illustrates the impact on relative competitiveness for different car manufacturer types for the two lower diesel share scenarios. The figure shows little to no impact on the relative cost increases for different manufacturer types compared to the central scenario for 2025, and essentially no impact at all versus the central scenario for 2030 (i.e. the net change is similar for all).

Figure 3.35: The impact of two lower diesel share scenarios on the relative cost increase for different passenger car manufacturer categories for Distribution: Mass 60% Slope, central ambition





3.2.9.7 Conclusions for the sensitivity on potential impacts of lower diesel share for cars

The scenario analysis has shown that even very extreme reductions in the market share of diesel and diesel hybrid vehicles by 2030 do not hamper achieving high ambition CO_2 targets cost-effectively. The modelling suggests only a modest increase in xEV uptake would be required compared to the regular scenarios. The modelling also suggests that overall costs could even decline, despite increased fuel costs, due to higher diesel vehicle prices (in part driven by more expensive exhaust treatment) and shifts between larger and medium vehicle segments.

However, in the most extreme case, the effectiveness of the overall CO_2 reductions is reduced by 18% from 6.7% to 5.5% comparison to the REF scenario, due to a larger differential between the WLTP and the real-world performance of gasoline cars versus diesel cars.

Reductions in external damage costs due to reduced air quality pollutant emissions outweigh the reduction in external costs resulting from GHG emissions compared to the regular central ambition scenario.

3.2.10 Conclusions from analysis for target level and timing

The main summary points and conclusions that may be drawn from the analysis are summarised below. A side-by-side summary comparison of the different impacts for the different ambition levels is also presented in Table 3.20 below, grouped according to the Effectiveness, Efficiency, Coherence and Proportionality criteria for Impact Assessments outlined by the Better Regulation Guidelines:

- All of the analysed options for the target level are effective in reducing GHG emissions compared to the baseline scenario. As expected, GHG emission reductions increase with increasingly strict targets.
- From a timing perspective, setting targets only at 2030 (instead of also at 2025) results in an 18% reduction in GHG emissions reductions versus the baseline scenario in the central (30%) ambition case, with only a small improvement in cost-effectiveness. This option would result in a reduction in the social equity benefits found for greater CO_2 reduction levels, as well as a reduction in the net total cost of ownership (TCO) savings from a societal and end-user perspective.
- From the TCO perspective, the greatest direct benefits are shown for the 30% ambition level for cars for the societal and first end-user perspectives. and for the higher ambition levels (up to 50% reduction) for LCVs. However, for second end-users, and also when including the external cost reduction benefits in the accounting for the societal perspective, the greatest net benefits are found at the high (~40% reduction) ambition level for cars. [17]
- The overall cumulative direct and external system costs for the whole light-duty vehicle (LDV) parc increase as the CO_2 target ambition increases.
- Other external cost savings, principally from a reduction in air pollution and noise, increase as CO_2 targets become more ambitious. Together with the reduced externalities associated with GHG emissions, these outweigh net increases in direct costs. This results in cumulative net societal benefits (i.e. cost savings) which increase in absolute magnitude with increasing ambition levels.
- There are significant social equity benefits. Households that purchase more efficient vehicles in the second-hand car market benefit to a greater extent from the annual fuel savings by only paying a fraction of the additional cost of the first owner. Net TCO benefits are greatest for the high ambition (40% reduction) scenario in 2030 for second users.
- Modelling (GEM-E3 model) showed that the overall macro-economic impacts are relatively small. In the central ambition (30% reduction) option, the cumulative impact on GDP over the period 2020-2040 is found to be well below 1% from the baseline, with total employment slightly increasing in 2030 with respect to the baseline despite lower labour intensity assumptions for electric vehicle (EV) manufacture. Results were very similar for other ambition levels, as the impacts are low compared to the size of the overall economy.
- *WLTP-RW gap:* This sensitivity illustrated the potential for an increasing WLTP-RW gap from 2020-2030 to significantly weaken the GHG reduction effectiveness of the post-2020 regulations and also the end-user benefits in terms of reduced fuel costs. The risk would further increase with lower than expected fuel prices.
- *Possible impacts of lower diesel share:* Analysis has shown that even high ambition CO_2 targets can be achieved cost-effectively with extreme reductions in the market share of diesel vehicles by 2030. However, the effectiveness of the overall CO_2 reductions in the central ambition case could be reduced due to a higher WLTP-RW gap for gasoline versus diesel cars. More ambitious targets would help mitigate for this risk.
- *Lower fuel prices:* the key risks of lower future fuel prices include a reduction in the net cost benefits of the regulatory targets, and *also* in their effectiveness in reducing GHG emissions.

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[17] It was not possible to fully account for the potential impact of utility parameter choice on the attractiveness of mass reduction technologies in the analysis.

Table 3.20: Comparison of impacts of the scenarios analysed for ambition level of post-2020 CO_2 targets in terms of achieving key objectives

Principal areas	Sub-areas	Scenario 1 Low Ambition (20% reduction for cars and LCVs)	Scenario 2 Central Ambition (30% reduction for cars and 25% for LCVs*)	Scenario 3 High Ambition (40% reduction for cars and LCVs)	Scenario 4 68g/km NL (non-linear reduction based on 68g/km NEDC by 2025)	Scenario 5 Very High Ambition (50% reduction for cars and LCVs)
Effectiveness						
1. Criterion:						
Ensure the regulations are consistent with meeting GHG reduction objectives	2030: emission reductions versus 2005 levels	28.6% savings versus 2005 scenario (and a 5.5% reduction on the baseline under default conditions. (*Note*: The baseline scenario results in 24.5% savings.)	29.5% GHG savings vs 2005 (and a 6.7% reduction on the baseline).	>32% savings versus 2005 (and a 10.8% reduction on the baseline).	~35% savings versus 2005 (and a 13.8% reduction on the baseline).	~36.4% savings versus 2005 (and a 15.8% reduction on the baseline.
2. Criterion:						
Increasing the uptake of LEVs		17.4% of new cars, 17.5% of new LCVs and ~9% whole LDV fleet share by 2030.	20% of new cars, 18.5% of new LCVs, and ~9.8% in the whole LDV fleet by 2030.	28% of new cars, 30.2% of new LCVs and ~12.7% of the whole LDV fleet by 2030.	30.9% of new cars, 30.2% of new LCVs and 14.8% of the whole LDV fleet by 2030.	38.4% of new cars, 45.1% of new LCVs and 16.9% of the whole LDV fleet by 2030.
3. Criterion:						
Avoidance of undesired competitiveness impacts on the EU automotive sector	Distribution equity between OEMs	No significant impacts identified in the quantitative analysis, however at very high ambition levels, it is expected there could be more significant impacts on slower movers, and for manufacturers of smaller/budget vehicles that would simultaneously find it more difficult to deploy larger shares of xEVs needed, and also may face competition from manufacturers of larger vehicles selling into smaller segments.				
	Impacts on first movers	No negative impacts identified.				
4. Criterion:						
Ensure the impacts of the regulations are socially equitable	Employment; social inclusion, distributional impacts; public health.	More ambitious targets drive in the market vehicle options that are less expensive to use, but more capital intensive. High-income classes that are more likely to purchase new cars face higher upfront cost, which are less likely compensated by the annual fuel savings at higher ambition levels. Conversely, households that purchase these vehicles in the second-hand car market (which are a much greater share for lower income groups) benefit from the annual fuel savings by only paying a fraction of the additional cost of the first owner.				

Principal areas	Sub-areas	Scenario 1 Low Ambition (20% reduction for cars and LCVs)	Scenario 2 Central Ambition (30% reduction for cars and 25% for LCVs*)	Scenario 3 High Ambition (40% reduction for cars and LCVs)	Scenario 4 68g/km NL (non-linear reduction based on 68g/km NEDC by 2025)	Scenario 5 Very High Ambition (50% reduction for cars and LCVs)
Efficiency						
5. Criterion:						
Ensure the environmental benefits of the LDV CO_2 targets are achieved cost-effectively	a) Total Cost of Ownership	TCO net benefits are below those of the central ambition option. For the societal perspective, direct cost savings are: €801 per car in 2030 and savings including externalities are €1616 per car. Equivalent savings per LCV are even higher, e.g. €2854 per LCV for societal savings including externalities.	TCO net benefits are very significant. For end-users direct cost savings per car are €818-987 in 2030 for cars - these are greatest for cars for the central ambition scenario for both societal (excluding externalities, at €876) and first end-user. Societal cost savings per car including externalities are €2053. Scenarios with low fuel costs or higher conventional powertrain costs decrease the net benefits, low battery /xEV cost scenarios increase them.	TCO societal net benefits excluding externalities are slightly below those of the low ambition scenario (at €653) for cars (typical costs), but greatest for LCVs in general. TCO benefits are highest for second users for cars for high ambition (€1022), and for societal perspective when including external costs (€2111). For LCVs, the savings per LCV are significantly higher than for the central scenario.	Direct societal cost TCO benefits are slightly lower than for the high ambition scenario – at €521 per car (but better than for central and low ambition for second end users). Societal TCO is similar to high ambition with externalities included (at €2118 per car). For LCVs, the benefits are slightly below those of the high scenario.	For cars, there is no benefit in direct TCO for the societal perspective, and reduced benefit vs 68g/km NL for first end users (at €282 per car). Second end user benefits are between central and high ambition (at €996 per car), as are societal costs with externalities (at €1923 per car). For LCVs the net societal benefits including externalities are the greatest of all the options at €5108 per LCV.
	b) Net Cost /Benefit, with externalities	Cumulative net benefits of 85 B€ for 2020-2040	Cumulative net benefits of 87 B€ for 2020-2040	Cumulative net benefits of 105 B€ for 2020-2040	Cumulative net benefits of 111 B€ for 2020-2040	Cumulative net benefits of 121 B€ for 2020-2040
6. Criterion:						
Ensure the impacts on the European economy are proportionate	Impacts on GDP, GVA, employment, trade, etc.	Small decrease on benefits for Central Ambition, resulting in a decrease of up to ~0.05% for GDP and 0.025% for employment.	Impact on GDP is an increase of ~0.05% to 0.07% versus the baseline. Total employment increases by ~0.02% to 0.065% compared to the baseline in 2030.	Further small increase on Central Ambition of ~0.035% to 0.055% for GDP, and ~0.015% to 0.025% for employment.	Not analysed.	Not analysed.

Principal areas	Sub-areas	Scenario 1 Low Ambition (20% reduction for cars and LCVs)	Scenario 2 Central Ambition (30% reduction for cars and 25% for LCVs*)	Scenario 3 High Ambition (40% reduction for cars and LCVs)	Scenario 4 68g/km NL (non-linear reduction based on 68g/km NEDC by 2025)	Scenario 5 Very High Ambition (50% reduction for cars and LCVs)
Coherence						
7. Criterion:						
Regulations are consistent other environmental objectives	Air quality and noise	Reduces monetised externalities by 4.2% vs baseline	Reduces monetised externalities by 5.3% vs baseline	Reduces monetised externalities by 9.7% vs baseline	Reduces monetised externalities by 12.7% vs baseline	Reduces monetised externalities by 14.7% vs baseline
8. Criterion:						
Regulations are consistent energy-related objectives	Improve energy efficiency, reduce overall consumption	Energy savings are ~24% reduction for LDVs versus the 2007 baseline energy projection.	Energy savings are ~25% reduction for LDVs versus the 2007 baseline energy projection.	Energy savings for LDVs are consistent with the economy-wide objective for 2030, which is 27% reduction versus the 2007 baseline energy projection. This compares to just under 21% reduction for the baseline scenario.		

Notes: * For central ambition with 30% reduction targets also for LCVs, the net GHG savings increase marginally to 29.7% GHG savings vs 2005 (and a 6.9% reduction on the baseline). Cumulative Net Cost/Benefit with externalities correspondingly increase to 89 B€ for 2020-2040. Net TCO benefits are also greater for LCVs for all user cases.

4 Options for distribution of effort amongst manufacturers

4.1 Distribution of the overall emission reduction effort across manufacturers

A number of approaches have been proposed to distribute the effort for meeting the EU fleet-wide CO_2 targets. The objective of the analysis in this area is to assess the way in which different distribution options and levels of ambition affect different categories of manufacturers. As a result of the way in which the targets have been set for 2020/1, i.e. using a (mass-based) utility parameter to relate a manufacturer's CO_2 target to the mass of its vehicles, each car and LCV manufacturer will have a different fleet average CO_2 target in 2020/1, which will be the reference year for the current analysis[18].

Those future targets could be distributed between different manufacturers in several ways.

The comparison of options needs to consider the CO_2 reductions achieved, the cost-effectiveness, and potential impacts on competitiveness and social equity.

The following approaches for distributing effort between manufacturers were analysed:

1) Utility parameter approach using mass as the utility parameter (with a variation of possible slopes;
2) Utility parameter approach using footprint as the utility parameter (with a variation of possible slopes);
3) Uniform target: same absolute target applies to all manufacturers (equal to the EU fleet-wide target);
4) Same percentage reduction from 2020/21 targets for each manufacturer (starting from individual 2020/21 target for the manufacturer concerned).

These four options were also the options considered in the IA (Impact Assessment) underlying the 2007 Commission proposal that eventually led to the 2009 passenger car CO_2 Regulation[19]. The lack of availability of data on 'footprint' was the strongest argument in that IA in favour of the choice of 'mass' as a utility parameter for the 2015/17 targets, while later on, for the 2020/21 targets, regulatory certainty was the strongest argument in favour of retaining mass. The main issue identified in the 2007 IA regarding Option 3, a uniform target, was that this would be harder to meet for manufacturers of larger vehicles. The main issues identified previously with respect to the percentage reduction targets for Option 4 were that the relative price increase would be higher for small cars – leading to affordability and equity concerns – and that manufacturers of small cars would then be locked into their current market position, whereas manufacturers of large cars could expand their range as a contribution to meeting their targets. A related issue is that for this option there does not appear to be a way to adjust for such potential shifts in the respective market shares of different OEMs, which could also result in over- or under-achievement of the overall ambition level.

Since the modalities for meeting the current 2020/21 targets were defined, the characteristics of the new car and LCV markets have changed which means it is t important to identify whether previous assessments relating to different options remain valid. An outline of the approach developed in this regard is provided in Section 2.3.1.

To assess the impacts of the mass and footprint utility parameters it was necessary to carry out an updated statistical analysis of the correlation with CO_2 emissions. This is further discussed in Section 4.1.1 below, with quantitative assessment of the impacts of different options presented in Section 4.2.

[18] For cars and vans, the formula for the current mass based limit value curve is the following: OEM specific target (g/km) = fleet-wide target + a x (M – M0), where M0 is the average reference mass of the vehicle fleet and 'a' is the slope as defined in the Regulations.
[19] The IA supporting the proposal that led to the LCV CO_2 Regulation did not consider the option of the same absolute target.

4.1.1 Determination of the slopes for the mass and footprint utility options

The mass utility function parameters currently utilised in the car and van CO_2 regulations were developed based on an earlier analysis, as set out in (TNO et al., 2011) and (TNO et al., 2012), using commercially sourced databases with the distribution of CO_2 emissions by reference mass and footprint for the EU new vehicle fleet for 2006 and 2009. However, these datasets did not fully cover the entire EU vehicle fleet, and were more limited in the data available for analysis of the footprint parameter (particularly for LCVs). There are now more detailed and fully-representative EEA CO_2 regulation monitoring datasets available, which better reflect the current composition, CO_2 emissions, mass and footprint characteristics of the new vehicles.

In this project, the 2013 EEA CO_2 monitoring datasets have been used to determine the parameter equations for the utility-based approaches. These 2013 datasets were already cleaned up (e.g. filling data gaps for key parameters where possible), and models allocated into seven car and van segments, as part of previous work for the Commission developing CO_2 reduction cost-curves[20]. Since the same database was used to define the baseline vehicles for the cost-curves used in this project, consistency is ensured by utilising it also for the utility parameter derivations.

During the current project, further analysis has been performed on the 2013 monitoring database. This included the conversion of the NEDC-based emissions (in gCO_2/km) to a WLTP basis at the vehicle model level, using the NEDC-WLTP conversion factors provided by the JRC, as included in Appendix 2.

The average CO_2 emissions, mass and footprint derived from the 2013 database are summarised in the following Table 4.1.

Table 4.1: Average vehicle parameters derived from the 2013 EEA CO_2 monitoring databases

	Av. Mass, kg	Av. Footprint, m^2	Av. NEDC gCO_2/km	Calc. Av. WLTP gCO_2/km
Passenger cars	1386	3.964	126.3	152.0
LCVs	1767	5.070	173.9	226.8

Notes: WLTP CO_2 emissions were estimated using the NEDC-WLTP conversion factors provided in Appendix 2.

Analysis of the 2013 EEA passenger car CO_2 monitoring database was used to derive least-squares fit trendlines of the correlation between CO_2 (WLTP-basis) and either mass or footprint.

This yielded the results shown in Figure 4.1 (mass) and Figure 4.2 (footprint, where each data point represents the values from a vehicle model for a specific country/make/model/powertrain/configuration. This means that each of these points includes multiple vehicle registrations. The figures provide an illustration of the difference in the derived trendlines with and without accounting/weighting for the numbers of registrations within each data point. It is most representative to use the ***weighted*** trendline in the development of the utility parameters, as this best represents the average relationship for the fleet. Similar trendlines for LCVs are presented in Figure 4.3 (for mass) and Figure 4.4 (for footprint).

A summary of the derived trendline parameters is also presented in Table 4.2 below.

Table 4.2: Summary of the WLTP CO_2 correlation trendlines for mass and footprint utility, based on analysis of the 2013 monitoring data

Type	Utility	'a' factor (slope)	'b' factor (y-axis intercept)
Cars	Mass	0.0596	69.887
Cars	Footprint	32.36	23.875
LCVs	Mass	0.1418	-24.429
LCVs	Footprint	38.673	31.584

[20] The 2013 CO_2 monitoring databases for cars and vans were used in the development the LDV CO_2 cost-curves produced as an output from earlier work for DG CLIMA (Ricardo Energy & Environment et al, 2016), and was extensively cleaned and modified to include vehicle segmentation by market class and powertrain type (i.e. explicitly conventional ICEVs, HEVs, PHEVs, REEVs, BEVs and FCEVs), as we. Further cleaning and refinement of this database was also undertaken as part of this work.

Figure 4.1: New car registrations - weighted and unweighted least squares fit trendlines for WLTP (gCO_2/km) versus vehicle mass in running order, 2013 monitoring

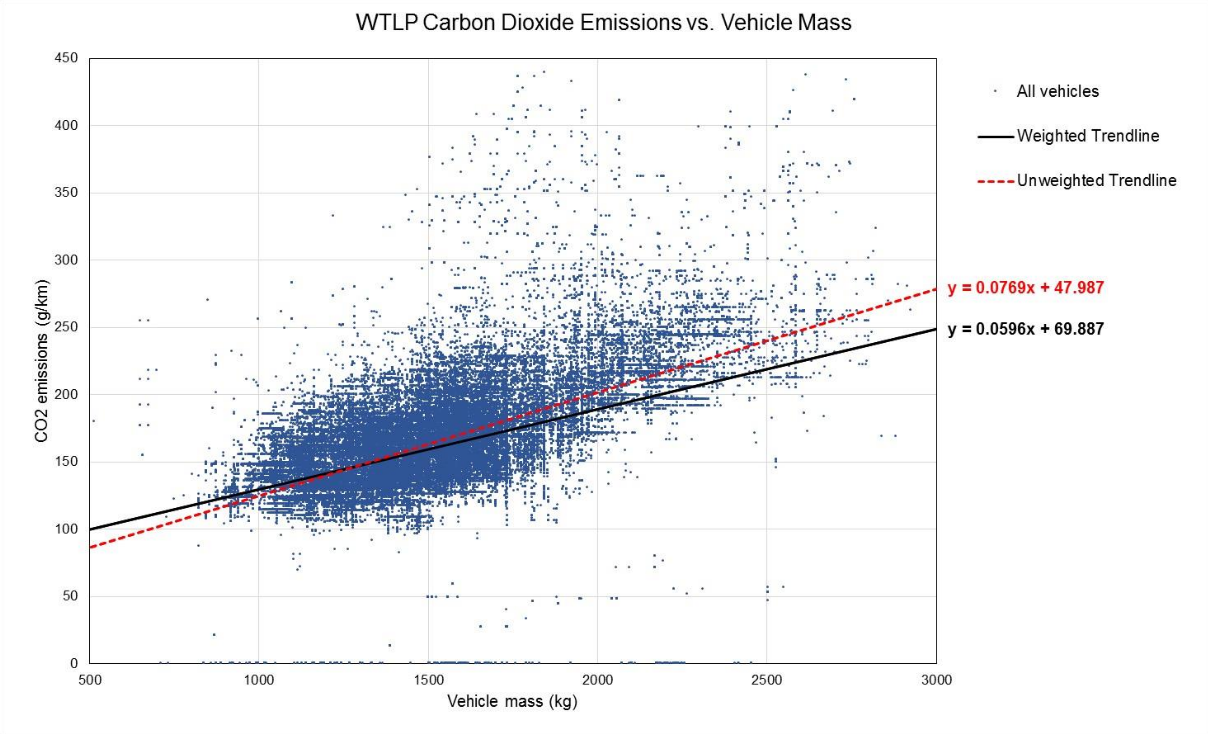


Figure 4.2: New car registrations - weighted and unweighted least squares fit trendlines for WLTP (gCO_2/km) versus vehicle footprint, 2013 monitoring

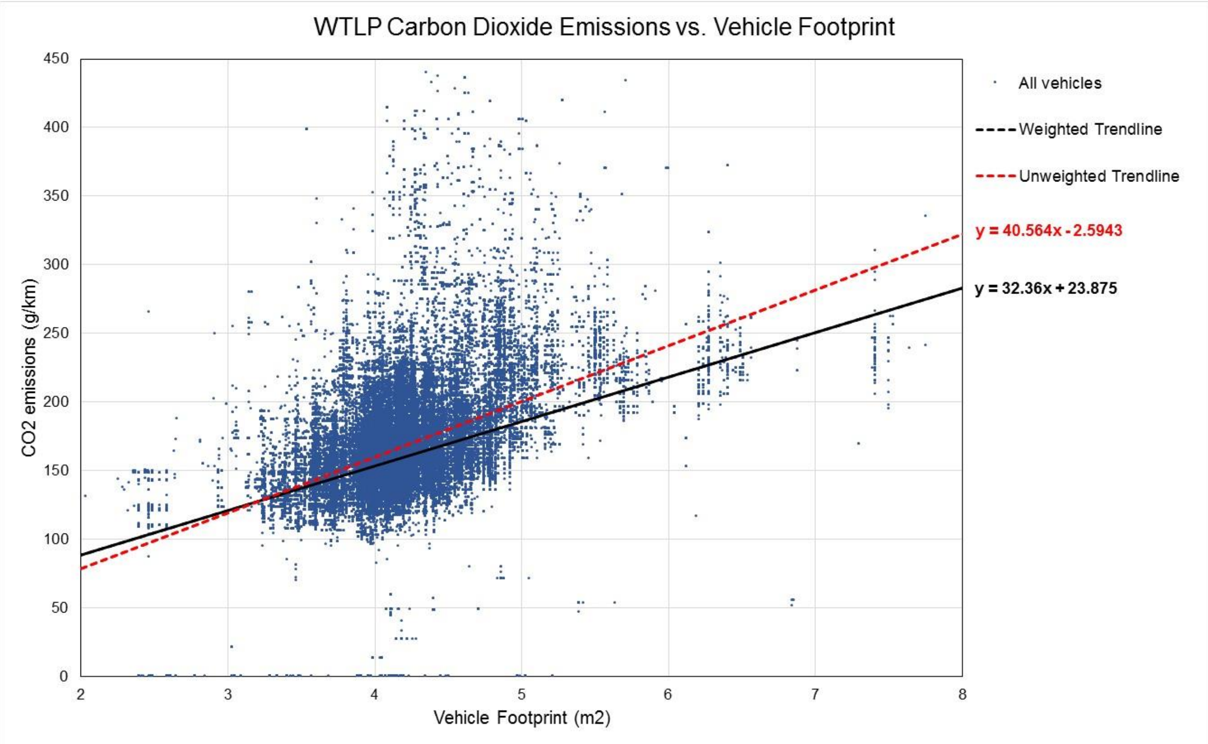


Figure 4.3: New van registrations - weighted and unweighted least squares fit trendlines for WLTP (gCO_2/km) versus vehicle mass, 2013 monitoring

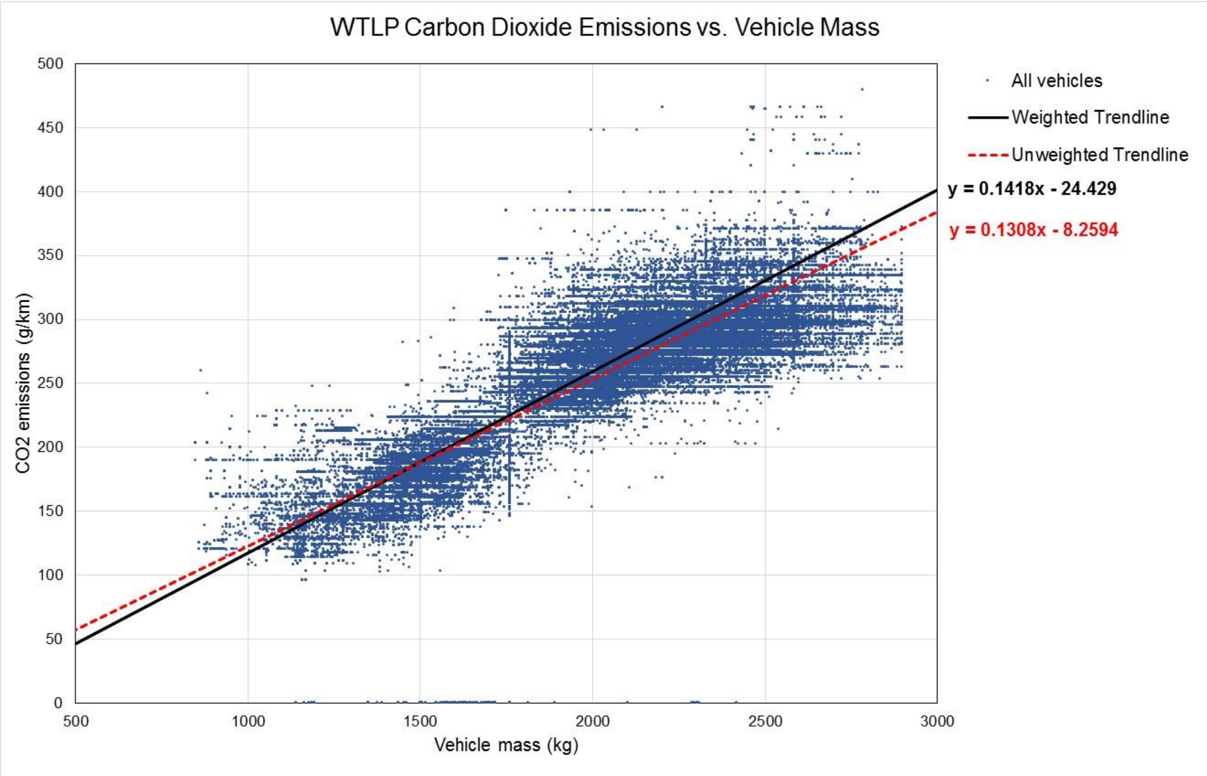
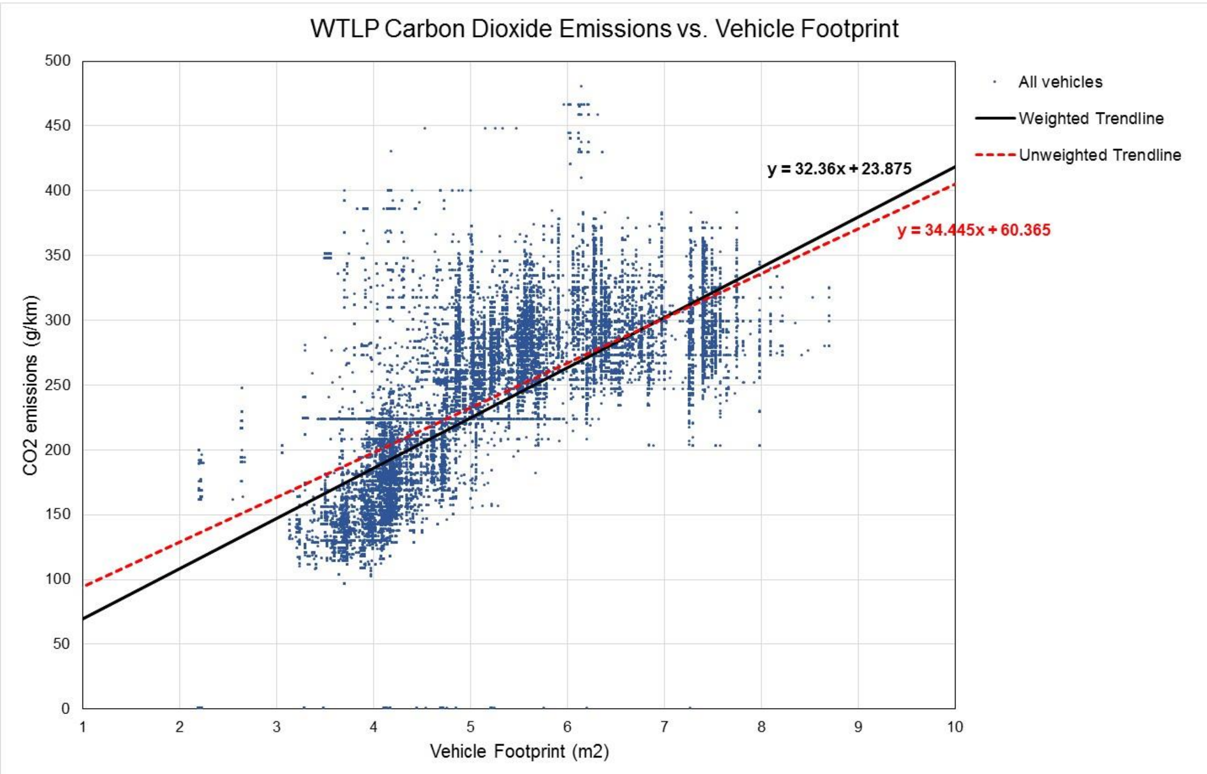


Figure 4.4: New van registrations - weighted and unweighted least squares fit trendlines for WLTP (gCO_2/km) versus vehicle footprint, 2013 monitoring



4.1.1.1 Examples of resulting utility parameters derived from the trendlines

This subsection provides worked examples of the resulting utility parameters derived from the 2013 trendlines of CO_2 with vehicle mass and footprint. Box 1 provides an outline of the use of the derived trendline parameters to define linear utility functions for specific targets.

Box 1: Summary of utility-based approach and the derivation of limit functions of different slopes

Linear utility-based limit functions

Linear utility-based limit functions are expressed as: CO_2 limit = a U + b, with U the utility parameter. The slope 'a' and y-axis intercept 'b' can be varied, provided that the following relation is fulfilled:

Overall CO_2 limit (in g/km) = a <U>20XX + b, **Equation (1)**

with <U>20XX the average utility value of all new vehicles registered in the EU in 20XX.

Variants with different slopes are defined relative to a "100% slope" base limit function, which is constructed from a sales-weighted least squares fit through the CO_2 emission values of all vehicle models, plotted as function of their respective utility values (i.e. mass or footprint). For the current analysis, this 100% slope baseline is based on the above mentioned 2013 limit function.

The 100% slope line for different CO_2 targets is derived from the 100% slope base limit line by lowering it to meet the average target in gCO_2/km in such a way that the relative (i.e. percentage) reduction is the same across the utility value range. This means that the slope of the 100% slope limit line will become lower (flatter line) with lower (stricter) CO_2 targets. The 100% slope limit function is therefore defined as the limit function for which the burden of CO_2 reductions up to 20XX is evenly distributed over the range of utility values. Relative to this reference, alternative limit functions based on different slopes can be defined. The labelling of these slopes is based on a percentage of the 100% slope values, with slopes above 100% being steeper, and those below 100% being flatter. A 0% slope represents an equal g/km target across the range of utilities (i.e. a uniform target).

Worked example:

To calculate a 100% slope parameter 'a' for a 30% reduction on 2021 CO_2 emission targets (on WLTP basis) using the trend line derived from the 2013 CO_2 monitoring database:

Parameter 'a' [100% Slope for 2030] = Parameter 'a' [100% Slope for 2013] x (1-Z%) x (1-30%)

Where, Z% = the % reduction in gCO_2/km between 2013 average emissions and 2021 fleet-wide target on a WLTP basis.

Equation (1) above can be rearranged as follows to the form in the car and van CO_2 regulations used to calculate manufacturer specific emissions targets and so that these individual targets can be adjusted based on changes in the fleet average utility (i.e. increase or decrease in average mass or footprint), so that the overall fleet average target is respected):

Specific CO_2 target (in g/km) = Overall CO_2 target for 20XX (in g/km) + a x ($U - U_0$) **Equation (2)**

Where, a = the utility slope parameter for 20XX;
U = Av. vehicle utility of the manufacturer, U_0 = average vehicle utility of the whole fleet.

Source: Updated and adapted from (TNO et al., 2011).

The above equation (2), in Box 1, has been applied in the current Regulation for cars, as regards the 2021 target (95 g/km) (and similarly for vans as regards the 2020 target of 147 g/km), in the following form:

Specific CO_2 Target for cars (in g/km) = 95 g/km + a x ($M - M_0$)

Where, a = 0.0333 (the current regulatory slope for cars);
M = Av. vehicle mass of the manufacturer, M_0 = average vehicle mass of the whole fleet.

Note: With the introduction of WLTP there will be a change in the definition of the vehicle mass relevant to the determination of the CO_2 test-cycle values, due to the inclusion of the mass of any options added to a specific vehicle. The test mass under WLTP is intended to better reflect the actual mass of the individual vehicle, rather than the mass of a basic vehicle (mass in running order) as was the case under NEDC (TNO, 2016). This has some potential implications for the mass utility function (only), since the defined parameters and the average vehicle mass are based on the mass in running order provided in the current monitoring database. Although this change will most likely result in an effective increase in average vehicle mass, it seems unlikely this will vary significantly between different manufacturers – and thus the relative stringency of their individual targets derived using the function.

It is not possible to conduct a quantitative estimate of the impact of this in relation to the data currently available in the CO_2 monitoring databases. However, the form of the utility function above will be able to account for this change, to ensure the overall and individual targets will be suitably adjusted.

Table 4.3 and Figure 4.5 provide illustrations on how the utility function (and the slope parameter) varies according to the CO_2 target in 2025 and 2030 for the 'central ambition' scenario (i.e. 30% reduction on 2021 target levels by 2030), and also according to the defined 'Slope'.

As an example, the 60% 'Slope' functions are also summarised in Figure 4.6 for comparison of how these differ from the 2013 trendline and how they change between 2025 and 2030. As the level of CO_2 reduction increases the absolute slope becomes flatter; the utility line slope for 2030:

2030: Slope 60% 'a' (central ambition) = 2013 trendline 'a' parameter x (1-Z%) x (1-30%) x 60%

Where, Z% = the % reduction in gCO_2/km between 2013 and 2021 on a WLTP basis = 24.6%.

Table 4.3: Overview of different slopes (parameter 'a' value) for the mass and footprint utility distributions for cars for the central ambition (30%) CO_2 target option (starting from the 2013 trendline)*

	Mass Utility (kg)		Footprint Utility (m^2)	
Utility Line Slope	**2025**	**2030**	**2025**	**2030**
2013 trendline	**0.0596**	**0.0596**	**32.3579**	**32.3579**
60%	0.0232	0.0190	12.6043	10.3386
70%	0.0271	0.0222	14.7050	12.0617
80%	0.0309	0.0254	16.8057	13.7848
90%	0.0348	0.0286	18.9064	15.5079
100%	**0.0387**	**0.0317**	**21.0071**	**17.2310**
110%	0.0425	0.0349	23.1078	18.9541
120%	0.0464	0.0381	25.2085	20.6772
130%	0.0503	0.0412	27.3092	22.4002
140%	0.0542	0.0444	29.4099	24.1233
CurrentReg*	**0.0333**	**0.0333**	**N/A**	**N/A**

Notes: * The central ambition level for cars represents a linear reduction of 30% in gCO_2/km from 2021 to 2030. ** The mass utility function slope applied for the 2021 car CO_2 target of 95 g/km (NEDC) in the current regulation (for the 2015 target of 130 g/km, the slope was 0.0457).

The table and these illustrations (dark blue dashed lines in Figure 4.5) show that for this specific ambition level, the current regulatory mass utility function slope (a = 0.0333) is equivalent to ~86% slope in 2025 and ~105% slope in 2030[21]. However, in order to provide for the same distribution of efforts across manufacturers (i.e. the same percentage of emission reductions) under different target levels, the slope needs to change depending on the specific CO_2 target (linear relationship). Keeping the slope parameter 'a' constant for different CO_2 target levels would therefore affect the relative distribution of effort (i.e. in effect resulting in a different % in relation to the 100% slope).

This analysis (and also for the equivalent current slopes for the van CO_2 regulation) shows that to continue to utilise the current 2020/21 utility function slopes (or any other fixed slope values that are not varied by CO_2 reduction level), would change the effective distribution of effort over time in terms of the impact on CO_2 reduction targets between different manufacturers.

21 Note: The current regulatory slope is also reportedly equivalent to a 67% slope, based on the year 2009 database used in (TNO et al., 2011) analysis, on an NEDC basis for the 2021 car CO2 targets.

Figure 4.5: Illustration of the impact of slope choice on the mass and footprint utility distributions for the central ambition WLTP CO_2 target assumptions

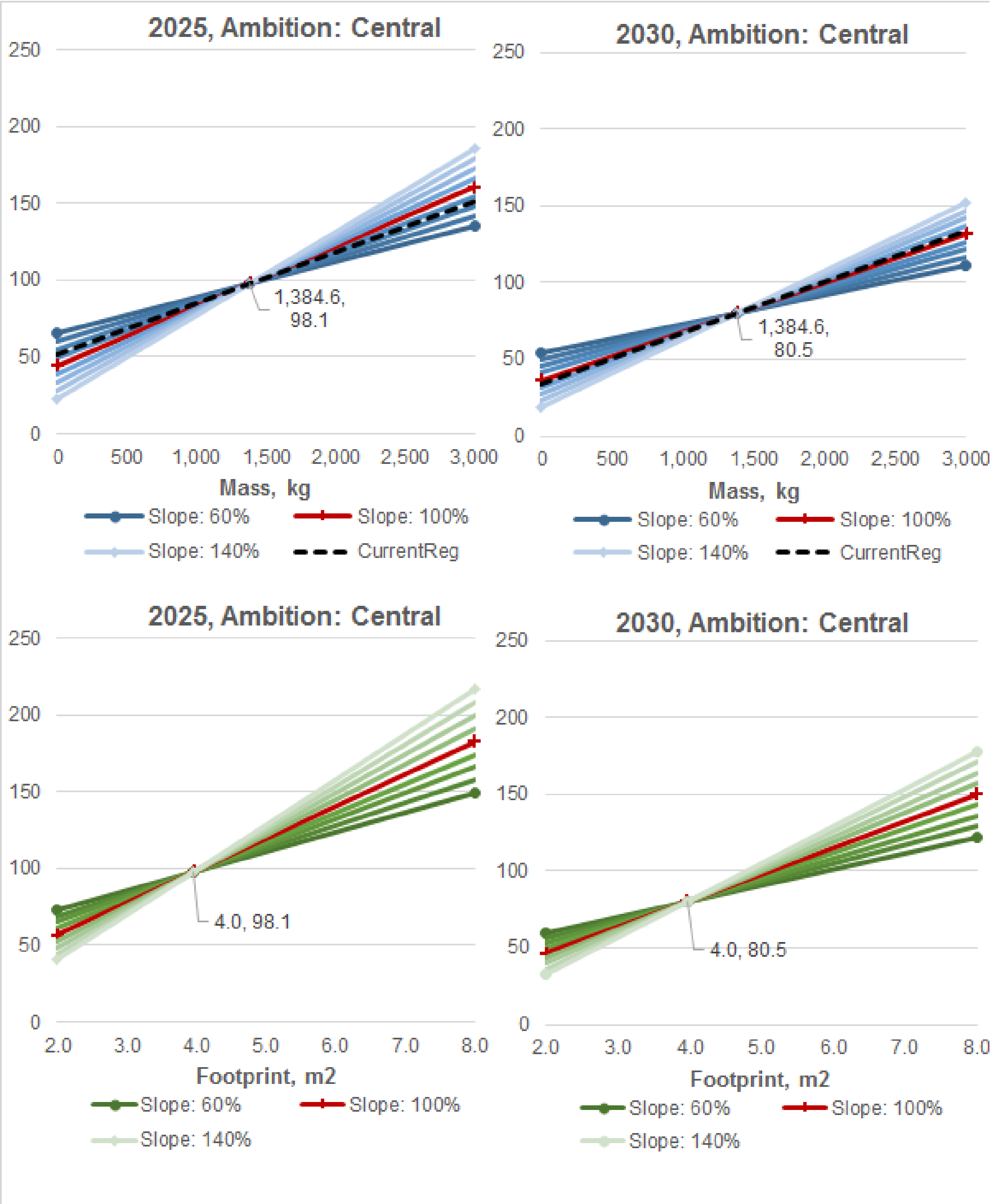
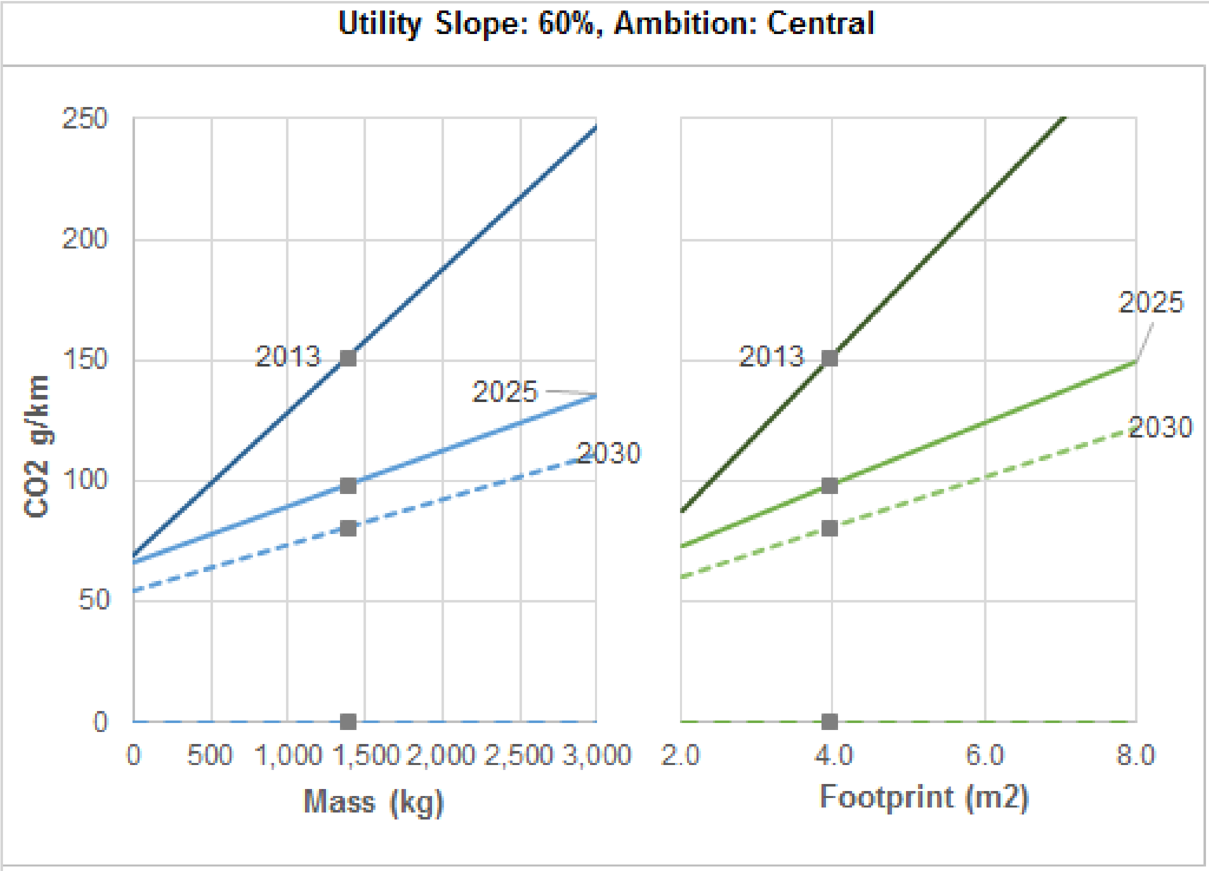


Figure 4.6: Illustration of mass and footprint utility distributions for different time-periods and slopes for the central ambition WLTP CO_2 target assumptions



Notes: '2013' = current derived CO_2 trendlines based on the 2013 CO_2 monitoring database (i.e. at 100% slope). 2025 and 2030 represent illustrative trendlines at 60% slope for central ambition targets for 2025 and 2030.

4.1.2 The impact of the utility parameter on the effectiveness of vehicle mass reduction

The impacts of the utility parameter choice on the effectiveness and costs of reducing CO_2 emissions from light duty vehicles has been explored in detail in earlier work for the Commission (Ricardo-AEA, 2015).

As part of that work, scenarios were developed to demonstrate mathematically the impact of the two mechanisms in the Regulations that link each manufacturer's CO_2 target to: i) the mass of its own new car fleet; and ii) the mass of the entire new EU car fleet (i.e. the M_0 adjustment). A summary is provided in the following Box 2 below.

The scenarios showed that if the average mass of a manufacturer's new fleet declines, the manufacturer would be closer to its CO_2 emissions target when 'footprint' was the utility parameter than when 'mass' is the utility parameter. This is because when 'mass' is the utility parameter, the manufacturer's position relative to the target line changes both horizontally to the left (lower mass) as well as vertically downwards (lower CO_2 emissions), whereas if 'footprint' was the utility parameter the manufacturer's position would only change vertically downwards (lower CO_2 emissions) – assuming that a lower mass does not automatically imply a lower footprint.

This finding suggests that with a 'footprint' based utility parameter manufacturers would benefit in full from the application of mass reduction technologies in terms of meeting their targets. Mass reduction technologies are thus incentivised more when ''footprint' is the utility parameter compared to a 'mass' utility parameter. The difference between the approaches will depend on the actual slope of the limit value curve. The lower the slope, the less prominent is the effect of using one or another utility parameter.

Furthermore, the effect mentioned is to some degree offset by the adjustment of M_0, although there is no guarantee for a manufacturer that other manufacturers will behave in the same way (which would be required for the M_0 adjustment to happen).

Box 2: Scenario analysis of the implications of changes to the mass of vehicles on individual manufacturer CO_2 targets under the car and van CO_2 Regulations

Implications of mass reduction on manufacturer CO_2 targets

Previous work on the potential of mass reduction for LDVs also explored the implications of changes to the mass of vehicles on individual manufacturer CO_2 targets under the car and van CO_2 Regulations. As part of this analysis, five scenarios were developed to explore the most interesting cases in which the average mass of a manufacturer (termed "Manufacturer A" for the purposes of this analysis), and its competitors change (or not) compared to business-as-usual (BAU).

Additionally, to explore the extent to which different types of manufacturer might be affected by the changes analysed, each of these five scenarios were developed in (Ricardo-AEA, 2015) for four different types of manufacturer, as follows, where:

i. Manufacturer A was an 'average' manufacturer, i.e. both the average mass and the average CO_2 emissions of its new car fleet were equal to the market average.
ii. Manufacturer A was a 'heavier' manufacturer, i.e. one that had a high average mass and high average CO_2 emissions;
iii. Manufacturer A was a 'lighter' manufacturer having a low average mass and low average CO_2 emissions; and
iv. Manufacturer A was a 'more efficient' manufacturer, where the emissions of this manufacturer are 10 g/km lower than those of the 'lighter' manufacturer, while its average mass and footprint are those of the 'average' manufacturer.

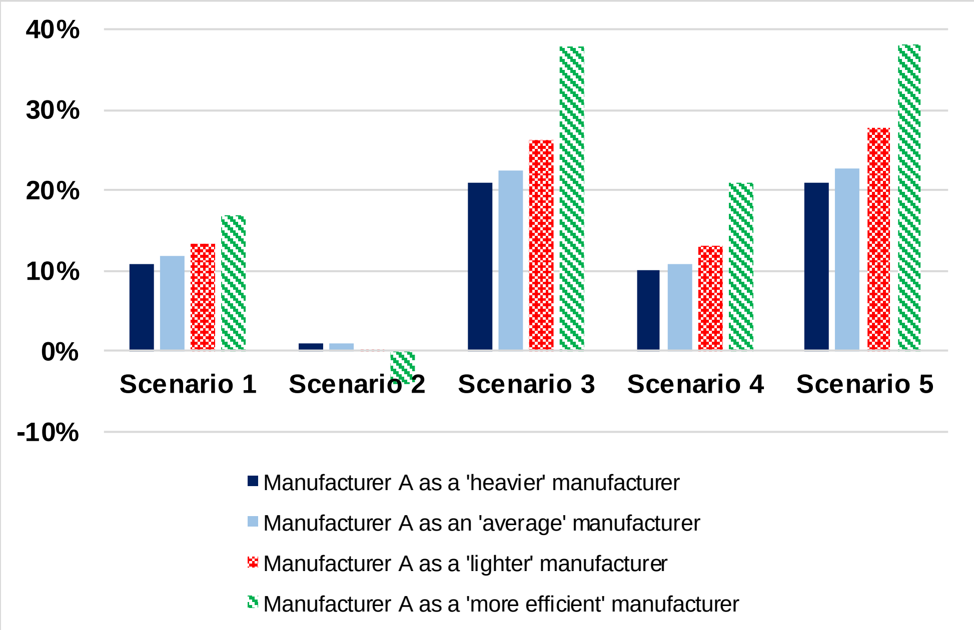
These scenarios are summarised in the table below, with the final illustrative results of the analysis also presented in the figure.

The results show that in an extreme case where only one manufacturer reduces the mass of their fleet under the current mass utility basis (Scenario 1) the benefits are around half of those with a footprint parameter (Scenario 5). Where one manufacture reduces the mass of their fleet under the current mass utility basis but others increase their mass by a proportional amount (Scenario 2), the single manufacturer may get close to zero benefit in closing the gap to their CO_2 target, or even be in a worse position than before the mass reduction. Only in the case where all manufacturers reduce their mass by 10% (Scenario 3) are the benefits of mass utility and footprint utility broadly equivalent.

Table 4.4: Scenarios developed for testing the impacts of changes in the sales-weighted average mass of vehicles sold by one or more car manufacturers

Scenario	Utility parameter	Mass reduction of "Manufacturer A"	Average mass change by other manufacturers	Subsequent change in average mass of market
BAU	Mass	0%	None	0%
1	Mass	10%	None	Down by 1%
2	Mass	10%	Up by 10%	Up by 8%
3	Mass	10%	Down by 10%	Down by 10%
4	Mass	0%	Down by 10%	Down by 9%
5	Footprint	10%	Not relevant for target of Manufacturer A	Not relevant for target of Manufacturer A

Figure 4.7: Relative changes in terms of the distance to their respective targets for a manufacturer with original CO_2 emissions of 115g/km compared to that for a 'heavier', 'average' and 'lighter' manufacturer after mass reduction and M_0 adjustment (where relevant)



Notes: A positive change indicates that Manufacturer A is closer to its target after mass reduction and the M_0 adjustment.

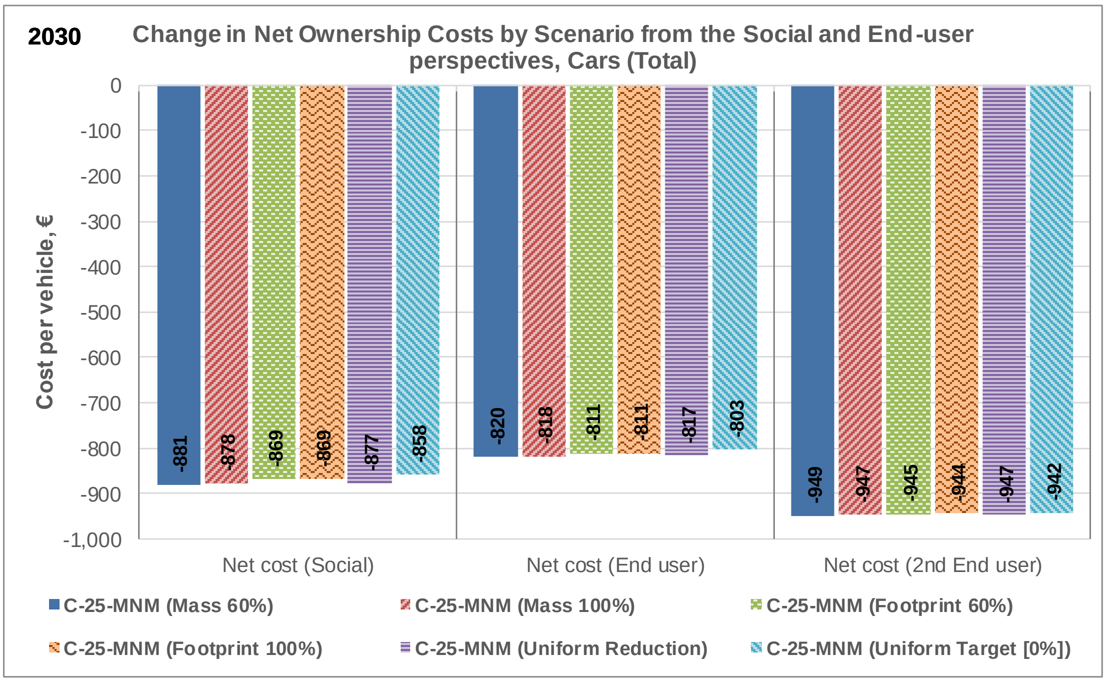
Source: Based on (Ricardo-AEA, 2015).

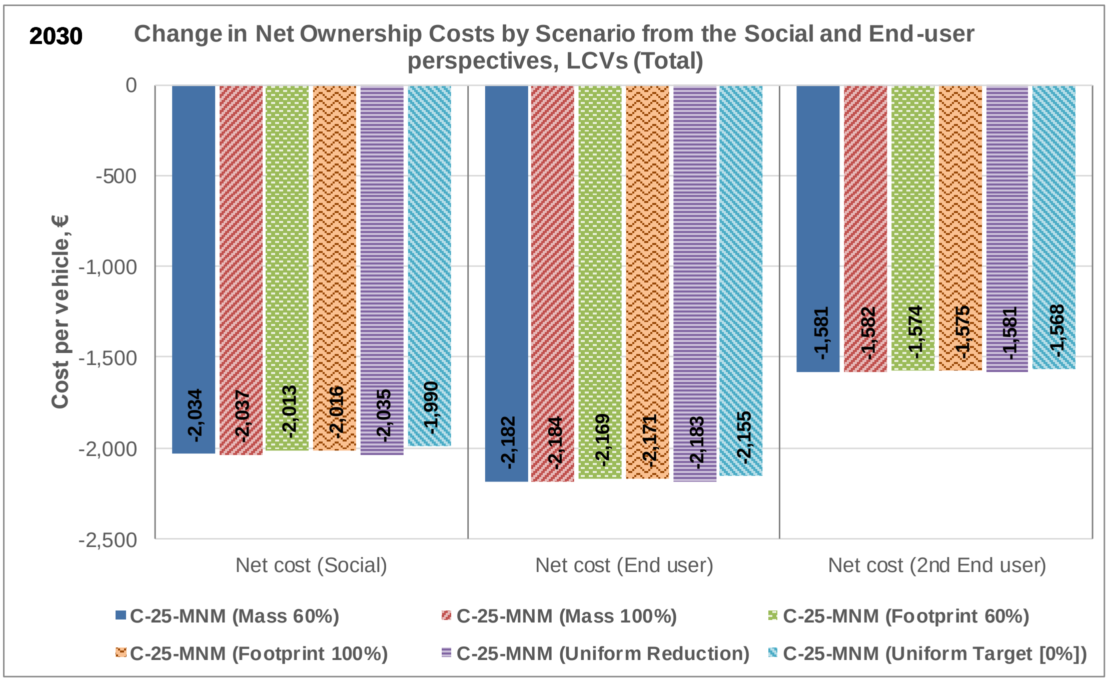
4.2 Impacts of options for distribution of effort amongst manufacturers

4.2.1 Impacts on average vehicle Total Cost of Ownership (TCO)

An analysis of the impacts of different distribution options was performed from the perspective of the total cost of ownership for an average vehicle. The results of this analysis, illustrated in Figure 4.8 below for the central ambition level, show negligible overall impact on the average TCO from societal or end-user perspectives for both cars and LCVs. The results are similar also for the low ambition (20%) and high ambition (40%) trajectories.

Figure 4.8: Summary of the average vehicle Total Cost of Ownership (TCO) of different options for distribution of effort compared to the baseline scenario for societal and end-user perspectives





Notes: **Societal** perspective = Total NPV costs (excluding taxes/mark-up) over the lifetime of the vehicle, with a 4% discount rate. **End-user** perspective = Total NPV over 5 years of ownership (first, second user), with a 11%/9.5% discount rate for cars/LCVs and accounting for the remaining vehicle residual value at the end of each period.

4.2.2 Assessment of impacts on competition between manufacturers

As indicated in Section 4.1, the impacts on competition between manufacturer categories were quantitatively assessed using outputs from the PRIMES-TREMOVE model and JRC's DIONE model[22]. The analysis below considers how different options analysed would affect the relative pricing of the previously defined different manufacturer categories (i.e. by relating additional manufacturing costs to average vehicle prices) and hence their relative competitiveness. This analysis also has implications for societal impacts where prices change to a greater or lesser degree on smaller to medium sized vehicles versus larger/heavier premium models.

An additional qualitative analysis is also presented based on an assessment of the relative preparedness for rolling out LEVs in the future, based on the current and future strategies of manufacturers with respect to LEV technologies. Further discussion on this is also provided in Section 5 on the options available for incentivising increased deployment LEVs.

Outputs of the JRC DIONE model have provided results for a range of scenarios, based on the output segment/powertrain shares derived from the PRIMES-TREMOVE modelling results. The principal scenarios that were utilised to inform the analysis in this section include the following:

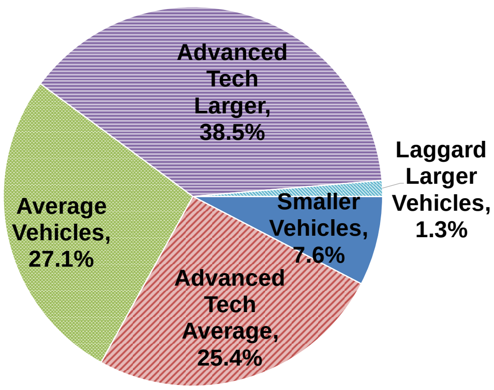
- L-25-MNM
- C-25-MNM
- H-25-MNM
- 68NL-25-MNM

Sensitivities regarding the cost assumptions:

- C-25-MNM-LO
- C-25-MNM-HICE
- C-25-MNM-LxEV
- H-25-MNM-LxEV

The following Figure 4.9 provides an overview of the respective market shares of EU new vehicle registrations for the different manufacturer categories discussed in this section, for 2013 registrations.

Figure 4.9: Share of new vehicle market by manufacturer category



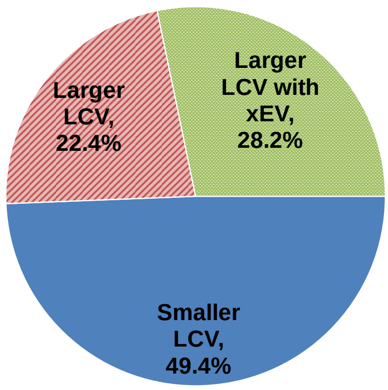


Figure 4.10 provides an illustration of the effects of distribution options for passenger cars. This confirms that lowering the slope of the limit value curves reduces the total costs and the relative price increase for manufacturers of smaller vehicles, and increases them for manufacturers of larger vehicles. A similar trend is also observed in Figure 4.11 for LCVs, albeit to a lesser extent. (Corresponding data tables for these figures are provided in Appendix 4).

In terms of overall average absolute costs, there are only very marginal differences between the different options for cars: the increase in total manufacturing cost under the C-25-MNM scenario only ranges from €1020 to €1051 per vehicle in 2030 and €380 to €399 per vehicle in 2025 [22]. For LCVs, the overall manufacturing cost increase is €619-€670 per vehicle in 2030 for the C-25-MNM scenario (and €354-€378 per vehicle in 2025).

For passenger cars, the average cost increase per vehicle is also in general lower for manufacturers having already higher levels of advanced / xEV technology deployed versus those that do not. This

[22]The same cost-curves ("central" costs) were used throughout the analysis. As noted in Section 4.1 , the use of a mass-based utility parameter may reduce the effectiveness of mass reduction measures in contributing to meeting a manufacturer's CO_2 target, but this effect is not modelled quantitatively in this analysis

trend is not consistent between different LCV manufacturers, where the differences in advanced /xEV technology deployment are a lot less than for passenger cars.

It was not possible to account for potential impacts on overall vehicle weight, and consequently individual manufacturer targets, resulting from technology selection in the analysis (e.g. heavier hybrid and xEV systems). Heavier CO_2 saving technologies (e.g. xEVs) will provide benefits for individual manufacturers since these will increase average vehicle weight and therefore also raise the gCO_2/km target of the individual manufacturer. This effect decreases (i.e. there is a lower incentive for heavy technologies) as the slope flattens towards 60%, and the effect increases (i.e. heavier CO_2 reducing technologies are more incentivised), for steeper slopes.

For cars, when considering costs relative to average vehicle price, slopes lower than 100% and the Uniform Reduction (UR) and Uniform Target (UT) options tend to lead to a more even distribution of effort amongst manufacturer categories. This is different for LCVs, where the UT and UR options show higher overall costs. In addition, the footprint-based options show slightly higher overall costs for LCVs versus mass-based options.

The analysis also shows that utilising the current mass-based regulatory slopes would lead to some of the most uneven distribution of effort between different manufacturers, particularly favouring manufacturers of larger vehicles and disfavouring manufacturers of smaller ones.

From the perspective of minimising the difference in the overall cost as a percentage increase on the average vehicle price for different manufacturers, the Uniform Target option provides the best solution for cars. However, this option would require significantly different GHG reductions for different manufacturers, and is not able to account for differences in manufacturers market niche offerings. Therefore, it could be viewed as the least fair unless a form of trading mechanism would provide flexibility for this diversity.

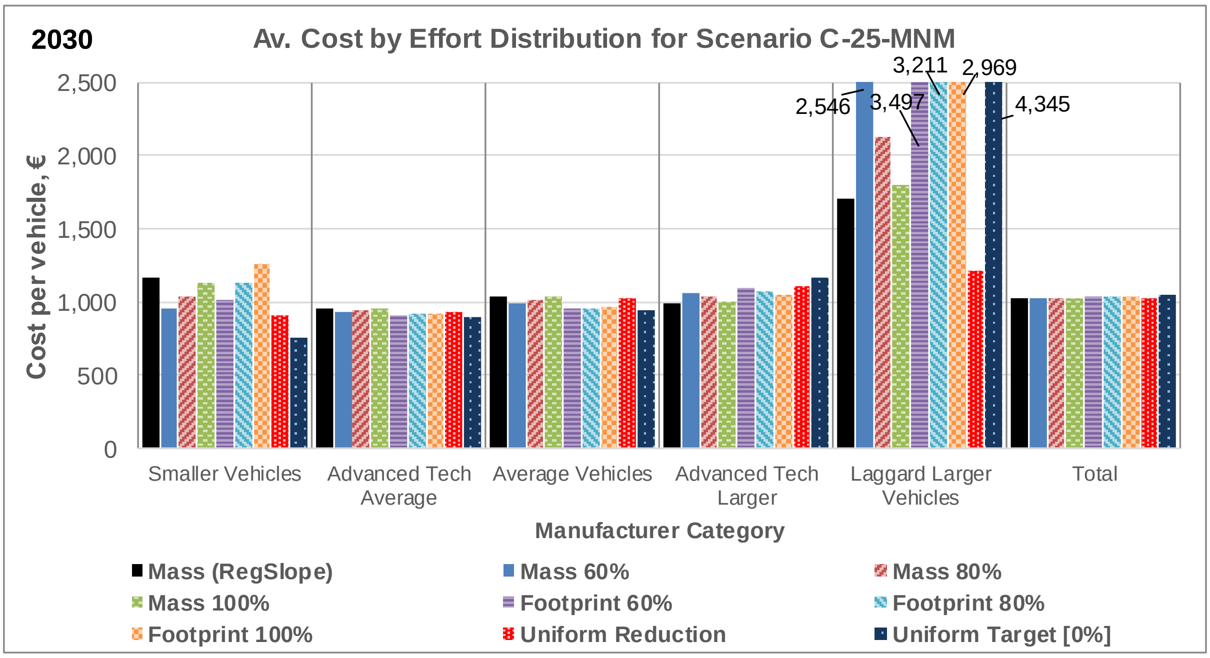
Apart from the general trend that slopes <100% for mass and footprint utility options tend to improve the overall balance of distribution of effort between different manufacturer types, there are no obvious significant net cost benefits for an individual distribution option for cars resulting from the analysis. (The impact on utility parameter on the effectiveness of mass reduction was discussed in Section 4.1.2).

The Uniform Reduction option provides no mechanism to account for changes in market shares or offerings between manufacturers. This potentially poses two risks: The first risk is that changes in market share could undermine the effectiveness of the fleet-level CO_2 in case manufacturers with a less strict target would increase their market share. The second risk is to manufacturers of smaller vehicles: These manufacturers have more limited possibilities for reducing the average CO_2 emissions from their vehicles through reducing the average size/mass of their vehicles, and increasing their market shares in larger vehicle segments would make it harder for them to meet their objectives. However, manufacturers of larger vehicles may much more easily change their offering to increase sales in smaller/lighter vehicle segments in order to meet their overall CO_2 target.

Therefore, both the Uniform Target and Uniform Reduction options pose greater difficulties for manufacturers at either extreme of the market, in the absence of any additional flexibility mechanisms. In this respect using a utility parameter based limit value curve with a sufficiently low/flat slope appears to be superior.

For LCVs, the apparently best option for minimising impacts as a percentage price (i.e. with the lowest variation for different manufacturer types) appears to be a mass utility option between 60% and 80% slope, and distribution of effort is more balanced between different manufacturer categories for flatter slopes. Costs are also minimised for 60-80% slopes within the footprint utility option, however net costs are slightly higher than for mass utility and there is more significant variation in the distribution of effort between different manufacturer types. The Uniform Target and Uniform Reduction options lead to higher average costs and the most significant differences in costs as a percentage of average price between different manufacturers.

Figure 4.10: Increased 2030 manufacturing costs relative to the baseline for passenger cars for different distribution parameters and slopes, values presented as absolute (€) and relative (%) to average prices



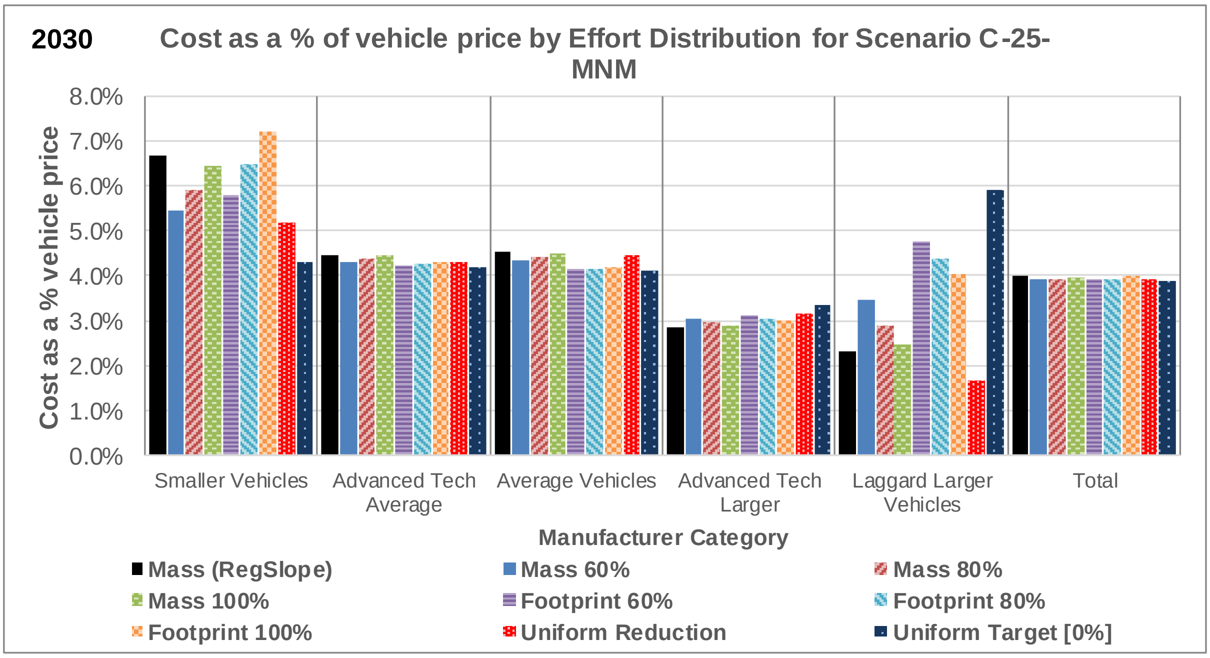
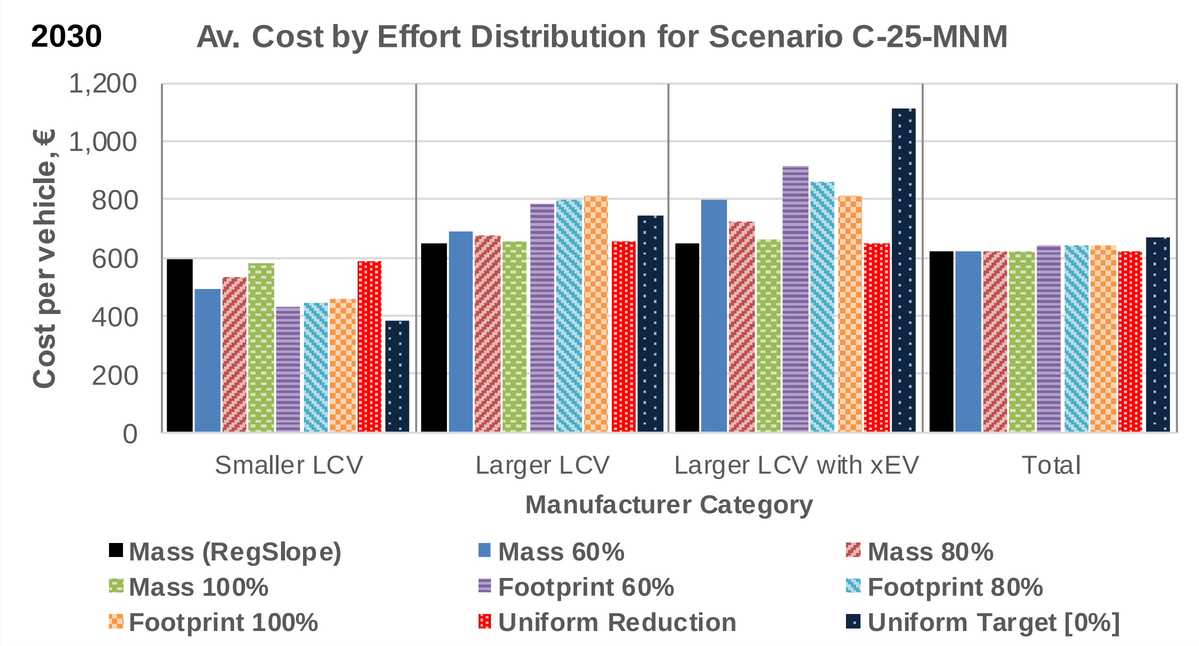
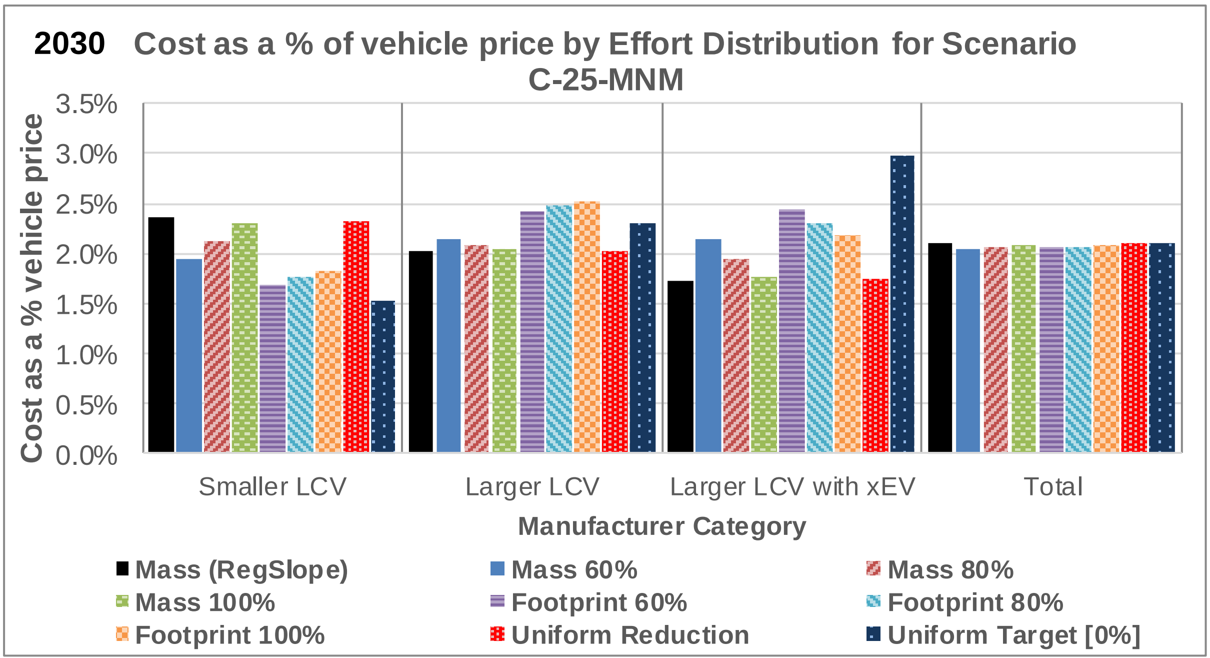


Figure 4.11: Increased 2030 manufacturing costs relative to the baseline for LCVs for different distribution parameters and slopes, values presented as absolute (€) and relative (%) to average vehicle prices





4.2.2.1 Impacts of ambition level and cost assumptions on distribution of effort

The following results presented in Figure 4.12 and Figure 4.13 illustrate that the general relationship between different distributions of effort options is consistent for different levels of CO_2 reduction ambition, and different cost-curves. Although these charts provide this illustration only for the relationship between the Mass Utility 60% Slope and 100% slope options for cars, the findings are similar between other pairs of options, and also for similar charts for LCVs.

This confirms it appears reasonable to make decisions regarding the selection of distribution of effort options independently of these considerations.

Figure 4.12: The impact of different levels of ambition on relative costs for different passenger car manufacturer categories for Distribution: Mass 60% Slope and Mass 100% Slope

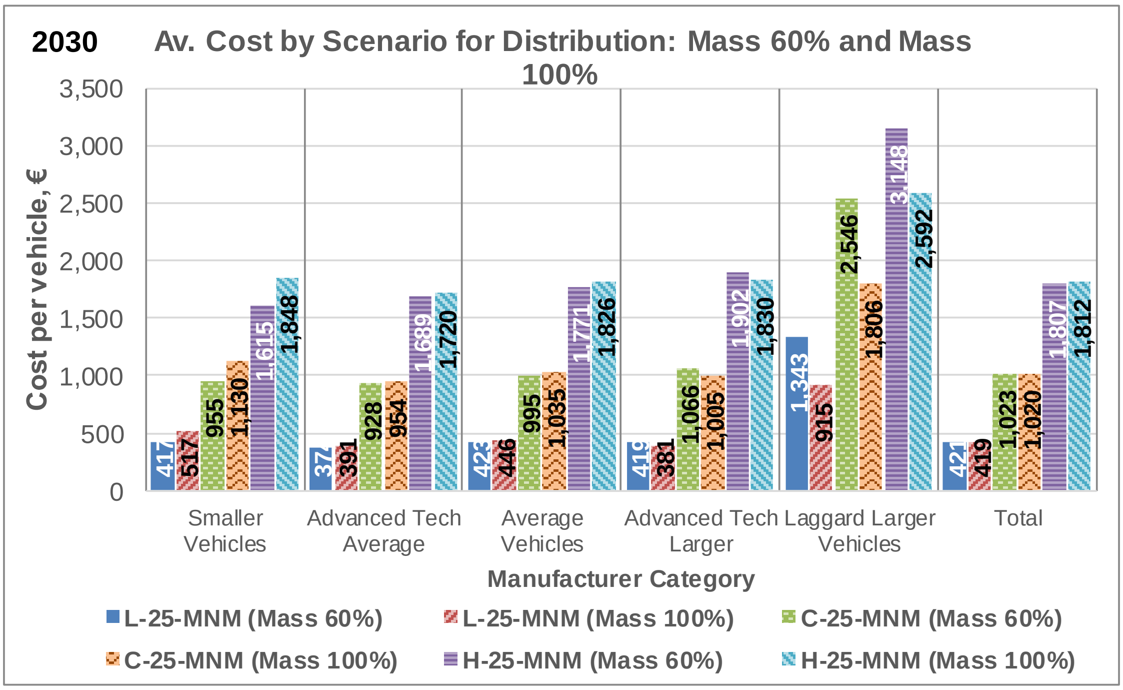
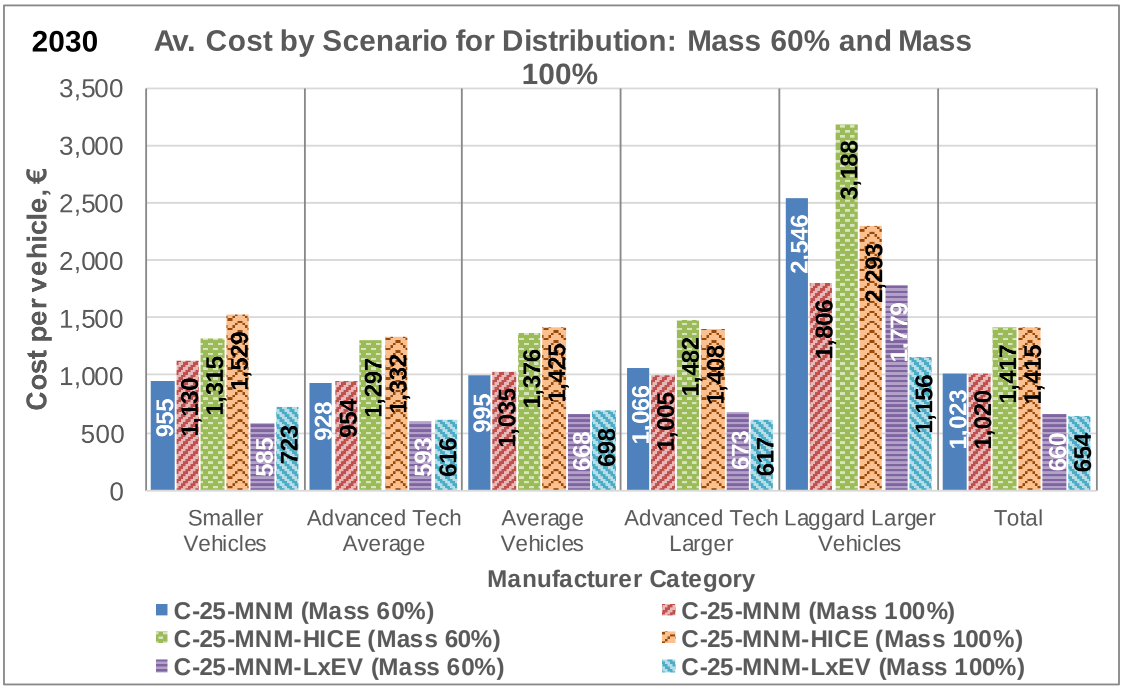


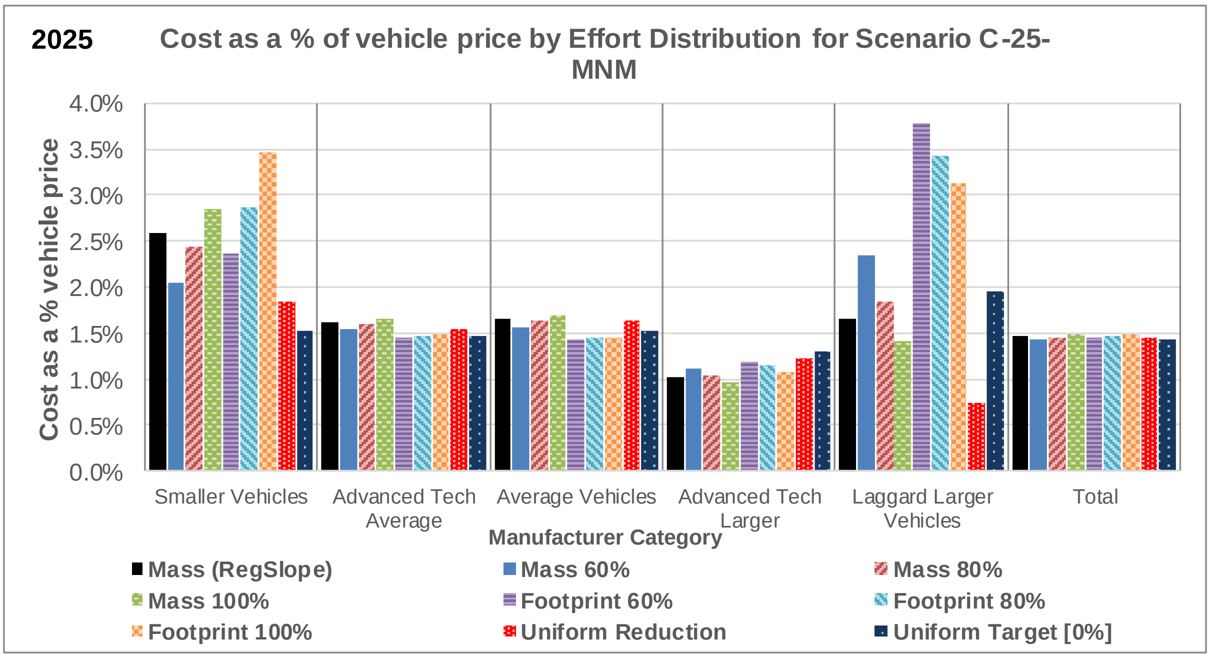
Figure 4.13: The impact of different cost-curve scenarios on relative costs for different passenger car manufacturer categories for Distribution: Mass 60% Slope and Mass 100% Slope Different cost scenarios

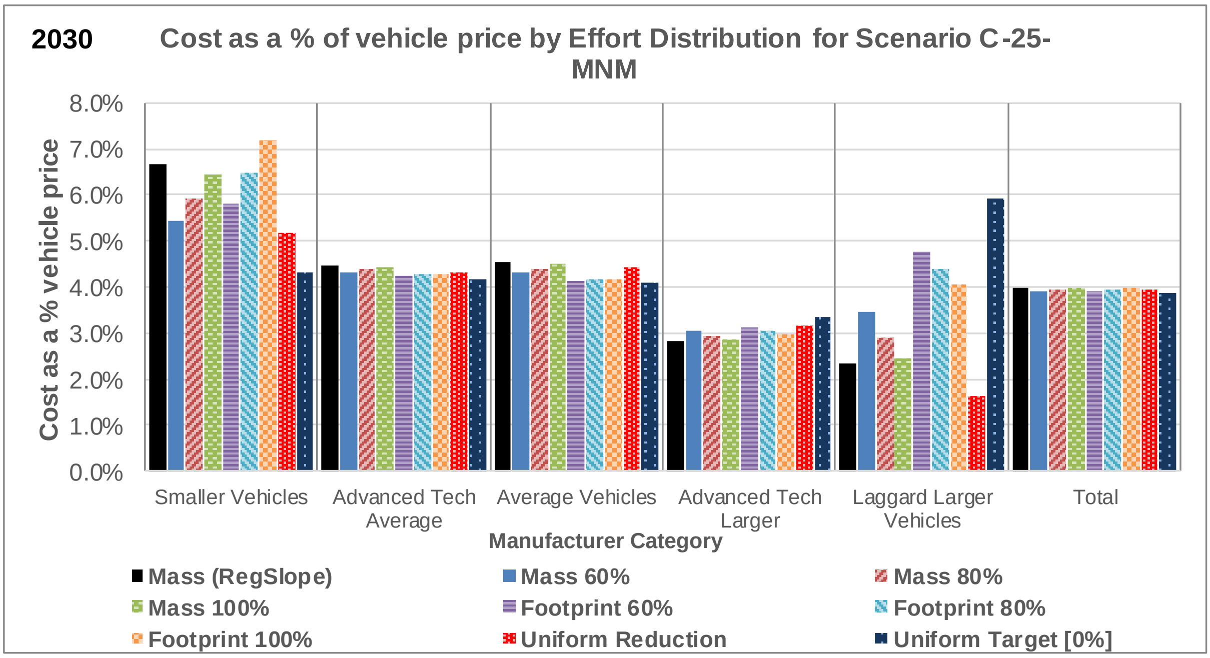


4.2.2.2 Impacts on average vehicle costs at 2025 versus 2030

A comparison is provided, in Figure 4.14, of the breakdown by distribution option in 2025 and 2030 for passenger cars. This illustrates that the relative impacts of the different options are similar for different manufacturer types in both periods, although the variability in the impacts between the different options is more pronounced in the earlier 2025 period. The earlier observations on the impacts of the different options therefore would appear be equally valid in 2025 as for 2030.

Figure 4.14: Increased manufacturing costs relative to the baseline for passenger cars for different distribution options, values presented as a relative (%) to average vehicle prices, or 2025 and for 2030





4.2.2.3 Impacts of xEV distribution on distribution of effort and competition

A number of alternative xEV distributions between manufacturers were also explored to assess their impacts. The two options used in the final assessment are:

a) **xEV equal increase** assumes similar rates of increase for all manufacturers, building on existing shares, with a slightly larger increase to laggard manufactures;

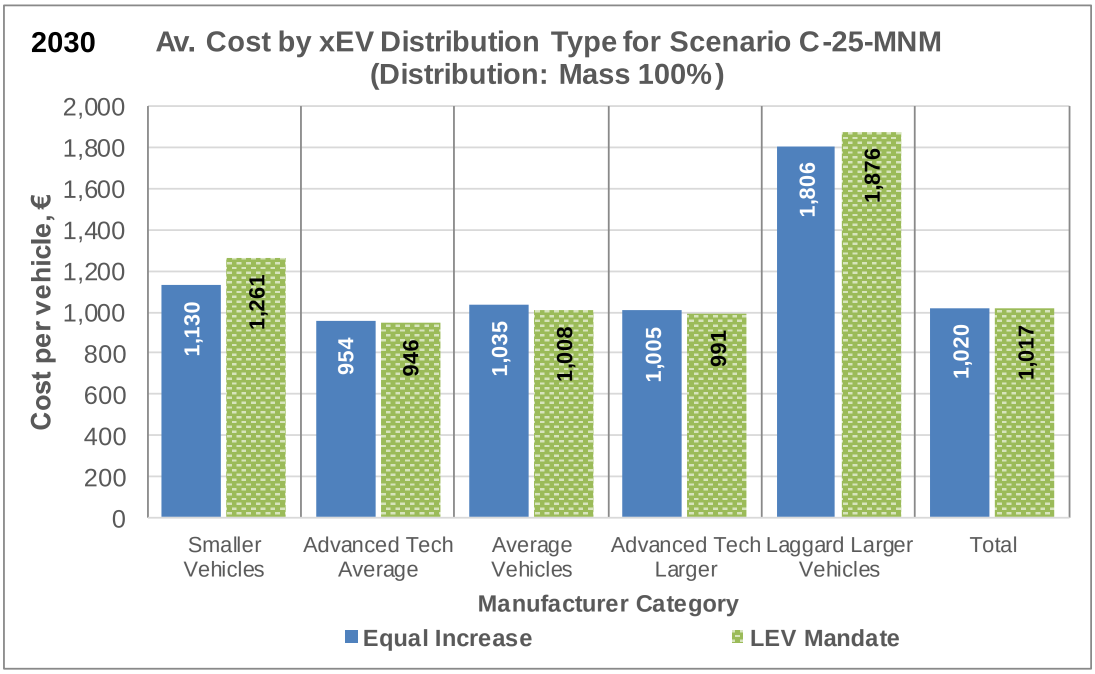
b) **LEV mandate** simulates the effect of an equal mandate on all OEMs, whereby xEV shares will be almost identical across all manufacturers.

The effects of these different distribution scenarios are illustrated for cars and LCVs in Figure 4.15 and Figure 4.16 respectively below. The LEV mandate scenario results in higher costs for the laggard larger car manufacturers and manufacturers of mainly smaller vehicles, where xEV deployment has been negligible to date, and marginally lower costs for other car manufacturers. For LCVs, there are no significant differences for different manufacturer categories between the two scenarios in terms of the overall cost outcomes.

In exploring the xEV distributions it was found that the distributions assumed had significant implications for whether some of the smaller or laggard larger manufacturers could meet targets defined by the different distribution of effort options. In particular, it was found that if lower shares of xEVs were distributed to these manufacturers (i.e. on the premise that they were behind others in xEV deployment) they may not be able meet their targets with certain options, or only at highly inflated costs.

Further supporting information on xEV model launch and strategy announcements is also provided in Appendix 4.

Figure 4.15: Increased 2030 manufacturing costs relative to the baseline for passenger cars for different xEV distribution scenarios, values presented as absolute (€) and relative (%) to average vehicle prices



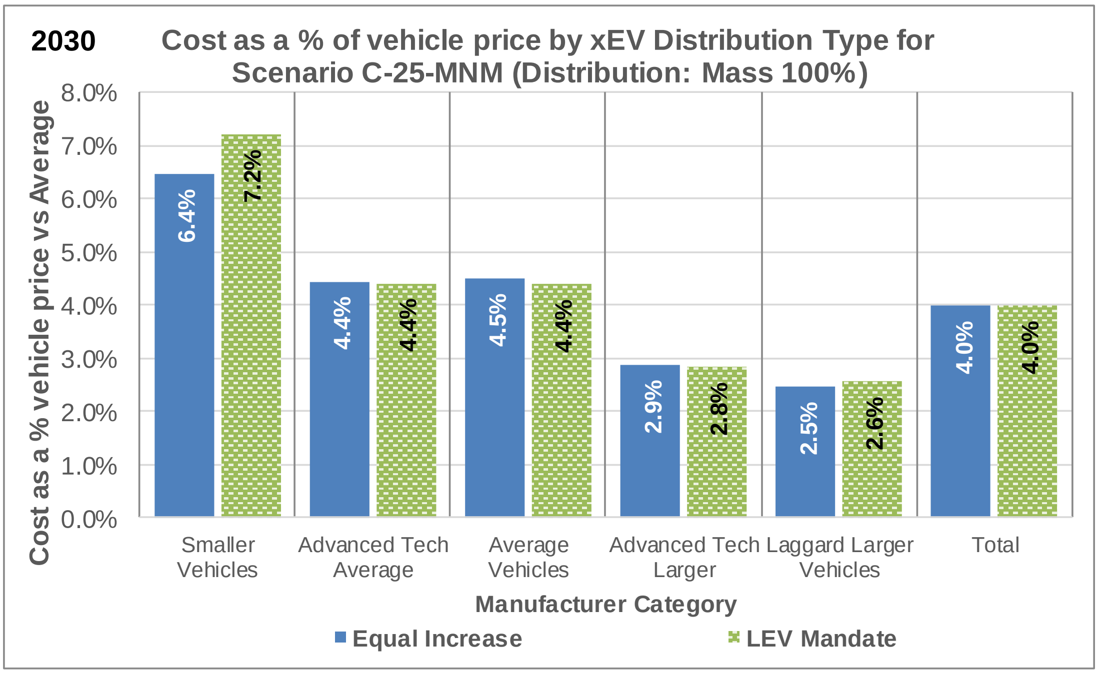
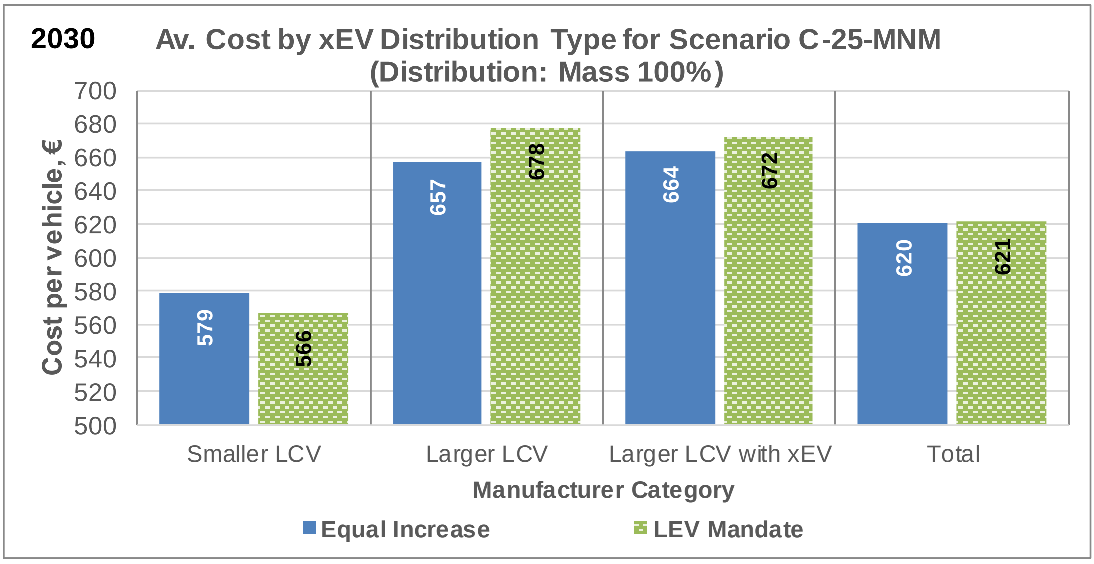
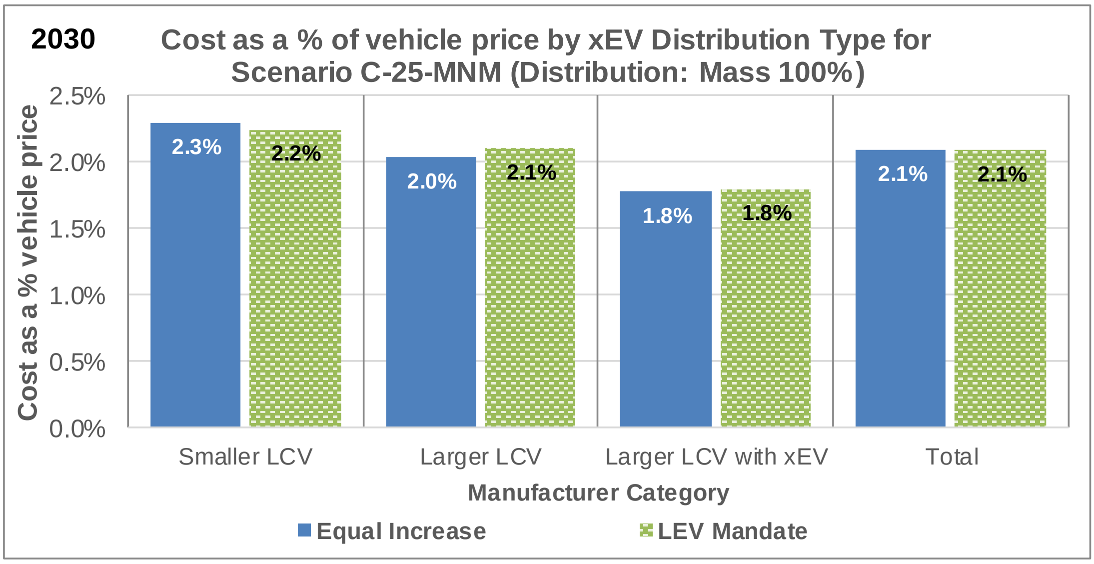


Figure 4.16: Increased 2030 manufacturing costs relative to the baseline for LCVs for different xEV distribution scenarios, values presented as absolute (€) and relative (%) to average vehicle prices





4.2.3 Distribution of impacts across income groups (social equity)

As far as the distribution of effort across manufacturers is concerned, the distribution of impacts across the income groups is not expected to differentiate significantly. From the analysis presented in Chapter 3, the implementation of the target per se (e.g. Central ambition) compared to the Baseline scenario is what drives the results.

A more detailed quantitative analysis would require additional background statistics such as the purchases of cars by household category, age and also size. However, such analysis by vehicle size is not currently available in existing research, such as that provided in (TML et al, 2016).

4.2.4 Conclusions from analysis for options for distribution of effort amongst manufacturers

The main conclusions that may be drawn from the analysis are summarised below. A side-by-side summary comparison of the different impacts is also presented in Table 4.5 below, grouped according to the Effectiveness, Efficiency, Coherence and Proportionality criteria for Impact Assessments outlined by the Better Regulation Guidelines:

- Varying the CO_2 reduction ambition level does not significantly alter the relative effects on different manufacturer types of different distribution of effort options.
- At the fleet-wide average level, the differences in cost increase relative to the vehicle price between the mass/footprint utility slopes investigated are relatively small compared to the overall cost increases (except for manufacturers of mostly smaller vehicles or mostly larger vehicles)[23]. Nevertheless, flatter slopes show the lowest % increases in vehicle price for mass and footprint.
- Considering the cost impacts, both the Uniform Reduction and Uniform Target options appear to be viable alternatives to mass and footprint based utility parameters, but other considerations make them less attractive. For example, the Uniform Reduction option would require an additional mechanism ensuring that the fleet wide target is met over time, and also poses significant risks to manufacturers of smaller vehicles who have limited possibilities to reduce CO_2 by increasing shares of smaller vehicles to help meet the target; larger manufacturers may much more easily enter smaller vehicle markets to help reduce their average CO_2. Overall, these two options pose greater difficulties for manufacturers at either extreme of the market in the absence of any additional mechanisms. For LCVs, the Uniform Target option results in significantly higher manufacturing cost increases versus the other utility options.
- Based on the analysis, the impacts on the overall fleet average TCO on a societal and end-user perspective of different options is negligible. However, the limited differences in impacts on costs for larger premium manufacturers versus average or smaller vehicle manufacturers would also carry through to a TCO type analysis at this level [24].
- The Uniform Target and the Mass and Footprint Utility options with the flatter slopes are likely to favour smaller and average vehicle manufacturers the most, which may be also more favourable to lower-income groups.

[23] The use of a mass-based utility parameter may reduce the effectiveness of mass reduction measures in contributing to meeting a manufacturer's CO_2 target, but this effect is not modelled quantitatively in this analysis

[24] It was not possible to fully account for the potential impact of utility parameter choice on the attractiveness of mass reduction technologies in the analysis.

Table 4.5: Comparison of impacts of the prioritised options for Distribution of Effort in terms of achieving key objectives

Principal areas	Sub-areas	Option 1	Option 2			Option 3			Option 4	Option 5
		Current Reg. Utility/Slope	Mass 60%	Mass 80%	Mass 100%	Footprint 60%	Footprint 80%	Footprint 100%	Uniform Reduction	Uniform Target
Effectiveness										
1. Criterion:										
Ensure the regulations are consistent with meeting GHG reduction objectives	2030 objectives	The effective slope increases from ~67% currently to >100% by 2030, gradually weakening the required CO_2 reduction from higher mileage larger vehicles.	Flatter utility slopes, i.e. below 100%, result in increasing levels of overall GHG reduction as they promote greater decreases in emissions from larger vehicles, which cover higher annual km. A slope of 100% (or maintaining the current slope) would effectively weaken the relative effort required by larger vehicle manufacturers compared with the current regulations for 2021/20.						Higher incentive for mass reduction options, increasing CO_2 reduction potential.	Results in significantly greater average CO_2 reduction from larger vehicles that have higher annual mileages.
2. Criterion:										
Increasing the uptake of LEVs		N/A	Mass utility with <100% slopes may benefit manufacturers introducing higher shares of xEVs, since these are generally heavier than alternative equivalents.			N/A			N/A	N/A

Principal areas	Sub-areas	Option 1 Current Reg. Utility/Slope	Option 2 Mass 60%	Mass 80%	Mass 100%	Option 3 Footprint 60%	Footprint 80%	Footprint 100%	Option 4 Uniform Reduction	Option 5 Uniform Target
3. Criterion:										
Avoidance of undesired competitiveness impacts on the EU automotive sector	Distributional impacts across OEMs / Equity between OEMs	A constant slope parameter results in a changing impact over time/CO_2 reduction objective, which results in increasing benefits to larger vehicle manufacturers in later periods.	Slopes less than 100% improve the overall balance of distribution of effort between different manufacturer types, with the 60% slope providing the most even distribution of cost increases relative to average vehicle prices. Slopes in the range 60-80% will broadly maintain the current status quo.			Higher incentive for mass reduction, which may lead to lower costs. Slopes <100% generally improve the balance of distribution of effort (costs relative to average vehicle price).			Poses significant risks to manufacturers of smaller vehicles who have limited possibilities to reduce CO_2 by increasing shares of smaller vehicles to help meet the target. Larger manufacturers may much more easily enter smaller vehicle markets to help reduce their average CO_2.	Would lead to significantly different GHG reduction targets for different manufacturers; ignores differences in manufacturers market niche offerings. Would require some form of trading mechanism to provide flexibility for this diversity.
	Impacts on first movers	Dis-incentivises first mover adoption of mass-reducing technical options.				No negative impacts identified.			No negative impacts identified.	No negative impacts identified.
4. Criterion:										
Ensure the impacts of the regulations are socially equitable	Employment; social inclusion, distributional impacts; public health.	Overall impacts are proportionally relatively small compared to the impacts resulting from selection of Ambition level.								
		Favours larger/premium manufacturers the most, with higher relative costs for smaller and average vehicles more frequently purchased by lower income groups.	Likely higher overall costs than non-mass utility options, disfavouring lower income groups to a greater extent. Flatter slopes (i.e. below 100%) favours smaller vehicles vs larger vehicles/premium brands.			Likely lower average capital costs compared to mass utility, particularly benefiting lower income groups. Flatter slopes (i.e. below 100%) favours smaller vehicles vs larger vehicles/premium brands.			Likely lower average capital costs compared to mass utility.	Likely lower average capital costs compared to mass utility. Costs are relatively lower for smaller vehicle manufacturers vs larger/premium brands.

Principal areas	Sub-areas	Option 1	Option 2			Option 3			Option 4	Option 5
		Current Reg. Utility/Slope	**Mass 60%**	**Mass 80%**	**Mass 100%**	**Footprint 60%**	**Footprint 80%**	**Footprint 100%**	**Uniform Reduction**	**Uniform Target**
Efficiency										
5. Criterion:										
Ensure the environmental benefits of the LDV CO_2 targets are achieved cost-effectively	Total Cost of Ownership, overall cost-effectiveness and Cost:Benefit ratio	Not directly assessed. May result in a slightly higher overall fleet average TCO and poorer net Cost:Benefit result due to dis-incentivisation of mass reduction. Costs are lower for slopes <100%.				Not directly assessed. May result in a slightly lower overall fleet average TCO and improved net Cost:Benefit result as no technological bias. Costs are lower for slopes <100% for footprint utility.				
Other considerations										
Explicit barriers and limitations	Barriers to implementation	N/A	N/A			High resistance from manufacturers to move away from the mass utility.			High resistance from manufacturers to move away from the mass utility. This option requires an additional mechanism to ensure that the overall CO_2 target is met.	High resistance from manufacturers to move away from the mass utility.
	Impact on mass reduction options	Decreases the incentive for mass reduction options, possibly increasing individual OEM and net costs.				N/A			N/A	N/A

Notes: The selection of different options is assumed to be negligible for the impact areas excluded from the table above.

5 Options for incentives to stimulate the market uptake of zero- and low-emission vehicles

Within the current Regulations, the uptake of zero- and low-emission vehicles (ZEV/LEVs) is stimulated by the existence of a CO_2 target in the first place, particularly as BEVs and FCEVs have zero tailpipe emissions. Manufacturers are also able for a limited time-period to use super-credits, which allow cars (but not LCVs with respect to the 2020 target) that emit less than 50 gCO_2/km to count as more than one vehicle for the purpose of calculating a manufacturer's specific CO_2 emissions. In the context of the post-2020 policy framework, there have been calls for additional mechanisms to be considered that directly incentivise ZEV/LEVs, particularly an incentive for such vehicles that could, for example, require manufacturers to ensure that a certain percentage of their new car fleet is made up of LEVs. In its 2016 Strategy for Low Emission Mobility[25], the European Commission committed to analysing the impact of different ways of incentivising ZEV/LEVs. This section reports on work that has been undertaken to develop and assess the impacts of options to incentivise LEVs and ZEVs. Section 5.1 presents the results of the development of the options, while Section 5.2 presents the potential impacts of the different options that were modelled.

5.1 Development of options for LEV Incentives

The aim of the work underlying this section was to define options for incentivising the market uptake of ZEV/LEVs and their interaction with the fleet-wide average CO_2 target. A paper (Appendix 1) was developed by the project team identifying the main elements of potential incentives to stimulate the market uptake of ZEV/LEVs. This section contains a summary of the conclusions of that work.

Before considering in more detail the form that an LEV incentive might take, it is important to be clear about the reasons behind the introduction of such an incentive. First, as the objective of the Regulations is to reduce (tailpipe) CO_2 emissions from new cars and LCVs, an additional incentive for LEVs should also work towards this objective, or at least not undermine it. Second, calls for the inclusion of additional LEV incentives are based on the recognition that LEVs have an important role to play in delivering CO_2 reductions, particularly in the longer-term, but that they are not currently being introduced onto the market at the scale needed.

The elements of the additional LEV incentive were assessed against the following criteria, i.e. that it should:

- Contribute to the objective of the Regulations, i.e. reducing tailpipe CO_2 emissions from light duty vehicles;
- Ensure that CO_2 reductions are delivered in the real world;
- Incentivise the deployment of vehicles having the potential to emit less CO_2 (both during the test and in real world) than comparable vehicles on the market today and which will provide benefits for the longer-term emissions reductions and decarbonisation goals.
- Be technology neutral;
- Be based on robust data.

Given that a potential LEV incentive is being discussed in the context of the 2025/2030 timeframe, and that the technologies that are likely to increase their market share significantly in this period are already known, it is possible to identify the types of vehicle that such an incentive should target, i.e. those that have a significant potential contribution to reducing the CO_2 emissions of the new car and LCV fleet in the long-term. The types of vehicle most relevant in this respect are:

- *Battery electric vehicles (BEVs)*, as these have zero tailpipe CO_2 emissions and their market uptake has been limited so far. There is currently a benefit in terms of WTW CO_2 emissions of BEVs over ICEVs and this will improve over time, as the carbon intensity of electricity production declines.

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- *Fuel cell electric vehicles (FCEVs)* using hydrogen, as these also have zero tailpipe CO_2 emissions and their market uptake has been very limited so far. Such vehicles will be beneficial with respect to WTW emissions, as long as hydrogen is produced from low carbon sources.
- *Plug-in hybrid electric vehicles (PHEVs)* with sufficiently "low" tailpipe CO_2 emissions, a level which needed to be determined to ensure that it is ambitious yet achievable and provides an incentive to reduce the CO_2 emissions of these vehicles below the values that are typical on the current market. For this type of vehicle, it also has to be recognised that their actual performance on the road is strongly influenced by consumer behaviour (charging behaviour in particular).

Of these, BEVs and FCEVs can be considered to be ZEVs as they have no tailpipe CO_2 emissions.

There are three main elements to the incentive: (i) the definition of the LEVs that would benefit from the incentive; (ii) the extent to which there is differentiation between different LEVs; and (iii) how the incentive might work in practice. These elements have been the subject of extensive analysis within the project (see Appendix 1). Section 5.1.1 summaries the analysis and conclusion on the potential definition of an LEV and Section 5.1.2 the options for differentiating between different LEVs, while Section 5.1.3 summaries the analysis and conclusion on how the incentive might work in practice. Section 5.1.5 contains some additional considerations and Section 5.1.6 provides a summary of the implications of the selected options for an LEV incentive for the quantitative analysis.

5.1.1 Defining an LEV

There are two elements to the definition of an LEV: the criterion to be used and the threshold to be set for this criterion. In relation to both, it is useful to set out a framework within which the potential options can be assessed in order for the analysis to be completely transparent and consistent. A full version of the analysis can be found in Appendix 1; a summary is provided here.

Based on the characteristics of the vehicle types that an LEV incentive should target, i.e. BEVs, FCEVs and PHEVs, potential criteria that might be used to define an LEV are:

- A vehicle's tailpipe CO_2 emissions;
- The zero-emission range of a vehicle; and
- The electrical energy consumption – or hydrogen consumption – of a vehicle.

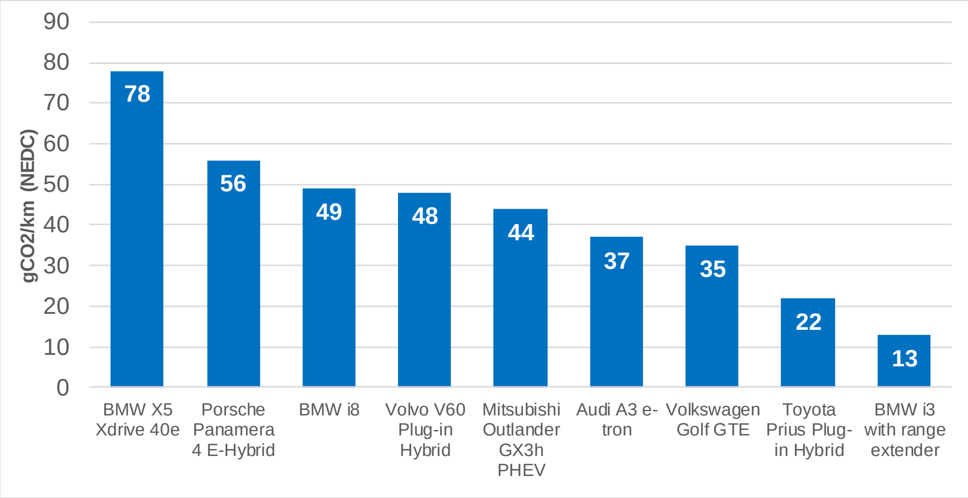
The terminology 'zero-emission range' is proposed rather than 'electric range' in order to apply equally to FCEVs, as well as BEVs and PHEVs. Similarly, while 'electrical energy consumption' applies to BEVs and PHEVs, 'hydrogen consumption' is the equivalent metric for FCEVs. This information is available on the certificate of conformity (CoC) of each vehicle, but some of this information is not currently collated under the Regulations.

Based on an assessment of the pros and cons of these options against the criteria identified above, defining an LEV according to a vehicle's CO_2 emissions seems to be the best option. It has the benefit that it provides a direct link to the objective of the Regulations, i.e. reducing tailpipe CO_2 emissions, is technologically neutral and would be based on data that is already used for the overall target, and so has been subject to a great deal of scrutiny and is considered to be reasonably robust. For the other two options, new data would need to be collected and be subject to a similar level of scrutiny before it could be considered to be sufficiently robust. This also poses a challenge for setting a threshold for these two options. The choice of a vehicle's CO_2 emissions as the criterion to be used to define an LEV applies equally to cars and LCVs.

The next important step is to ***define the threshold*** below which a vehicle is to be considered to be an LEV. Given that BEVs and FCEVs have zero tailpipe CO_2 emissions, the issue in determining the threshold is effectively whether, and if so which, PHEVs should be included in the definition of an LEV. The discussion below first focuses on cars, followed by LCVs.

One option for the threshold is that it should only cover ZEVs, in which case the threshold would be zero tailpipe CO_2 emissions. While this option provides a strong signal with respect to ZEVs, it does not provide an additional incentive for low emitting PHEVs, which may be important in the transition towards ZEVs. As noted above, in the context of the 2021 target for cars, the threshold at which a car is eligible for a super-credit is 50 gCO_2/km, which suggests that this is an appropriate upper-bound for the consideration of the threshold to determine an LEV for the post-2020 policy framework. The identification of potential thresholds between these two extremes, i.e. zero gCO_2/km and 50 gCO_2/km, was undertaken with reference to the existing market (see Figure 5.1) and a consideration of the potential CO_2 emissions of such vehicles in the future, as projected by the PRIMES-TREMOVE model. Many PHEVs currently emit around 50 gCO_2km, while others emit less, e.g. around 35 gCO_2/km and even 22 gCO_2/km for the new 2017 Toyota Prius Prime PHEV and 13 gCO_2/km for the BMW i3 with range extender. This suggests that lower thresholds, of around 25 to 35 gCO_2/km might be appropriate for the next decade.

Figure 5.1: Examples of NEDC CO_2 emissions of currently available PHEVs



Source: Update of data collected as part of the SR4 project (Ricardo Energy & Environment et al, 2016)

Additionally, as overall CO_2 reduction targets are potentially being considered for both 2025 and 2030, and that PHEV technology is likely to continually improve between 2020 and 2030, it would be appropriate to have different thresholds for the two overall target years. In which case, it is worth considering a scenario in which the threshold for defining an LEV is more stringent in 2030 than it was in 2025.

In summary, therefore, the following thresholds were explored further in the quantitative analysis for cars:

- CO_2 emissions of zero at the tailpipe **for both** 2025 and 2030 (Option T1).
- CO_2 emissions less than or equal to 25 gCO_2/km **for both** 2025 and 2030 (Option T2).
- CO_2 emissions less than or equal to 35 gCO_2/km in 2025 ***reducing to 25 gCO_2/km in 2030*** (Option T3).
- CO_2 emissions less than or equal to 50 gCO_2/km **for both** 2025 and 2030 (Option T4).

There are fewer data to justify the choice of values to define an LEV for the LCV market, as result of the limited number of plug-in LCVs and electric LCVs on the market. Consequently, the above options for the thresholds for passenger cars were also taken as the starting point for the LCV thresholds for the respective PRIMES-TREMOVE model runs. During this analysis it became clear that, for LCV the 35 gCO_2/km and 25 gCO_2/km thresholds were too low for significant numbers of PHEVs to qualify, so the threshold was raised to 40 gCO_2/km.

5.1.2 Differentiating between different LEVs

As discussed above, different types of LEVs have the potential to contribute differently to reducing tailpipe CO_2 emissions. Consequently, there is a clear rationale for **differentiating between different types of LEV**, e.g. between ZEVs and PHEVs, in the LEV incentive. The decision as to whether to treat all LEVs the same (Option D1) or to differentiate between different types of LEV (Option D2) is linked to the consideration of the appropriate threshold to use, as discussed in Section 5.1.1, as differentiation is more relevant for less stringent thresholds. In this respect, the following combinations were evaluated quantitatively:

- LEV1: Option D2 (differentiation between LEV types) and Option T3 (in which the threshold is 35 gCO_2/km in 2025 and 25 gCO_2/km in 2030);

- LEV2: Option D1 (no differentiation) and Option T1 (threshold of 0 gCO_2/km);
- LEV3: Option D2 (differentiation) and Option T4 (threshold of 50 gCO_2/km); and
- LEV4: Option D1 (no differentiation) and Option T2 (threshold of 25 gCO_2/km).

Option D2 could be seen as a manufacturer being rewarded with a 'credit' for each LEV it sells, with the value of this credit being '1' for a ZEV, and less than '1' for other types of LEV. In order to implement this option, the way in which **non-ZEV LEVs count towards the incentive** needs to be decided. The option of counting a PHEV as a fraction of a ZEV depending on its CO_2 emissions, rather than as a fixed fraction of a ZEV, is an elegant solution as it rewards each PHEV in a way that is directly linked to its contribution to the overall objective of the Regulations. This means of counting non-ZEV LEVs was taken forward.

The **value of a non-ZEV LEV credit** can be determined in several ways based on its tailpipe CO_2 emissions, including comparing the latter to the annual fleet-wide average, or the next fleet-wide CO_2 target. The option that provides a greater differentiation between the values of the credit allocated to different PHEVs and so which provides more of an incentive to develop LEVs with lower CO_2 emissions, is the following:

$$\text{Value of a credit to be used} = 1 - \frac{CO_2\text{ emissions of the LEV}}{\text{(Threshold used to define an LEV)}}$$

In other words, the denominator on the right-hand side of the above equation would be 35 g CO_2/km (for the years 2025 to 2029) and 25 g CO_2/km (from 2030 on) under T3 and 50 gCO_2/km (from 2025 on) under T4.

5.1.3 Determining how the LEV incentive would work in practice

There are various aspects that need to be considered in order to determine how the LEV incentive would work in practice, including the:

- Form of the incentive, i.e. mandate or credit-based system.
- The value of the mandate or benchmark.
- How to apply the incentive.
- To what extent and how to reward over-achievement / penalise under-achievement under a credit-based system.

The focus of the assessment below is on passenger cars, although much of it also applies to LCVs. It is explicitly noted where the assessment is different for LCVs.

Criteria for assessing the various options considered in this section were that the incentive should:

- Increase the uptake of vehicles that will provide benefits for the longer-term emissions reduction, but without weakening the 2030 target.
- Deliver emissions reductions as cost-effectively as possible, i.e. not disproportionately increase compliance costs.
- Treat manufacturers fairly, including not penalising those that have taken early action to reduce their emissions.
- Minimise additional administrative burden.
- Provide regulatory certainty for manufacturers.

In relation to the **form that the incentive might take**, potential options considered were:

- ***Mandate***, in which a mandatory minimum requirement with respect to the uptake of LEVs is set (i.e. applying in addition to a fleet-wide CO_2 target) (Option F1); or a
- ***Credit-based system***, in which a benchmark relating to the number/share of LEVs is set, which is not mandatory as such, but is used to determine (emission) credits and/or debits with respect to the CO_2 target based on a requirement relating to LEVs (Option F2).

Compared to a mandate, a credit-based system provides more flexibility to manufacturers, but it risks weakening the overall CO_2 target (particularly if it only relied on credits), may increase the complexity of the regulatory approach and does not ensure that a specified level of LEVs are put on the market. Both Options F1 and F2 were assessed quantitatively.

The next step is to identify the **metric that might be used for the incentive**. The obvious options in this respect are to base the incentive on an absolute number of LEVs or on a share of the new vehicle fleet. Basing the incentive on an absolute number of LEVs has risks as this number is not related to the overall size of the fleet, and so its impact would change if the overall new vehicle fleet declined in size or grew, while the approach would also effectively require setting manufacturer-level objectives. This risks becoming unfair on manufacturers, as it would not take account of potential shifts in market share, potentially increasing or decreasing the relative burden on different manufacturers as a result. It therefore seems more appropriate – for both Options F1 and F2 – to use the 'share of the new vehicle fleet' as the metric for the incentive.

The next consideration is how to determine **the value of the mandate or benchmark**, i.e. the appropriate share of the new vehicle fleet that should be LEVs. At the minimum, the incentive – mandate or benchmark – would be set at the proportion of LEVs in the new vehicle fleet projected by PRIMES-TREMOVE under a scenario with a given CO_2 target level. Alternatively, as more LEVs will be needed in the longer-term, the value of the LEV incentive could be set at a higher level in order to speed up the introduction of such vehicles, while maintaining the same fleet-wide CO_2 target. In this case, the value of the incentive for LEVs is set higher than the cost-optimised level of LEVs under the scenario concerned.

In summary, the options for setting the value of the incentive are:

- Set the incentive at the level of uptake of LEVs indicated by the respective PRIMES-TREMOVE run for the scenario corresponding with the CO_2 target level considered (Option VM1).
- Compared to VM1, ***increase the incentive level***, e.g. beyond that indicated by the PRIMES-TREMOVE run for the CO_2 target level considered (Option VM2).

Options relating to VM2 were evaluated quantitatively and are discussed in later sections.

The next consideration is whether or not to **differentiate the level of the incentive between manufacturers**. The options here are, at least in the first instance, whether each manufacturer has the same level of incentive or whether the incentive is applied differently for individual manufacturers. The latter is administratively more complex and would need a decision on how the incentive should be distributed between manufacturers. Unless this is set appropriately, there is a risk of penalising first movers if the fact that these have more LEVs on the market already leads to a higher incentive. Consequently, it seems most appropriate for the same LEV incentive to be given to all manufacturers, either under a mandate or a credit-based system.

Finally, under a credit-based system (Option F2), the way in which **overachievement is rewarded and/or underachievement is penalised** needs to be identified. As noted above, a credit-based system risks potentially weakening the target, depending on the level of the reward. In work for T&E, Element Energy demonstrated that rewarding a 1% overachievement in the incentive with a 2 gCO_2/km reduction in the overall target (equivalent to around 4%) led to a substantial potential weakening even with the cap. Options for rewarding overachievement should deliver a much lower level of reward than this to avoid the risk of significant weakening. Consequently, an option that was taken forward was to reward a 1% overachievement of the LEV benchmark by a relaxation of a manufacturer's CO_2 target by 1%, but limit the level of the reward to 5% (Option R1). The inclusion of a similar level of penalty for underachievement, i.e. a penalty of 1% for an underachievement of 1%, would potentially increase the incentive for delivering the benchmark, and so is included as part of a second option under a credit-based system (Option R2). Consequently, the following two options for implementing the credit-based system were evaluated quantitatively:

- Reward a 1% overachievement in the LEV benchmark by a reduction in the manufacturer's overall CO_2 emissions target of 1%; level of reward limited to 5%.
- Reward a 1% overachievement ***and penalise a 1% underachievement*** in the LEV mandate by a reduction / ***increase*** in the manufacturer's overall CO_2 emissions target of 1%; level of reward limited to 5%.

5.1.4 Overview of scenarios and sensitivities modelled

The scenarios developed and modelled are listed in Table 5.1. The following elements are the same in all cases (unless otherwise indicated):

- Mandate/benchmark is based on the ***share*** of LEVs in the new car fleet.
- Each manufacturer has the ***same level*** of incentive.

Furthermore, under Option D2, where there is ***differentiation*** between different types of LEV, the following elements are the same in all cases:

- Count a LEV ***as a fraction*** of a ZEV depending on its CO_2 emissions, where a ZEV counts as one LEV and other LEVs as:

$$1 - \frac{CO_2 \text{ emissions of the LEV}}{\text{(Threshold used to define an LEV)}}$$

Scenarios were undertaken to explore the potential impact of setting an incentive at a higher level than indicated by the PRIMES-TREMOVE run for the CO_2 target level considered in order to identify the extent to which this would drive the uptake of xEVs under different cost assumptions. Twenty-seven scenarios were modelled – nine each with the overall target set according to the ***'low ambition'*** scenario (i.e. L-25-MNM), the ***'central ambition'*** scenario (C-25-MNM) and the ***'high ambition'*** scenario (H-25-MNM).

For nine scenarios (three for each of the three CO_2 target levels mentioned), the low battery costs were used (LxEV) and for the 18 others the very low battery cost assumptions (VLxEV). The rationale for considering these scenarios is that the presence of a strong regulatory incentive would help accelerate the investment in and deployment of xEVs, thus driving down battery costs relative to the 'central ambition' scenario in the absence of such an incentive. These scenarios are summarised in Table 5.1. The results relating to these scenarios based on PRIMES-TREMOVE modelling are discussed in Section 5.2.1 (see also Section 2.2 for a discussion of the practicalities in this regard).

Table 5.1: Overview of scenarios modelled

Scenario	LEV definition	Counting	Costs	Target implied by	LEV Mandate*
L2_15-LxEV	ZEV only	ZEV = 1; PHEV = 0	LxEV	L-25-MNM C-25-MNM H-25-MNM	15%
L3_25-LxEV	<50 g/km	ZEV = 1; PHEV < 1	LxEV	L-25-MNM C-25-MNM H-25-MNM	25%
L4_25-LxEV	<25 g/km	ZEV/PHEV = 1	LxEV	L-25-MNM C-25-MNM H-25-MNM	25%
L2_15-VLxEV	ZEV only	ZEV = 1; PHEV = 0	VLxEV	L-25-MNM C-25-MNM H-25-MNM	15%
L3_25-VLxEV	<50 g/km	ZEV = 1; PHEV < 1	VLxEV	L-25-MNM C-25-MNM H-25-MNM	25%
L4_25-VLxEV	<25 g/km	ZEV/PHEV = 1	VLxEV	L-25-MNM C-25-MNM H-25-MNM	25%
L2_20-VLxEV	ZEV only	ZEV = 1; PHEV = 0	VLxEV	L-25-MNM C-25-MNM	20%

Scenario	LEV definition	Counting	Costs	Target implied by	LEV Mandate*
				H-25-MNM	
L3_30-VLxEV	<50 g/km	ZEV = 1; PHEV < 1	VLxEV	L-25-MNM C-25-MNM H-25-MNM	30%
L4_30-VLxEV	<25 g/km	ZEV/PHEV = 1	VLxEV	L-25-MNM C-25-MNM H-25-MNM	30%

Note: * The LEV mandate includes the counting methodology.

Practically, the impacts of LEV incentives can only be explored in PRIMES-TREMOVE directly at LEV mandate levels greater than the LEV uptake rate for a given scenario without such mandates (otherwise the results are the same). Since the model does not include separate manufacturers, the effect of a credit-based / benchmark system cannot directly be explored, except for sensitivities on potential under- or over-achievement of the mandate (and consequent changes to overall CO_2 targets). A separate analysis is performed for this purpose and it is described in Section 5.2.2.

5.1.5 Other provisions for implementing LEV incentives

Several other points relating to the LEV incentive are also worth noting. For consistency, an incentive should be set for the same year(s) as the overall target(s) and the incentive should not necessarily apply to those manufacturers that benefit from a derogation from the emission targets. In the case of a mandate, i.e. Option F1, a system would need to be put in place to penalise those manufacturers that failed to deliver the incentive which should be equivalent to the existing 'excess emissions premiums'.

5.1.6 Implications for the quantitative analysis of impacts of LEV incentive options

Since only those options are considered where the mandate applies equally to all manufacturers, this could potentially result in a less than cost-optimal distribution of xEVs between different manufacturers. This has been modelled by an alternative xEV distribution scenario (i.e. that sets these xEV shares the same) in the distribution of effort analysis using the JRC DIONE model (discussed in earlier Section 2.3.1).

5.2 Fleet composition under different LEV incentive scenarios

This section reports on how the fleet composition changes under the different LEV incentive scenarios set out in Section 5.1.4 above.

This section presents the results of the modelling runs showing how the composition of the fleet varies under various LEV scenarios, and, in particular, how these incentivise the uptake of LEVs and ZEVs. Additionally, it considers the impact of the LEV mandates on the implied gCO_2/km target[26] for ICEVs and HEVs, relative to the implied target under the central scenario without a mandate (i.e. C-25 MNM).

For the sake of presenting the results, the scenarios are grouped into the following categories, as described in Section 5.1.4:

- Section 5.2.1: Main LEV mandate scenarios, as presented in earlier Table 5.1.
- Section 5.2.2: Scenarios exploring the credit-based / benchmark system, i.e. LEV1F and LEV1FL.

5.2.1 Main LEV mandate scenarios

The results of these scenarios for cars and LCVs, for those cases where the overall target was set in accordance with the ***'central ambition'*** scenario C-25-MNM are presented in Table 5.2 and Table 5.3.

[26] This refers to the maximum emission level of the vehicles concerned that would still allow meeting the overall fleet-wide CO_2 target.

The results of similar scenarios for cars and LCVs, relating to the situations where the overall target was set in accordance with the ***'low ambition'*** or ***'high ambition'*** scenarios are presented in Appendix 4, Tables Table A17 to Table A21.

Table 5.2: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for cars (where the overall target was set in accordance with the *'central ambition'* **scenario, i.e. C-25-MNM)**

Scenario	Summary	% in 2030				
		LEV Mandate (set)	ZEVs	PHEVs	Total xEVs	Change* in implied ICEV /HEV target gCO_2/km
C-25 MNM	No LEV incentive	n/a	9.0%	10.8%	19.8%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	14.6%	8.4%	23.0%	+4.9
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	16.1%	10.9%	27.0%	+10.7
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	20.0%	9.0%	29.0%	+14.4
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	16.2%	9.8%	26.0%	+8.5
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	18.1%	9.9%	28.0%	+11.9
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	20.1%	9.5%	29.6%	+14.6
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	19.9%	7.6%	27.5%	+11.6
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	21.9%	10.0%	31.9%	+19.0
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	25.9%	7.7%	33.6%	+22.9

Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario C-25 MNM.

Table 5.3: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for LCVs (where the overall target was set in accordance with the *'central ambition'* **scenario, i.e. C-25-MNM)**

Scenario	Summary	% in 2030				
		LEV Mandate (set)	ZEVs	PHEVs	Total xEVs	Change* in implied ICEV /HEV target gCO_2/km
C-25 MNM	No LEV incentive	n/a	3.7%	15.0%	18.7%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	14.9%	6.8%	21.7%	+9.4
-L4_25-LxEV	40/40; ZEV/PHEV = 1; low xEV costs	25%	8.5%	16.6%	25.1%	+14.0

Scenario	Summary	% in 2030				
		LEV Mandate (set)	ZEVs	PHEVs	Total xEVs	Change* in implied ICEV /HEV target gCO_2/km
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	23.9%	3.0%	26.9%	+23.8
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	15.0%	9.4%	24.4%	+14.5
-L4_25-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	25%	9.5%	15.7%	25.2%	+14.0
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	23.4%	4.6%	28.0%	+25.7
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	19.9%	5.6%	25.5%	+18.8
-L4_30-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	30%	14.5%	15.3%	29.8%	+25.8
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	29.3%	2.4%	31.7%	+35.9

Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario C-25 MNM.

The results show that setting a higher mandate increases the **proportion of new ZEVs that come on to the market**, both in absolute market share, and as a proportion of the total number of xEVs for both cars and LCVs. The mandates also increase the overall share of xEVs in the car and van fleet in 2030.

Compared to the respective scenario without a mandate, setting a high mandate generally decreases **the proportion of PHEVs that come on to the market**. The main exception for both cars and LCVs, is for mandate LEV4, under which the proportion of PHEVs coming onto the market increases under all of the various mandate/technology cost assumptions for the 'low ambition' scenario.

Overall, the higher ZEV uptake makes up for any decline in PHEV uptake, so that in all but one case the **total proportion of new xEVs** coming onto the market is higher (under all of the various mandate/technology cost assumptions) than if there was no mandate. Generally, **the implicit gCO_2/km target for ICEVs and HEVs was weakened** significantly less under LEV2 than under LEV3 and LEV4. This was the case under equivalent assumptions about the level of the mandate and about the costs of xEV technology, and applied equally to cars and LCVs.

5.2.2 Credit-based mechanism

In addition to the different LEV scenarios focusing on different mandates discussed earlier, variations were also undertaken to explore the effect of using a credit-based system instead of a LEV mandate, as described in Section 5.1.3 and 5.1.4. The results of these for cars are presented in Table 5.4 and for LCVs in Table 5.5. LEV1F and LEV1FL are the upper and lower bounds of the variation that might result from using a credit-based system, in an example where 2030 LEV benchmark of 12.5% for cars and 8.5% for vans are set.

Together LEV1F and LEV1FL illustrate the impacts of a two-way crediting system in which a 1% overachievement is rewarded with a 1% less stringent target, up to a maximum of 5%, while a 1% underachievement is penalised with a 1% more stringent target.

LEV1F demonstrates the effect of the maximum potential weakening of the overall CO_2 target if all manufacturers would over-achieve on the LEV benchmark and were thus rewarded with the maximum relaxation (of 5%) of their CO_2 target. On the other hand, LEV1FL demonstrates the maximum potential strengthening if all manufacturers were to underachieve on the LEV benchmark, and were thus penalised with a 3.5% more stringent target for the scenario as modelled.

For the purpose of the modelling the LEV1FL scenario, the maximum penalty (+3.5% CO_2 target) was calculated based on achieving the same LEV shares achieved under the central ambition scenario without LEV incentives (resulting in a 2% strengthening of the CO_2 target in 2025, and 3.5% in 2030) – i.e. resulting in the modelled mandate/benchmark in Table 5.4. Otherwise the parameters, including the thresholds and the way in which ZEVs and PHEVs are differentiated, are the same as in LEV1, which modelled the equivalent mandate.

Table 5.4: Impact of variations reflecting a credit-based system based on the LEV1 scenario on ZEV and PHEV uptake for cars

Scenario	Summary	% in 2030					Change* in implied ICEV /HEV target gCO_2/km
		Modelled mandate/ benchmark	ZEVs	PHEVs	Total xEVs	% of xEVs that are ZEVs	
LEV1 (-L1)	35/25; ZEV = 1; PHEV < 1	12.5%	11.7%	9.2%	20.9%	55.9%	+2.4
LEV1F (-L1F)	Credit-based = max bonus	17.5%	16.8%	5.6%	22.4%	75.1%	+8.8
LEV1FL (-L1FL)	Credit-based = max malus	9.0%	8.6%	10.9%	19.5%	44.1%	-3.3

Note: The implied ICEV/HEV target in the final column of the table is presented relative to the central scenario (i.e. C-25 MNM).

Table 5.5: Impact of variations reflecting a credit-based system based on the LEV1 scenario on ZEV and PHEV uptake for LCVs

Scenario	Summary	% in 2030					Change* in implied ICEV /HEV target gCO_2/km
		Modelled mandate/ benchmark	ZEVs	PHEVs	Total xEVs	% xEVs that are ZEVs	
LEV1 (-L1)	40/40; ZEV = 1; PHEV < 1	8.5%	7.2%	11.9%	19.1%	37.6%	+3.2
LEV1F (-L1F)	Credit-based = max bonus	13.5%	8.7%	10.0%	18.7%	46.7%	+5.4
LEV1FL (-L1FL)	Credit-based = max malus	5.5%	3.7%	16.0%	19.7%	18.7%	-0.5

Note: The implied ICEV/HEV target in the final column of the table is presented relative to the central scenario (i.e. C-25 MNM).

The results for LEV1F, as compared to LEV1, show that if manufacturers were to take full advantage of the credit-based system, there would be a significant shift in the car fleet towards ZEVs as the market share of ZEVs in 2030 increases by around 5% to 16.8%. For LCVs the increase is limited to only 1.5%, as the costs are relatively significantly higher than for PHEVs (versus fuel savings). However, this overachievement of the LEV benchmark would be accompanied by a weakening of the CO_2 target, meaning that ICEVs and HEVs could emit 6.4 gCO_2/km (cars) or 2.2 gCO_2/km (LCVs) more.

At the other extreme, the results for LEV1FL show that if manufacturers did not meet the LEV benchmark, and thus would need to comply with a stricter CO_2 target, there would be 3.1% fewer ZEV cars registered in 2030 and 3.5% fewer ZEV LCVs.

5.2.3 Summary

The specific design criteria for potential LEV incentives has a strong influence on the effectiveness of a given level of mandate – i.e. to achieve the same level of effect in terms of increasing the uptake of xEVs, different mandate levels would have to be set depending on the design criteria chosen.

Overall, mandates tend to increase the proportion of ZEVs coming onto the market, weaken the implicit gCO_2/km target for ICEVs and HEVs and generally decrease the proportion of PHEVs compared to the situation without a mandate. The elements of the mandate that have been put in place to provide more of an incentive to ZEVs, i.e. the setting of the thresholds (with stricter thresholds effectively excluding some PHEVs from qualification) and the way in which the values of a non-ZEV credit are determined, appear to work for both cars and LCVs.

The LEV mandates considered appear to have the highest impact under the 'low ambition' scenario for cars, and under the 'high ambition' scenario for LCVs. A higher mandate level tends to increase the proportion of ZEVs coming onto the market, reduce the proportion of PHEVs, increase the proportion of new xEVs that are ZEVs and weaken the implicit ICEV/HEV gCO_2/km target.

If the costs of xEV technology proved to be 'very low', there would be a significant increase in the proportion of ZEVs coming onto the market.

5.3 Impacts of LEV incentives

This section reports on the quantitative assessment of the environmental and economic impacts of various LEV incentive scenarios.

5.3.1 Assessing the effectiveness in reducing TTW and WTW emissions of CO_2

5.3.1.1 Main LEV mandate scenarios

The results of the model runs (in Table 5.6 and Table 5.7 for central ambition) indicate that, compared to the C-25-MNM scenario, the scenarios with an additional LEV incentive deliver greater reductions in TTW GHG emissions by 2030 relative to 2005. This is not always the case for WTW emissions, as for some scenarios there is a slightly larger increase in the WTT emissions associated with the production of the electricity and hydrogen that outweigh the TTW trend (previously discussed in earlier Section 3.2.1.2). WTW savings are greatest for ZEV mandates (-L2), and the least for scenarios with the 50g/km LEV threshold (-L4) for scenarios that feature the same assumptions on costs, regardless of the level of ambition. Of the scenarios including mandates, the LEV2_15-VLxEV scenario delivers the highest WTW emission reduction in 2030 under the Central level of ambition framework, despite featuring less ambitious LEV mandates than the other options modelled.

All the scenarios that are run with the most optimistic cost assumptions for advanced vehicle technologies, deliver consistently the highest emission reduction in 2030. This is discussed also further in Section 5.3.1.3.

Additional tables summarising equivalent results for the low and high ambition LEV incentive options are provided in Appendix 4.

5.3.1.2 Credit-based system

LEV1FL delivers, a higher emission reduction in 2030 versus 2005 levels compared to the LEV1F scenario (30.1% in the former compared to 29.5% in the latter scenario). The LEV1FL scenario introduces much more efficient conventional diesel and gasoline powertrains in the market as a result of the tightened CO_2 emission target.

In contrast, the market share of conventional powertrains is lower in the LEV1F scenario; but on average these vehicles have higher emissions as the CO_2 target is effectively relaxed for them. This will lead to a lower emission reduction in 2030 (at levels equal to the case of C-25-MNM scenario) despite the large uptake of LEVs.

5.3.1.3 Sensitivities around the cost assumption

The TTW and WTW CO_2 emission reduction trajectory of the sensitivities with low and very low costs of advanced technologies (LxEV and VLxEV, respectively) show increased reductions versus 2005 and the baseline. This is contributed to by both an increased deployment of LEVs and a relatively lower increase in ICE and HEV powertrain gCO_2/km emissions compared to the central cost case vs the base scenario without LEV incentives.

5.3.1.4 Concluding remarks

The implementation of LEV mandates is found to lead to further reductions in the TTW GHG emissions, compared to the case where the same CO_2 emission target is set without any mandates. However, particularly for the LEV3 (25 g/km level threshold for cars, 40 g/km for LCVs) and LEV4 (50g/km level threshold) scenarios, the WTW GHG emissions reductions are worsened. Model findings indicate that, regardless of the type of the LEV mandate, a reduction in the future costs associated with xEV, as might be stimulated by a strong incentive, which could lead to further emission reduction in 2030.

Table 5.6: Impact of LEV scenarios for credit based systems on TTW and WTW CO_2 for the main LEV mandate scenarios and sensitivities

Scenario	Summary	2030 Car LEV Mandate	Reduction versus 2005	Reduction versus REF	
			TTW CO_2	TTW CO_2	WTW CO_2
C-25-MNM	No mandate	N/A	29.5%	6.7%	6.0%
C-25-MNM-L1	35/25; ZEV = 1; PHEV < 1	12.5%	29.7%	6.9%	5.7%
C-25-MNM-L1F	As for -L1, with credit-based – max weakening	17.5%	29.5%	6.6%	4.8%
C-25-MNM-L1FL	As for -L1, with credit-based – max tightening	9.0%	30.1%	7.4%	6.8%

Table 5.7: Impact of LEV scenarios with higher mandates on TTW and WTW CO_2 (where the overall target was set in accordance with the *'central ambition'* scenario, i.e. C-25-MNM)

Scenario	Summary	2030 Car LEV Mandate	Reduction versus 2005	Reduction versus REF	
			TTW CO_2	TTW CO_2	WTW CO_2
C-25-MNM	No LEV incentive, Central costs	n/a	29.5%	6.7%	6.0%
C-25-MNM-LxEV	Low xEV costs	n/a	30.1%	7.5%	6.4%
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	30.6%	8.2%	6.2%
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	30.1%	7.5%	5.5%
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	30.6%	8.2%	5.3%
C-25-MNM-VLxEV	***Very*** low xEV costs	n/a	31.1%	8.8%	7.4%
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	31.7%	9.6%	6.9%
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	31.1%	8.8%	6.3%
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	31.6%	9.4%	5.9%

Scenario	Summary	2030 Car LEV Mandate	Reduction versus 2005	Reduction versus REF	
			TTW CO_2	TTW CO_2	WTW CO_2
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	31.3%	9.1%	7.2%
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	31.1%	8.8%	6.8%
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	31.4%	9.2%	6.6%

5.3.2 Assessment of other impacts

A summary is provided in Table 5.8 and Table 5.9 of the impacts of the different LEV incentive scenarios and sensitivities in terms of transport externalities for the whole LDV vehicle fleet (i.e. including air quality pollutant emissions, noise, congestion and accidents). A summary is provided in the following subsections on the observed impacts.

5.3.2.1 Main LEV mandate scenarios

Table 5.9 summarises the resulting impacts on transport externalities for the scenarios targeting higher LEV incentive levels. The results show that all the scenarios quantified under the Central level of Ambition deliver a greater reduction in the external costs of the transport system compared to the C-25-MNM scenario. This clearly depicts the positive impacts of the higher penetration of advanced powertrains under the LEV mandate configuration. The reduction is, driven by the higher reduction in the external costs from air pollution and noise. This finding is also identified under the Low Ambition target on CO_2 emissions. The highest reduction takes place in the -L3-25_VLxEV scenario (2.2% reduction in 2030 relative to Baseline), while the reduction in the external costs in the L-25-MNM scenario is 1.1% in 2030, due to the much lower market uptake of LEVs in this particular scenario. The picture changes when comparing the scenarios under the High Level of Ambition, where the changes in the external costs are not so profound. Again, the overall decrease in the external costs is driven by the market uptake of LEVs and ZEVs. The external costs in the H-25-MNM-VLxEV scenario with 'Very Low' technology assumptions and without mandates delivers the lowest reduction in the external costs, mainly influenced by increased external costs from congestion.

5.3.2.2 Credit-based mechanism

Table 5.8 shows that the C-25-MNM-L1F scenario (flexible mandate with over-achievement of LEV target, weaker CO_2 targets) delivers a significant reduction in the external costs when compared to the C-25-MNM-L1FL scenario (flexible mandate with under-achievement of LEV target, stronger CO_2 targets). The changes in the external costs are again driven by the different degree of market penetration of LEVs and ZEVs, as occur due to the mandates, in the C-25-MNM-L1F scenario. The latter shows a reduction in external costs in transport by 1.8% in 2030 relative to the Baseline scenario, while the C-25-MNM-L1FL scenario exhibits a reduction by 1.4% at the same timeframe.

5.3.2.3 Concluding remarks

The implementation of LEV mandates is found to contribute to a further reduction in the external costs related to noise and air pollution, thanks to the increased market share of LEVs and more importantly ZEVs. The increased costs of the transport system due to higher capital needed to purchase such vehicles may lead to a reduction in passenger transport activity, which entails though a reduction in external costs from congestion. However, the lower operational costs of LEVs may counteract this effect to a degree also.

Table 5.8: Impact of LEV scenarios for credit based systems on externalities for the main LEV mandate scenarios and sensitivities

Scenario	Summary	2030 LEV Mandate	% reduction in 2030 relative to baseline (REF)						
			Acci-dents	Noise	Cong-estion	Air Pollution	WTW GHG	Total Cost	Total (excl. GHG costs)*
C-25-MNM	No mandate	N/A	0.0%	-4.9%	-0.2%	-5.8%	-6.1%	**-1.4%**	**-0.5%**
C-25-MNM-L1	35/25; ZEV = 1; PHEV < 1	12.5%	-0.2%	-8.1%	-0.4%	-9.3%	-5.7%	**-1.7%**	**-0.9%**
C-25-MNM-L1F	As for -L1, with credit-based – max weakening	17.5%	-0.6%	-9.3%	-0.6%	-10.7%	-4.6%	**-1.8%**	**-1.3%**
C-25-MNM-L1FL	As for -L1, with credit-based – max tightening	9.0%	0.1%	-3.8%	-0.1%	-4.8%	-7.0%	**-1.4%**	**-0.3%**

Table 5.9: Impact of LEV scenarios on externalities (where the overall target was set in accordance with the *'central ambition'* scenario, i.e. C-25-MNM)

Scenario	Summary	2030 LEV Mandate	% reduction in 2030 relative to baseline (REF)						
			Acci-dents	Noise	Cong-estion	Air Pollution	WTW GHG	Total Cost	Total (excl. GHG costs)*
C-25-MNM	No LEV incentive, Central costs	n/a	0.0%	-4.9%	-0.2%	-5.8%	-6.1%	**-1.4%**	**-0.5%**
C-25-MNM-LxEV	Low xEV costs	n/a	0.3%	-6.7%	0.1%	-7.3%	-6.4%	**-1.4%**	**-0.4%**
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	0.0%	-9.0%	-0.1%	-10.6%	-6.1%	**-1.7%**	**-0.8%**
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	-0.2%	-13.1%	-0.3%	-14.3%	-5.3%	**-1.9%**	**-1.2%**
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	-0.6%	-13.8%	-0.6%	-15.0%	-4.9%	**-2.1%**	**-1.5%**
C-25-MNM-VLxEV	***Very*** low xEV costs	n/a	0.5%	-9.8%	0.3%	-9.5%	-7.4%	**-1.5%**	**-0.4%**
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	-0.1%	-12.9%	-0.1%	-14.0%	-6.8%	**-2.0%**	**-1.0%**
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	-0.1%	-16.0%	-0.1%	-16.8%	-5.8%	**-2.0%**	**-1.2%**
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	-0.7%	-16.5%	-0.4%	-17.0%	-5.1%	**-2.2%**	**-1.6%**
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	0.3%	-11.2%	0.1%	-11.5%	-7.2%	**-1.7%**	**-0.6%**
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	0.2%	-14.3%	0.1%	-15.2%	-6.6%	**-1.9%**	**-1.0%**
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	-0.1%	-14.2%	-0.1%	-14.6%	-6.4%	**-2.0%**	**-1.1%**

Notes: *Total of all external costs, excluding GHG costs.

5.3.3 Assessment of net costs for manufacturers and society

5.3.3.1 Impacts on average vehicle manufacturing costs and Total Cost of Ownership (TCO)

A total cost of ownership (TCO) analysis for an average vehicle was conducted for the different LEV incentive options.

Table A22 to Table A27 in Appendix 4 provide a detailed summary of the results with regards to the impacts on TCO for society (excluding externalities) and end-users (for first and second end-users).

For the LEV mandate scenarios, there are net benefits (relative to the base case with central costs) in all the scenarios / perspectives for 2030, and for all end-user perspectives in 2025; however, there are net costs for the societal perspective for the -L3 options for cars and for LCVs in 2025. In general, for passenger cars the net benefits are highest for the ZEV mandate (i.e. -L2 scenarios), and lowest for the mandates with 50g/km LEV threshold and variable PHEV credit (i.e. -L3 scenarios).

For LCVs, the TCO benefits are greatest for the mandates with 40g/km LEV threshold (-L4 scenarios).

In xEV cost sensitivities, where it was instead assumed there was no reduction in the xEV costs as a result of the LEV incentive (i.e. comparing to a baseline with either low or very low xEV costs), in all cases for cars the ZEV mandate (-L2) options resulted in only a relatively small reduction in net benefits. However, in the worst cases for the other options, these benefits (vs an equivalent xEV cost case) were more significantly reduced.

This is also illustrated in Figure 5.2 and Figure 5.3 below for the central ambition case.

Figure 5.2: Summary of the average vehicle Total Cost of Ownership (TCO) of different options for the LEV incentive options with higher mandate levels for passenger cars compared to the baseline scenario for societal and end-user perspectives, Central ambition CO_2 targets

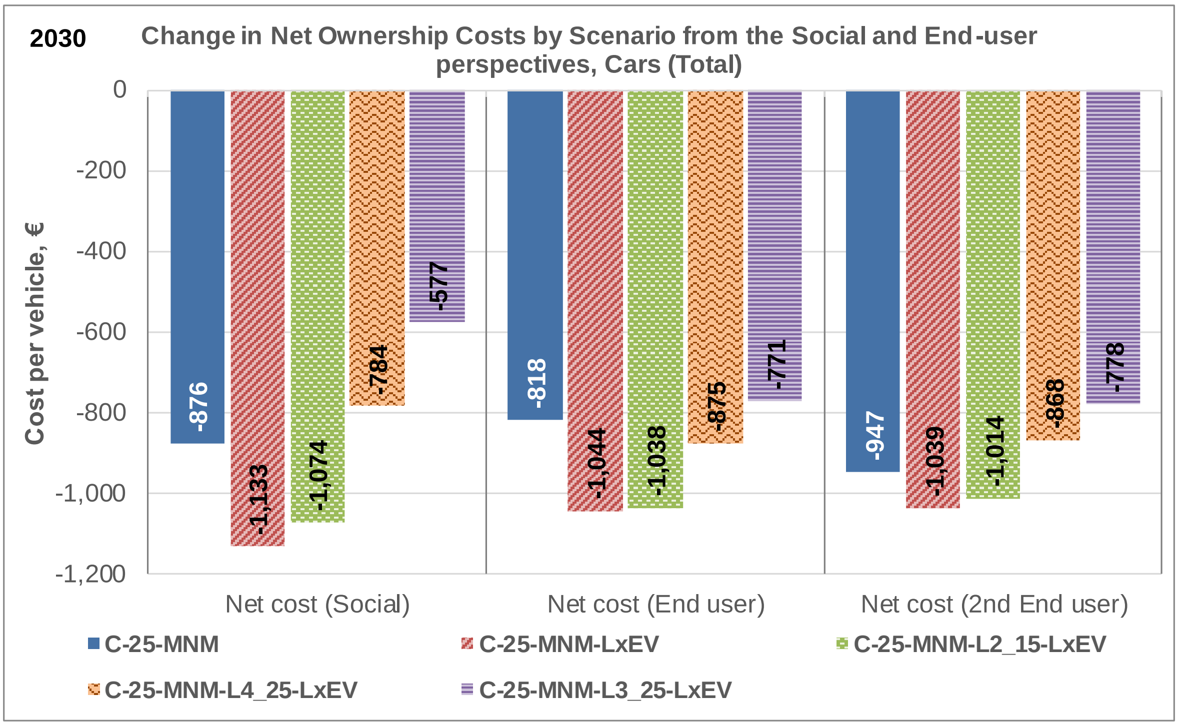
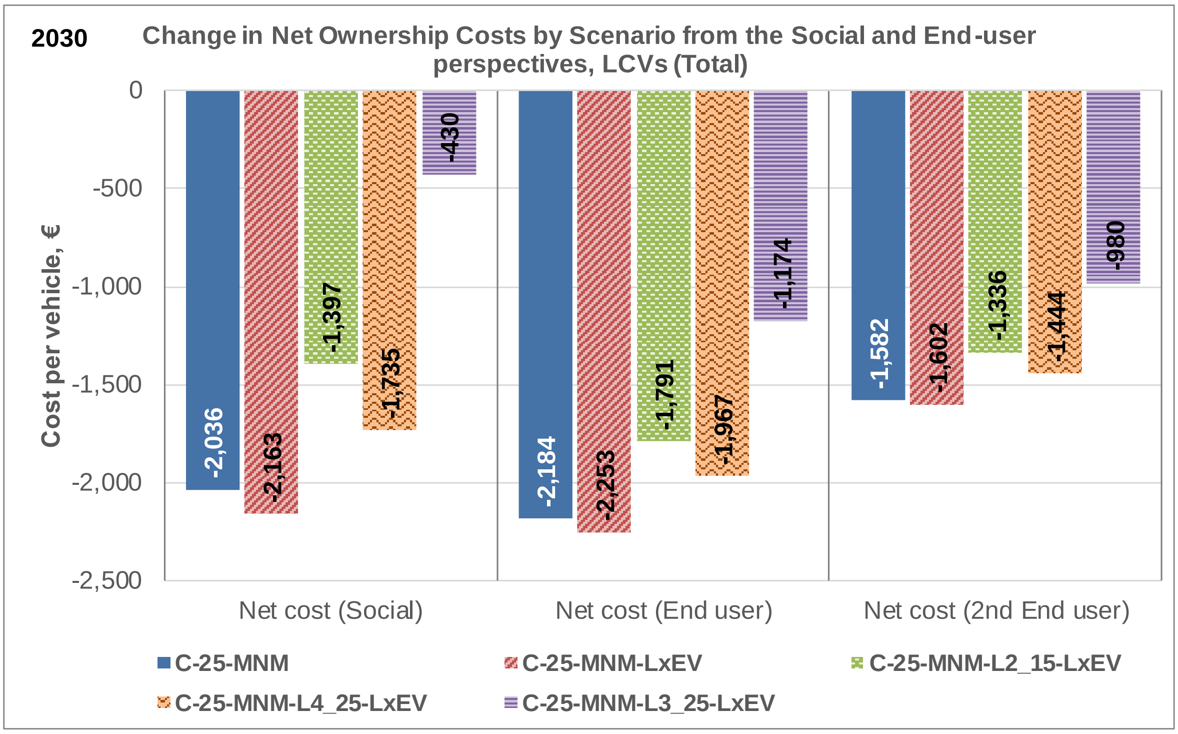


Figure 5.3: Summary of the average vehicle Total Cost of Ownership (TCO) of different options for the LEV incentive options with higher mandate levels for LCVs compared to the baseline scenario for societal and end-user perspectives, Central ambition CO_2 targets



For **Central Ambition**, the results of the TCO analysis for passenger cars also show that if the introduction of strong mandates would result in lower xEV costs relative the equivalent case without the mandates (e.g. from Central to Low xEV costs, or from Low xEV costs to Very Low xEV costs), this would in many cases result in a greater net TCO benefit from both the societal and end-user perspectives. For ZEV mandates (-L2), there were found to be improvements in almost all cases. For the 25g/km LEV threshold mandates (-L4), some options resulted in poorer TCO savings versus the no mandate case (i.e. for all cases for 2025; for a 25% mandate and low xEV costs: societal and second end-users, and also just for second end-users for very low xEV costs with a 30% mandate). For the mandate options with 50g/km LEV thresholds (-L3), in most cases there were poorer TCO savings versus the no mandate case. Comparing options with Very Low xEV costs to the equivalent no mandate scenario with Central costs results in greater TCO benefits in all but the most extreme mandate cases for the mandate options with 25g/km and 50g/km LEV thresholds.

For **Low Ambition**, the results of the TCO analysis for passenger cars showed that there are in general only TCO improvements relative to the no mandate case for the ZEV mandate options with Very Low xEV costs in comparison to the Central cost case with no mandate. Whilst there were still net TCO benefits compared to the baseline (REF) scenario, in almost all other cases these were poorer than for the no mandate cases. As for Central Ambition, net benefits were generally greatest/best for ZEV mandate scenarios, and poorest for the mandates with 50g/km LEV threshold.

In some cases, for both the Central and particularly Low Ambition scenarios with Very Low xEV costs, the average vehicle net manufacturing costs were found to be *lower* than for the baseline (REF) scenario for passenger cars. This is most likely a result of the much lower xEV costs, combined with fewer improvements to conventional ICE and hybrid powertrain vehicles necessary to comply with the overall CO_2 target.

For **High Ambition**, the results for passenger cars showed net TCO improvements (i.e. lower costs) across all LEV mandate options for all cases. The costs for the 15/25/25 LEV mandates for L2/L4/L3 scenario options were also in general very similar to each other. This is most likely because the shares of xEVs deployed under high ambition CO_2 targets was in most cases not much less than the high ambition mandates investigated. For the most ambitious LEV mandate levels, as under Central and

Low Ambition, net benefits were generally highest for ZEV mandate scenarios, and lowest for the mandates with 50g/km LEV threshold.

For LCVs, in all cases for the higher mandate levels the net TCO was higher (i.e. lower net benefits vs the baseline/REF scenario) than the comparable scenario with Central xEV costs.

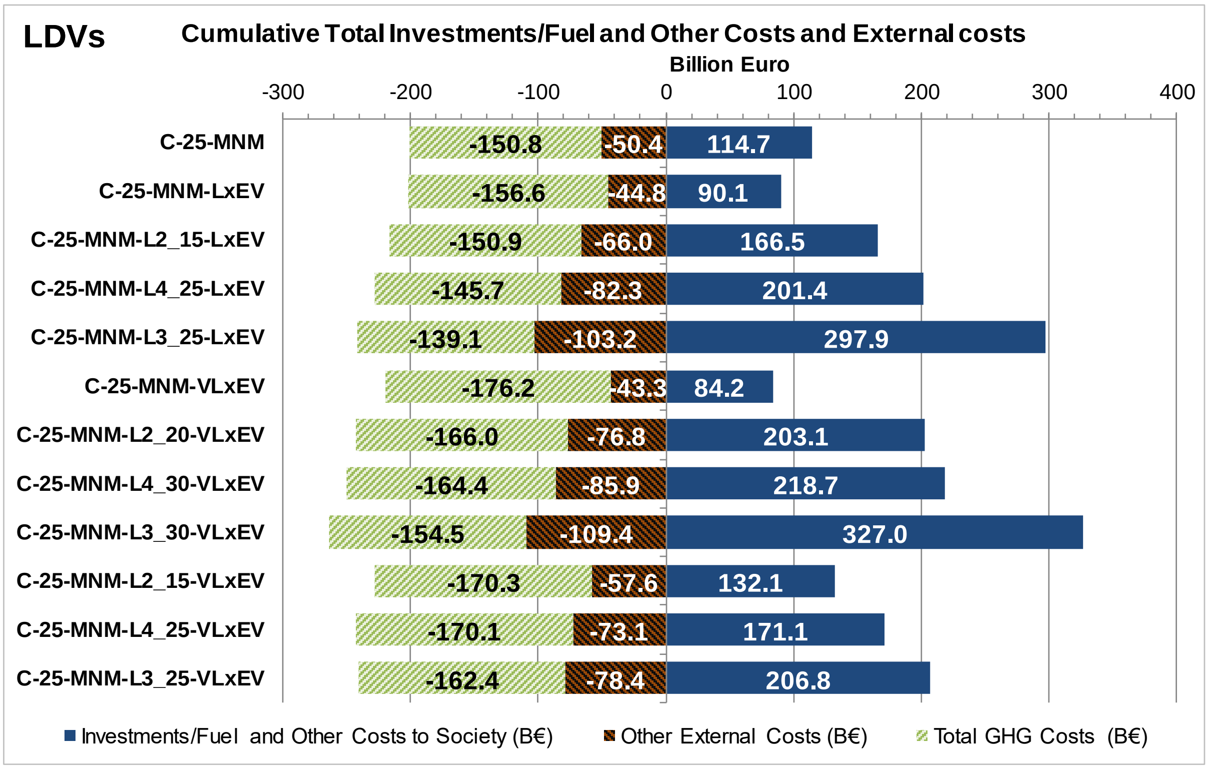
5.3.3.2 Cost-benefit analysis of system-level PRIMES-TREMOVE results

An assessment of the cumulative impacts of the direct and indirect cost components and net societal cost-benefit analysis for a range of central ambition LEV mandate scenarios is presented in Figure 5.4 below (for central GHG costs) (based on (Ricardo-AEA, 2014), see also Appendix 4).

The figure shows that the system-level (whole LDV fleet/stock) costs associated with the different LEV incentive design options follow a similar pattern to the TCO analysis findings (in Section 5.3.3.1), i.e. that the net benefits are highest for the ZEV mandate (-L2 scenarios) and lowest for the mandates with 50g/km LEV thresholds (-L3 scenarios). In all LEV mandate scenario cases, the direct costs are higher (with lower cost-effectiveness on a €/tCO_2 reduction basis) than for the basic central ambition case with default xEV costs, even for the -VLxEV cost cases. For only the ZEV mandate at 15% in 2030 and very low battery cost assumptions are the net societal benefits greater than the basic central ambition case (C-25-MNM). The situation is similar also for other ambition levels.

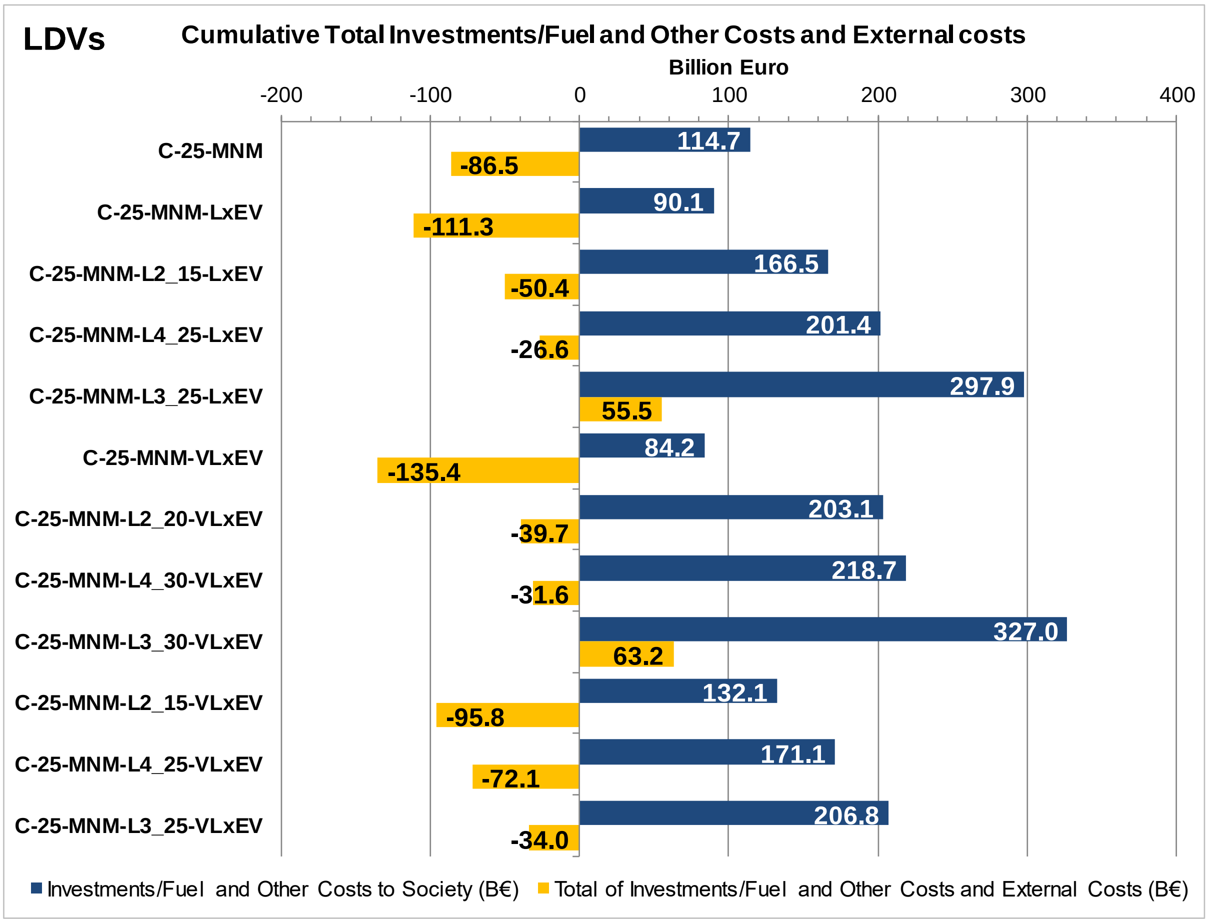
More information is also provided in Appendix 4.

Figure 5.4: Summary of the cost-benefit analysis for a range of higher ambition LEV incentive scenarios for the central CO_2 target ambition compared to the baseline scenario (central GHG costs)



Notes: "Investments/Fuel and Other Costs" = includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

Figure 5.4: Summary of the cost-benefit analysis for a range of higher ambition LEV incentive scenarios for the central CO2 target ambition compared to the baseline scenario (central GHG costs) (continued)



Notes: "Investments/Fuel and Other Costs" = includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

5.3.3.3 Concluding remarks

The implementation of the LEV mandates promotes the market uptake of LEVs and ZEVs. On the assumption that the costs of the advanced powertrains would decrease at a faster pace as a result, it was found that reduced xEV costs would increase the cost-effectiveness of the LEV mandate scenarios. The analysis found that if a policy that sets LEV thresholds is to be pursued, then setting optimistic targets on the LEV thresholds is likely to reduce costs and be more efficient for the transport system with minimum costs/greatest benefits for a ZEV incentive, and the least for incentives defined by the 50 gCO_2/km criterion.

From the perspective of the total cost of ownership (TCO) of an average passenger car, the ZEV mandate options in general showed the greatest net TCO benefits, and the options with mandate with 50g/km LEV threshold (plus graduated credits for PHEVs) showed the lowest net TCO benefits.

For the Central and High CO_2 target ambition levels, assuming reduced xEV costs, LEV mandates would result in an increase in overall TCO benefits. For the Low Ambition CO_2 target levels, and in case of no further xEV cost reductions, TCO benefits were eroded compared to equivalent 'no mandate' scenarios.

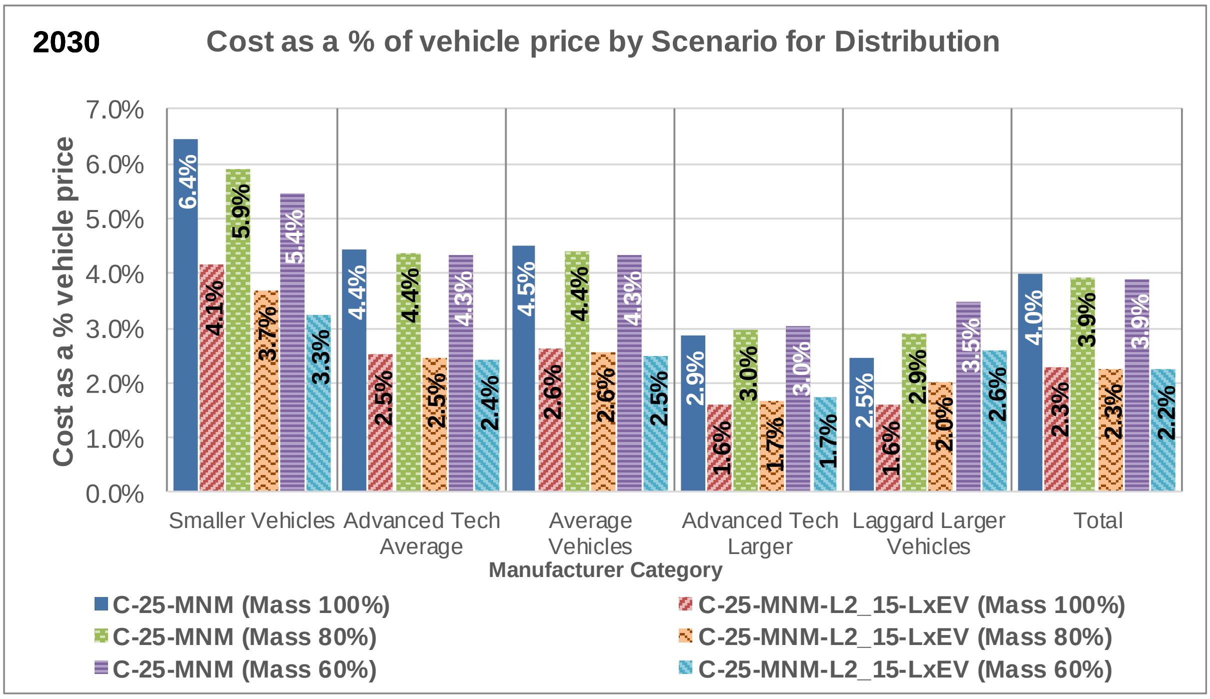
For LCVs, whilst there were still net TCO benefits compared to the baseline (REF) scenario, the introduction of LEV mandates was found to increase the TCO compared to the equivalent case with no mandate, even for Very Low xEV cost assumptions.

5.3.4 Assessment of impacts on competition between manufacturers

Section 4.2.2.3 explored the potential impact of alternative xEV distribution options on distribution of effort between manufacturers and found that for the same level of CO_2 ambition, the presence of a moderate mandate (i.e. all manufacturers had to provide similar shares of xEVs) did not have a significant impact for the quantitative analysis.

When considering the quantified impacts for distribution of effort for various LEV mandate scenario options, no significant variation was found in the trends in comparison with equivalent scenarios with no mandate present. An example is presented in Figure 5.5 below for passenger cars and a ZEV mandate; the overall findings are similar for different LEV mandate options, and for LCVs.

Figure 5.5: Increased 2030 manufacturing costs relative to the baseline for passenger cars for different mass utility distribution slopes, values presented as relative (%) to average prices, comparison of central ambition scenario with no mandate and an equivalent scenario with a ZEV mandate and low xEV costs



From a qualitative perspective, the definition of the mandate and the level it is set at would be expected to have impacts on different manufacturers that might be more variable based on their market offering (in particular its diversity) and their relative preparedness/existing deployment of xEV powertrains.

For example, certain manufacturers are more advanced than others in their plans for xEVs. Currently at least, the types of xEVs being offered by different OEMs is varied, with certain manufacturers having a greater focus on BEVs, whilst others have a larger share of PHEVs. Whilst this might be expected to influence their relative ability to meet different types of mandate, looking at OEM model plans in the period up to 2025 suggests that most OEMs have a relatively balanced portfolio of PHEV and BEV model launch plans. Overall, xEV models are expected to cover more than half of the models responsible for the vast majority of sales in the EU by 2025.

However, as also discussed earlier, certain car manufacturers do appear to be further behind than others in xEV development. It seems likely that the achievement of higher mandate levels for manufacturers that have a high share of smaller / budget vehicle sales, where margins are particularly tight and the relative increase in prices would be most significant, could be more difficult in the absence of flexibilities, such as trading. In contrast, for manufacturers of larger premium vehicles electrification costs may comprise a smaller proportion of their overall costs, and they are likely to be in a better position to offset these/sell the additional benefits of electrification to their customers. In these larger/premium segments, the relative savings from the elimination (or downsizing) of conventional powertrain components is also likely to be greatest (although offset to an extent by likely greater customer electric range requirements). In addition, cross-over and SUV segments are also more easily able to incorporate battery packs for electrified powertrains into their designs.

For LCV manufacturers, there are market segments (such as parcel delivery and utilities' vehicle fleets) that have usage profiles that are likely to lend themselves well to electric vehicles. However, other users (particularly those more sensitive to up-front costs) may be more difficult to reach, and the sector is more conservative / cost-sensitive compared to passenger cars. The LCV sector also has significantly lower volumes to offset development costs (less relevant for smaller LCV segments sharing car-derived architectures), and is further behind in terms of model availability/experience. It seems also likely that manufacturers of larger LCVs might also be more constrained than those who sell more smaller vehicles, as there are concerns that BEV variants of the largest models may move beyond the N1 segment regulatory cut-off kerb weight of 2610 kg (and therefore would not contribute to meeting the target). However, we have analysed the registrations and kerb weights of LCVs in the EEA's CO_2 monitoring database for the Large LCV segment (where the average kerb weight of a conventional diesel van is ~2 tonnes). This analysis suggests that the numbers of such larger model BEVs falling beyond this limit would account for a smaller share of the overall total registrations, even for longer-range BEVs, given the advances in battery energy density both in recent years and that expected in the 2020-2030 period. In addition, PHEV options would be less constrained in this respect.

5.3.5 Distribution of impacts across income groups (social equity)

In the LEV scenarios quantified, an increasing number of low income households are likely to purchase electric vehicles that will be available in the second-hand car market. As a result, those households would realise significant savings in the annual fuel bill. Whether such households end up in a better or worse position will depend on the price differential of the second hand electric car compared to a second hand conventional car that would be purchased in the Reference scenario.

Currently, most electric vehicles lose value at a faster rate than for conventional technologies, however this is likely a function of unfamiliarity in the marketplace and concerns over battery degradation/electric range at this early stage of their deployment. It is expected that this profile is likely to stabilise as more evidence becomes available on the robustness of EV batteries, electric ranges increase and as the consumer becomes more familiar with the technology.

Whilst historically, it was considered that there might be a need to replace the battery of the car within its lifetime, more recent evidence (and manufacturer warranties, e.g. (Fleetcarma, 2017)) suggests that batteries are now generally expected to last the full life of the vehicle, except perhaps in very extreme usage cases or environmental conditions. In fact, it has been suggested that the battery might last even longer than most of the rest of the vehicle, and could enjoy a second life in energy storage applications once the vehicle has been scrapped.

The more optimistic cost curves 'VLxEV', used in some of the LEV scenarios, decrease the financial burden to the consumers and are expected to also drive down the prices of the second hand electric vehicles, to the benefit of the low income households.

The earlier analysis (in Section 5.3.3.1) has also shown that impacts of LEV incentives on total cost of ownership (TCO) for second end-users are similar to those for first end-users.

Overall, it therefore seems likely that increased LEV deployment through the addition of incentives for such vehicles will lead to net benefits for lower income groups, however there are key uncertainties (i.e. relating to overall xEV costs influenced by battery prices) that provide uncertainties in this area.

5.3.6 Conclusions from analysis for LEV incentives

The main conclusions that may be drawn from the analysis are summarised below. A side-by-side summary comparison is also presented in Table 5.10 below, grouped according to the Effectiveness, Efficiency, Coherence and Proportionality criteria for Impact Assessments outlined by the Better Regulation Guidelines:

- The specific design criteria for potential LEV incentives have a strong influence on the effectiveness of a given level of LEV mandate or crediting system – i.e. to achieve the same level of effect in terms of increasing the uptake of xEVs, different incentive levels would have to be set depending on the design criteria chosen.
- Overall, all the design options considered tend to increase the proportion of zero emission vehicles (ZEVs) coming onto the market, weaken the implicit gCO_2/km target for conventional ICEVs and hybrids.
- A one-way crediting system providing for a less strict CO_2 target when exceeding an LEV objective threshold, without a penalty for not meeting that threshold, may result in a weakening of the effectiveness in terms of both TTW and WTW CO_2 reductions in the case where all OEM overachieve the benchmark in a significant way. A two-way crediting system could result in a net outcome either with greater or lower CO_2 reductions. In both cases a cap on the extent to which the CO_2 target may be relaxed will help to minimise such effects.
- LEV incentive options are found to contribute to a further reduction in the external costs related to noise and air pollution, especially thanks to the increased market share of ZEVs.
- Stronger LEV incentives may facilitate more rapid xEV cost reductions; for the options investigated, this resulted in net benefits for the cumulative cost-effectiveness indicator and total cost of ownership (TCO) for certain scenarios for passenger cars. However, for scenarios with similar xEV costs assumptions, the implementation of the LEV mandates was found to worsen these metrics, relative to scenarios without them. Cost-effectiveness and net TCO benefits were found to be highest for ZEV mandates.
- For LCVs, whilst there were still net TCO benefits compared to the baseline (REF) scenario, the introduction of the LEV mandates considered was found to increase the TCO compared to the equivalent case with no mandate, even for very low xEV cost assumptions.
- From the perspective of competition between manufacturers, there were no significant quantitative distribution of effort implications identified in the analysis resulting from the LEV incentive options explored. However, some manufacturers may currently be in a better position than others to deliver higher shares of xEVs. In the absence of flexibility mechanisms (such as trading), some manufacturers would likely struggle to meet high LEV mandates or benchmarks.
- Manufacturers of mostly smaller LCVs (which are often car-derived or share technology with cars) would likely find it easier to fulfil LEV mandates than manufacturers that sell more larger LCVs that may not so easily share technology (e.g. where this is shared with smaller HDVs, rather than LDVs) and where heavier model BEV versions could fall beyond the kerb weight limit for the regulations (out of scope).
- Simulating an increase in domestic production of BEVs and PHEVs through appropriate LEV incentives could help EU car manufacturers reduce costs and increase their international competitiveness. China, in particular, is pushing the xEV agenda hard, so advancing EU manufacturers offerings in this area will likely help them more effectively compete.

Table 5.10: Comparison of impacts of the prioritised options for LEV incentives in terms of achieving key objectives

Principal areas	Sub-areas	Option 1 No Mandate	Option 2 ZEV Mandate	Option 3 LEV Mandate: 25/40g/km Qualification	Option 4 LEV Mandate: 50g/km Qualification, Variable credit
Effectiveness					
1. Criterion:					
Ensure the regulations are consistent with meeting GHG reduction objectives	2030 objectives, versus 2005	As per Ambition level	Improves TTW GHG, and also WTW GHG assuming xEV cost reduction resulting from the mandates.	Improves TTW GHG, and also WTW GHG assuming xEV cost reduction resulting from the mandates, but fewer WTW GHG savings versus Option 2.	Improves TTW GHG, but fewer WTW GHG savings versus Option 2 and 3.
2. Criterion:					
Increasing the uptake of LEVs		As per Ambition level	All the options investigated were effective in increasing the share of LEVs, with higher shares for higher mandates. ZEVs were more favoured (vs no mandate shares) in all cases		
3. Criterion:					
Avoidance of undesired competitiveness impacts on the EU automotive sector	Distribution equity between OEMs	N/A	The definition and level of mandate is expected to impact manufacturers to different degrees depending on their market offerings (in particular diversity) and relative preparedness for xEV deployment. In addition, manufacturers of smaller/budget cars are likely to find it more difficult to comply with higher mandate levels in the absence of flexibility mechanisms (such as trading). In contrast, manufacturers of predominantly larger LCVs may find mandates more challenging as these platforms have less potential to share platforms/technology with cars, and are restricted by upper reference mass limits.		
	Impacts on first movers	N/A	No negative impacts identified.		
4. Criterion:					
Ensure the impacts of the regulations are socially equitable	Employment; social inclusion, distributional impacts; public health.	As per Ambition level	Overall, it seems likely that increased LEV deployment through the addition of incentives for such vehicles will lead to net benefits for lower income groups, however there are key uncertainties (i.e. relating to overall xEV costs influenced by battery prices) that provide uncertainties in this area. According to the average new vehicle TCO analysis for second end users (most relevant for lower income households), benefits are likely to be greatest for Option 2 and least for Option 4.		

Principal areas	Sub-areas	Option 1 No Mandate	Option 2 ZEV Mandate	Option 3 LEV Mandate: 25/40g/km Qualification	Option 4 LEV Mandate: 50g/km Qualification, Variable credit
Efficiency					
5. Criterion:					
Ensure the environmental benefits of the LDV CO_2 targets are achieved cost-effectively	a) Total Cost of Ownership	As per Ambition level	Assuming the inclusion of LEV mandates leads to cost reductions for xEVs vs no mandate, average new car TCO net savings/benefits are generally increased/greatest for Option 2 with reduced benefits for Option 3, and in most cases significantly reduced TCO savings (vs no mandate) for Option 4. For LCVs, the net TCO savings were greater than the no mandate situation in all cases, even assuming very low xEV cost assumptions.		
	b) Net Cost /Benefit, with externalities	As per Ambition level	In all LEV mandate cases, overall fleet-level net costs including externalities increased versus the no mandate situation. The costs are increased the least for Option 2, and the most for Option 4 (with net increase in costs with externalities in some cases vs net savings for no mandate).		
6. Criterion:					
Ensure the impacts on the European economy are proportionate	Impacts on GDP, GVA, employment, trade, etc.	As per Ambition level	Anticipated benefits for competitiveness of EU manufacturers due to more rapid learning on xEVs (in particular helping compete with manufacturers in other regions like China which is pushing hard towards xEVs). Net impacts on employment (and GDP) is uncertain, and depends on the degree to which battery manufacture is conducted within the EU (i.e. simply battery pack assembly vs also cell production).		
Coherence					
7. Criterion:					
Regulations are consistent other environmental objectives	Air quality and noise	As per Ambition level	Significantly increases external cost savings vs no mandates (from 0.5% savings for central ambition with no mandate, up to 1.0% savings for 15% mandate for cars).	Very significantly increases external cost savings vs no mandates – up to twice the improvement over Option 2 compared to no mandate.	Very significantly increases external cost savings vs no mandates – up to twice the improvement over Option 2 compared to no mandate.
8. Criterion:					
Regulations are consistent energy-related objectives	Improve energy efficiency, reduce overall consumption	As per Ambition level	Impacts are similar to those for WTW emissions vs no mandate situation for a given ambition level.		

Principal areas	Sub-areas	Option 1 No Mandate	Option 2 ZEV Mandate	Option 3 LEV Mandate: 25/40g/km Qualification	Option 4 LEV Mandate: 50g/km Qualification, Variable credit
Proportionality					
9. Criterion:					
Minimise where possible the administrative burden and costs for SMEs of the Regulations.		As for current regulation.			
Other considerations					
Explicit barriers and limitations	Barriers to implementation	N/A	Manufacturers are likely to be resistant to the introduction of significant LEV mandates by themselves. Flexible mandates would increase monitoring complexity and administrative costs, and potentially decrease certainty on the net outcome (increasing the risk of lower than expected GHG savings).		
Improvement of ICEV efficiency		N/A	Weakening of efficiency improvements for conventional/hybrid powertrains (vs equivalent ambition with no LEV mandates) was least for Option 2 (ZEV mandate) and greatest for Option 4. This weakening also increases for higher LEV mandate levels.		

Notes: The selection of different options is assumed to be negligible for the impact areas excluded from the table above.

6 Options for flexibility mechanisms

6.1 Overview of flexibility mechanisms

The aim of this sub-task was to explore the added value of selected additional flexibility mechanisms, which could be applied to facilitate compliance with the emission targets. The two flexibilities assessed were:

- *Derogations for niche- and small-volume manufacturers:* this allows for the setting of alternative targets for manufacturers with smaller sales in the EU.
- *Off-cycle technologies/eco-innovations:* allow manufacturers to claim and use credits for the deployment of novel technologies that are verified to achieve real-world emissions savings that do not show up on the regulatory tests.

6.1.1 Derogations for niche- and small-volume manufacturers

As they stand, the LDV CO_2 Regulations have the following derogations (Ricardo-AEA and TEPR, 2015):

- Derogation for ‘niche’ car manufacturers, i.e. those manufacturers responsible for between 10,000 and 300,000 new cars that are registered each year. These manufacturers can apply to the Commission to have a reduction target set as a specified percentage (45% in 2021) of their respective 2007 CO_2 emissions.
- Derogation for ‘small volume’ car and LCV manufacturers, i.e. those manufacturers that are responsible each year for fewer than 10,000 new cars registered, or fewer than 22,000 new LCVs registered. These manufacturers must propose a CO_2 reduction target that is consistent with their production potential, which needs to be approved by the Commission.
- *De minimis* exemption, i.e. those manufacturers responsible for fewer than 1,000 new cars or new LCVs registered each year. These manufacturers do not have a CO_2 target.

The niche derogation was not included in the Commission’s original proposal for the Regulation. The small volume derogation was originally justified to provide an additional flexibility for these manufacturers, which otherwise might find it costly to deliver the targets as a result of their limited range of vehicles. The *de minimis* exemption was added in 2014 in order to reduce the burdens on SMEs.

The evaluation of the Regulations concluded that these derogations had had only a relatively small weakening effect on the overall targets, but that the niche derogation had the potential for further weakening, as not all of the eligible manufacturers had made use of it yet (Ricardo-AEA and TEPR, 2015).

As the reasons for introducing the ‘small volume’ and *de minimis* exemption are still largely valid, the analysis undertaken for this report focused on the niche derogation.

According to the annual monitoring reports from the EEA ((EEA, 2014b), (EEA, 2015), (EEA, 2016)), since 2013 only four manufacturers have used this derogation, namely:

1. Jaguar Land Rover (JLR);
2. Mazda;
3. Suzuki;
4. Subaru.

It is worth noting that Volvo, Honda and Mitsubishi have been eligible to make use of the niche derogation, but have chosen not to. Of the four manufacturers that make use of the niche derogation, only one has a significant operation (i.e. vehicle development and production) within the EU (i.e. JLR, owned by the Indian company Tata Motors). These manufacturers have few or no hybrid or xEV vehicle models on the market, though all have announced that they will be bringing electric cars to the market in the next few years. This suggests that the current approach is not sufficiently incentivising these manufacturers to improve their performance (). All except Subaru have new registrations in excess of 150,000 vehicles per year, and the number of their vehicles that are being registered each year is increasing. Therefore, the impact of including/excluding such a derogation has been explored as a sensitivity to accompany the main analysis.

The quantitative assessment of the impacts of the flexibilities modelled and the subsequent recommendations for prioritisation are presented in Section 6.2 below.

6.1.2 Accounting for off-cycle improvements (eco-innovations)

A sensitivity scenario was developed to assess the potential impacts of including technologies that improve off-cycle emissions performance, e.g. those covered via eco-innovations in the current EU regulation within the accounting for CO_2 regulations. This was done by applying the corresponding cost-curves that include these technical options to the central ambition scenario. This sensitivity, and its implications, is further discussed in Section 6.2 below.

6.2 Impacts of flexibility mechanisms

This section provides a summary of the additional mainly quantitative analysis of the different flexibility mechanisms investigated.

6.2.1 Niche manufacturer derogation and accounting for off-cycle technologies

6.2.1.1 Definition of the sensitivity scenarios

Two separate sensitivity scenarios for flexibility options were explored using PRIMES-TREMOVE modelling:

a) C-25-MNM-NMD: Exploring the potential impacts of a niche manufacturer derogation for cars.
b) C-25-MNM-OFF: Exploring the potential impacts of including accounting for 'off-cycle technologies'.

The sensitivity scenario exploring the potential to include a niche manufacturer derogation assumes that those passenger car manufacturers that would currently qualify for the niche manufacturer derogation are also given future derogated targets for 2025/2030 based on their current CO_2 targets for 2021 and the overall level of CO_2 reduction ambition. In the central ambition case analysed (C-25-MNM-NMD) their future targets would be defined by a 30% reduction on their current 2021 targets, rather than those calculated using one of the distribution of effort options, i.e. via a utility-function (i.e. mass or footprint), or the uniform target approach for setting manufacturer-level CO_2 targets. The scenario also assumes that there are no future changes in the current market shares of those manufacturers.

The objective of the sensitivity on the potential for accounting for off-cycle technologies (C-25-MNM-OFF) was to investigate the maximum potential impacts/net benefits that could be accrued from incorporating accounting for the real-world fuel efficiency/CO_2 reduction benefits of technologies that do not have an impact on the results from regulatory type-approval testing.

This sensitivity scenario utilises an alternative set of cost-curves produced from the wider set of technology cost and performance data, i.e. including the 'off-cycle' technologies, as developed under our previous work for DG CLIMA (Ricardo Energy & Environment et al, 2016). *Note*: at the moment, not all off cycle technologies are or could be eligible as eco-innovations under the currently applicable legal definitions/constraints, either under NEDC or WLTP, as also discussed in Section 6.2.1.7 below.

6.2.1.2 Assessing the effectiveness in reducing TTW and WTW emissions of CO_2

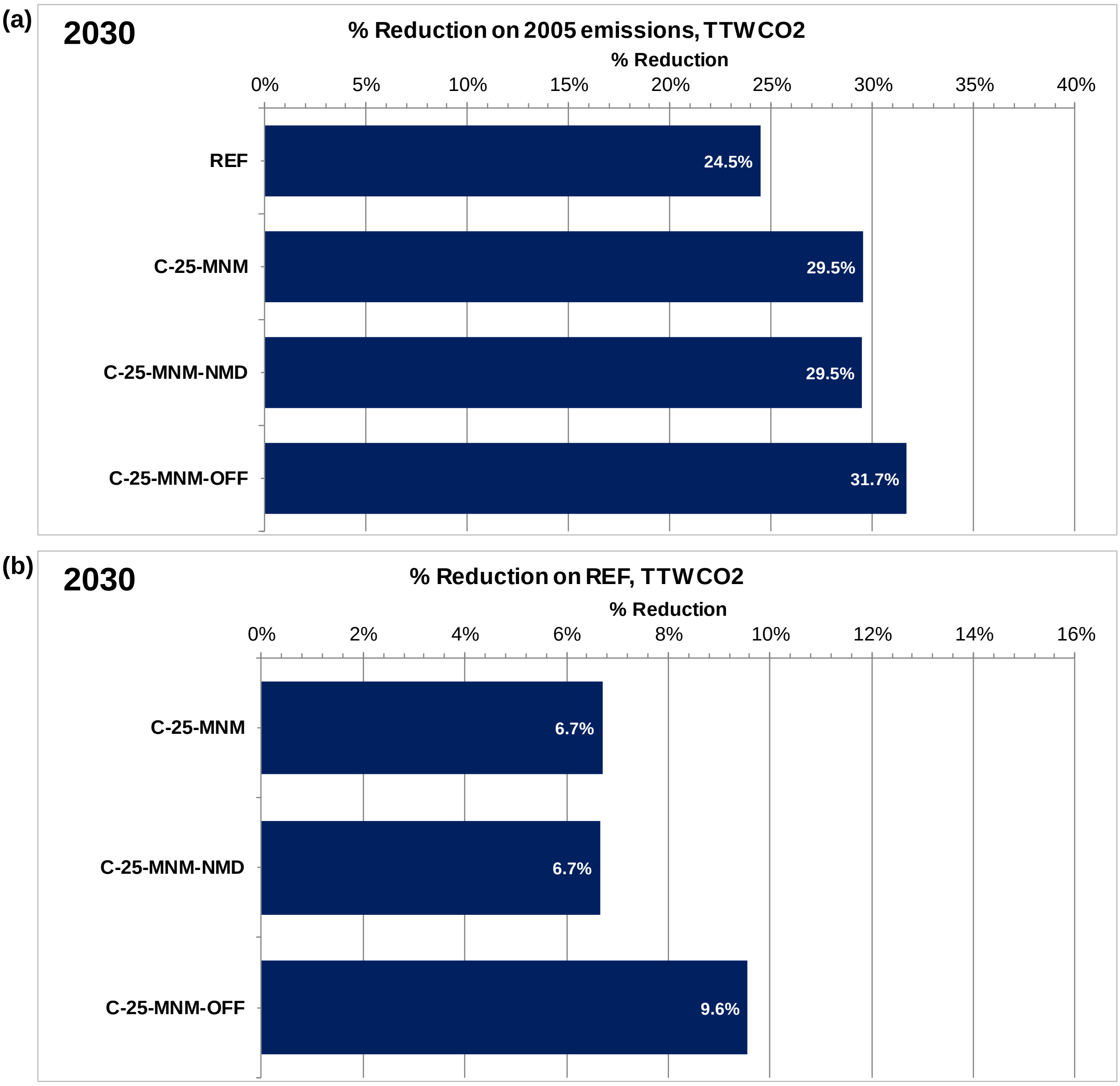
The quantification of the C-25-MNM scenario with the niche manufacturer derogation shows only marginal changes in the overall TTW CO_2 emissions in the transport sector in 2030. The emissions reduce at almost an equivalent rate between the C-25-MNM and the C-25-MNM-NMD compared to 2005 (-29.5%). In absolute terms, the C-25-MNM-NMD results in a marginal increase of 0.3 Mt CO2 emissions in 2030 compared to the C-25-MNM scenario.

The C-25-MNM-OFF scenario that includes the accounting of the off-cycle improvements depicts a significant positive impact in terms of reduction of the total transport CO_2 emissions by 2030. The latter decrease by an additional 2.2 p.p. compared to the C-25-MNM scenario that does not include accounting for the off-cycle technologies. The modified input on the techno-economic assumptions drives the significant reduction in both the real-world TTW and WTW CO_2 emissions.

There is a significant increase in real-world (RW) emissions reduction vs test-cycle at reduced cost for cost-curves including all technologies with the potential to reduce off-cycle (i.e. real-world) CO_2 emissions. This option also has potential to mitigate for the risk of an increasing WLTP-RW gap in the future also, since the credits for off-cycle technological options would be based on an assessment of their real-world performance.

The impacts observed are proportionate also for WTW GHG emissions.

Figure 6.1: CO_2 emission reduction from LDVs for sensitivities on the car niche manufacturer derogation and accounting for off-cycle technologies, (a) relative to 2005, (b) relative to the baseline scenario



6.2.1.3 Assessment of other impacts

Marginal changes are identified when comparing the external costs in transport between the C-25-MNM-NMD and the C-25-MNM scenarios, as the niche manufacturer derogation is not expected to "distort" the picture set in the C-25-MNM scenario to a significant degree. Both scenarios depict almost an identical reduction in the total external costs (0.5% in 2030) relative to the Baseline scenario.

The C-25-MNM-OFF scenario shows an *increase* in the total transport external costs compared to the Baseline scenario by 0.2% in 2030. This increase is driven mainly by the external costs from congestion. The latter increase is due to an increase in passenger transport activity of cars linked to the modified cost curves related to the efficiency improvement possibilities of technologies that decrease the unit cost of transportation by car. Indeed, the efficiency improvement possibility is much cheaper under this framework of assumptions and consumers opt to purchase more efficient car options (in the real-world context) that otherwise would be more capital intensive (e.g. in the C-25-MNM scenario).

Overall energy consumption reductions are also improved for the C-25-MNM-OFF scenario, in proportion to the TTW GHG emissions savings, with the overall reduction versus 2007 baseline projection increasing from 25.1% in the central case to 27.2% in the C-25-MNM-OFF scenario.

Table 6.1: Change in external costs of other impacts from transport – niche derogation and off-cycle technology sensitivities, million Euro

	REF	C-25-MNM	C-25-MNM-NMD	C-25-MNM-OFF
Million Euro				
Accidents	77,376	77,403	77,416	77,827
Noise	11,415	10,852	10,864	11,018
Congestion	192,233	191,928	191,949	193,007
Air Pollution	9,052	8,527	8,537	8,669
Total	**290,075**	**288,710**	**288,767**	**290,520**
% Difference to REF				
Accidents		0.0%	0.1%	0.6%
Noise		-4.9%	-4.8%	-3.5%
Congestion		-0.2%	-0.1%	0.4%
Air Pollution		-5.8%	-5.7%	-4.2%
Total		**-0.5%**	**-0.5%**	**0.2%**

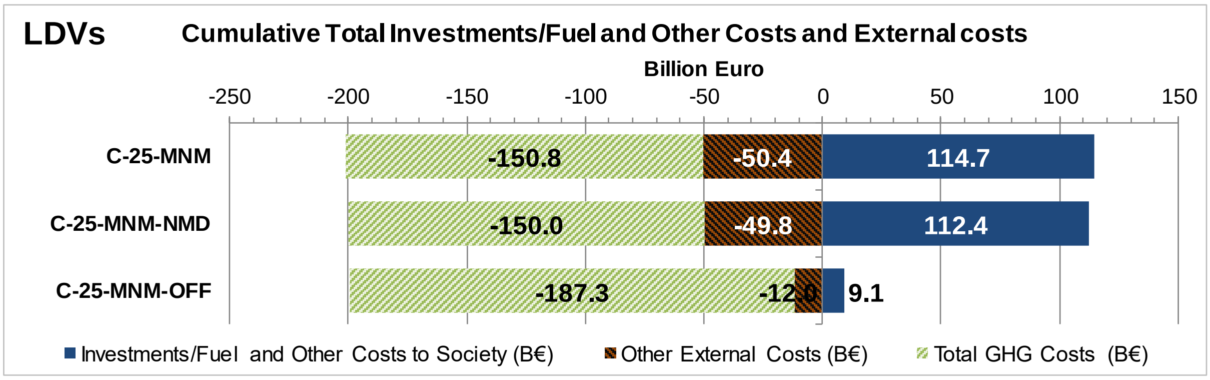
6.2.1.4 Cost-benefit analysis of system-level PRIMES-TREMOVE results

An assessment of the cumulative impacts of the direct and indirect cost components and net societal cost-benefit analysis for sensitivities on niche derogation and accounting for off-cycle technology is presented in Figure 6.2 below (for central GHG costs) (based on (Ricardo-AEA, 2014), see also Appendix 4).

The figure shows that the system-level (whole LDV fleet) direct and external costs are not significantly affected for the niche-manufacturer derogation sensitivity (C-25-MNM-NMD). However, for the C-25-MNM-OFF scenario, the direct costs are very significantly reduced and net societal benefits greater by more than double than the basic central ambition case (C-25-MNM).

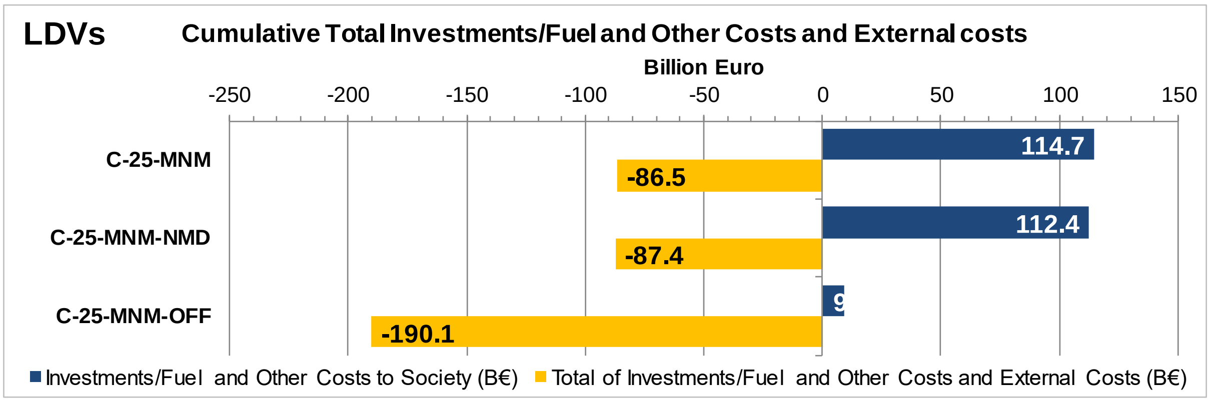
More information is provided in Appendix 4 on this methodology, together with a more detailed breakdown of the different components.

Figure 6.2: Summary of the cost-benefit analysis for sensitivities on niche derogation and accounting for off-cycle technology for the central CO_2 target ambition compared to the baseline scenario (central GHG costs)



Notes: "Investments/Fuel and Other Costs" includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

Figure 6.2: Summary of the cost-benefit analysis for sensitivities on niche derogation and accounting for off-cycle technology for the central CO2 target ambition compared to the baseline scenario (central GHG costs) (continued)



Notes: "Investments/Fuel and Other Costs" includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "Other External Costs" includes air quality pollutant emissions, noise, accidents and congestion.

6.2.1.5 Assessment of impacts on competition between manufacturers

No quantitative analysis was performed on the impacts on competition between manufacturers for the niche manufacturer derogation and off-cycle technology sensitivities for this study. The potential impacts have been explored qualitatively in previous analysis for DG CLIMA by (Ricardo-AEA and TEPR, 2015) and (CE Delft et al., 2017).

For the niche manufacturer derogation, previous analysis of the current regulations concluded that there are larger risks (compared to the small volume derogations) of reduced effectiveness and market distortions (i.e. with unfair distributional impacts across manufacturers). The current upper threshold of 300,000 car registrations per year is relatively high. At least some of the manufactures between 150,000 and 300,000 per year in the EU are competing with larger manufacturers in certain sales segments, rather than with other niche manufacturers. In addition, at least some of these are also major global manufacturers that simply have relatively small sales in the EU. Continuing the niche derogation at the current levels/sales cut-off point therefore might result in a distortion of the market and may provide new entrants in the EU market a competitive advantage. One option suggested by (CE Delft et al., 2017) would be for such derogations to be based upon a global sales criterion, rather than on EU sales.

Currently, the competitive distortion may be rather small, as larger niche manufacturers (such as Honda and Volvo) have not applied for the derogation so far (Ricardo-AEA and TEPR, 2015). However, this situation could change in the future, particularly with the tightening of CO_2 targets post-2020. In addition, the attractiveness (or not) of utilising a derogation (if available) would also be affected by the distribution of effort option adopted. Removing entirely the current derogation runs the risk of some of those manufacturers previously derogated having a much steeper CO_2 reduction profile, compared to other manufacturers, which could significantly impact on cost and competitiveness, and their ability to make improvements over the relevant period. However, the earlier DoE analysis (presented in Section 3.2.4) has also shown that the costs for laggard larger vehicle manufacturers is expected to be lower in relation to their current average market price than for other types of manufacturers.

Continuing to include a derogation for niche manufacturers, but linking the future reduction objectives to the current 2021 derogated targets and same level of overall ambition/CO_2 reduction by 2030 could provide a level of consistency to reduce the likelihood of significant negative consequences post-2020 for niche manufacturers. In addition, changing the method for defining the volume threshold or lowering it could also be an option to further reduce the risk of potential market distortion.

For the option to reward off-cycle emission reductions, no significant competitiveness impacts have been identified in this study. Previous analysis in (CE Delft et al., 2017) has, however, suggested that there may be small competitive advantages for European manufacturers (defined as ACEA members).

6.2.1.6 Conclusions for the flexibility on continuing the niche manufacturers derogation for cars

The derogations provided to niche car manufacturers have so far been found to have very small impacts on the effectiveness of the current regulations in terms of CO_2 reductions. The potential for negative impacts in this area in the future has been shown to be minimal if future targets for such manufacturers were to be set in line with the overall ambition for reduction between 2021 and 2030. However, the derogation has some drawbacks in terms of competitive neutrality, in particular if it would be taken up by larger manufacturers qualifying for them. To mitigate for more significant competitiveness impacts (and other negative consequences) in the future, removing the derogation, amending the qualifying threshold to be set based on global sales levels, or reducing the threshold could be useful options to consider. However, it is noted that the former option would require further analysis to define suitable lower and upper limits for global sales.

6.2.1.7 Conclusions for the flexibilities on off-cycle technologies (eco-innovations)

The analysis has shown that the cost-effectiveness (and overall CO_2 reduction effectiveness) is significantly enhanced by the inclusion of rewards/credits for off-cycle technologies. The current approach in the Regulations is to reward some of these technologies through eco-innovation credits. There is also currently a cap in the overall credit for eco-innovations, which is significantly lower than the CO_2 reduction potential for off-cycle technologies identified in (Ricardo Energy & Environment et al, 2016). To reduce the administrative burden, and increase the potential application (and benefits) of such technical options, the main options to consider (also in combination) include:

- Extending the current definition of technologies that could be considered for eco-innovations;
- Increase the current cap and reduce the qualifying threshold for CO_2 reduction;
- Allow the use of default credits for specific technologies that have well-defined real-world CO_2 saving potential (e.g. as is currently already done in the US).

Careful consideration of the setting of appropriate credits should be made to avoid the risk of reducing the effectiveness of the regulation. For example, these could be set at conservative levels with the option to increase the credit where validated evidence of an OEM-specific solution exceeding this benefit is provided – i.e. similar to the approach for eco-innovations.

6.2.2 Conclusions for flexibility mechanisms

The main conclusions that may be drawn from the analysis are summarised below.

- *Small Volume and 'de minimis' derogations:* Continuing the derogations for small volume manufacturers (SVM) would have extremely small impacts on the overall effectiveness of the regulations, while avoiding significant negative competitiveness implications for such OEMs otherwise.
- *Niche Manufacturer Derogation:* Whilst unlikely to result in a very significant reduction in the overall effectiveness of the regulations, there would be significant competitiveness risks for retaining the current approach unchanged. These (together with impacts on effectiveness) could be mitigated through a combination of: (a) setting targets relative to the 2021 derogated targets and consistent with the overall ambition level, and (b) amending the qualifying criteria to reduce the upper sales limit, or setting an alternative definition based on global sales.
- *Accounting for off-cycle technologies:* Clear and significant potential economic and CO_2 reduction benefits have been established through the inclusion of rewards for off-cycle technologies.

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Appendices

Appendix 1: Discussion Paper – Analysis and discussion on LEV incentives

Appendix 2: NEDC-WLTP and WLTP-RW conversion factors by powertrain type and vehicle segment

Appendix 3: Updated operation and maintenance costs used in the analysis of impacts on TCO

Appendix 4: Additional results and data tables

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A1 Appendix 1: Discussion Paper – Analysis and discussion on LEV incentives

A1.1 Need for incentivising LEVs

First, it is important to be clear about the rationale for considering the introduction of a Low Emission Vehicles (LEV) incentive in the legislation. As the objective of the Regulations is to reduce (tailpipe) CO_2 emissions from new cars and light commercial vehicles (LCVs), an additional incentive for LEVs should also work towards this objective. Consideration is being given to the inclusion of additional LEV incentives, as LEVs have an important role to play in delivering CO_2 reductions, particularly in the longer-term, but are not currently being introduced onto the market at the scale needed.

In principle, one could question the need for an additional incentive that aims to trigger a higher uptake of LEVs in the case where the fleet-wide CO_2 target is sufficiently stringent and cannot be met cost-effectively by relying solely on conventional (internal combustion engine) vehicles. This by itself should be a strong incentive for LEVs and has the advantage that it is fully technology neutral, does not affect the stringency of the overall CO_2 target, does not incur any additional administrative burden and has no additional impacts on the distribution of effort or costs faced by manufacturers.

In case of opting for an additional LEV incentive, its set up should be assessed against the following criteria, i.e. the extent to which the scheme would:

- Contribute to the objective of the Regulations, i.e. reducing tailpipe CO_2 emissions from new light-duty vehicles.
- Ensure that CO_2 reductions are delivered in the real world.
- Incentivise the deployment of vehicles having the potential to emit less CO_2 (both during the test and in real world) than comparable vehicles on the market today and which will provide benefits for the longer term emissions reductions and decarbonisation goals.
- Be technology neutral.
- Be based on robust data.

Vehicles that could usefully be encouraged should have a significant potential contribution to reducing the CO_2 emissions of the new car and LCV fleet, and the incentive should help to overcome barriers to their market uptake. The types of vehicle most relevant in this respect are:

- Battery electric vehicles (BEVs), as these have zero tailpipe CO_2 emissions and their market uptake has been limited so far. The benefit in terms of WTW CO_2 emissions of BEVs over ICEVs will improve over time, as the carbon intensity of electricity production declines.
- Fuel cell electric vehicles (FCEVs) using hydrogen, as these also have zero tailpipe CO_2 emissions and their market uptake has been limited so far. They will be beneficial with respect to WTW emissions as long as hydrogen is produced from low carbon sources.
- Plug-in hybrid electric vehicles (PHEVs) with sufficiently “low” tailpipe CO_2 emissions. For this type of vehicle, it has to be considered that their actual performance on the road is strongly influenced by consumer behaviour (charging behaviour in particular).

Of these, BEVs and FCEVs can be considered to be zero emission vehicles (ZEVs) as they have no tailpipe CO_2 emissions.

A1.2 Elements to a potential regulatory approach for incentivising LEVs

There are different elements to a potential regulatory approach for incentivising LEVs. The approach to the full definition of the options to be assessed consists of two steps:

1) The definition of an LEV, including the criteria to be used and the appropriate thresholds.
2) The extent to which there is differentiation between different LEVs.
3) How the incentive might work in practice, including:

i. Form of the incentive, i.e. mandate or credit-based.
ii. The value of the mandate or benchmark.
iii. How to apply the incentive.
iv. To what extent and how to reward over-achievement / penalise under-achievement under a credit-based system.

Each of these is discussed in turn, below.

The assessment below has been undertaken with passenger cars in mind. Consideration is given to where the assessment would be different for LCVs.

A1.2.1 Defining an LEV

The definition of an LEV covers the criteria and the thresholds to be used. These elements are covered below.

A1.2.1.1 The criterion for defining an LEV

An LEV could be defined using different criteria, the pros and cons of which are summarised in the following Table 7.1.

Table 7.1: Options for the criterion for defining an LEV

Options for the criterion (C)		Pros	Cons
C1	CO_2 emissions (tank to wheel)	• Same metric as the targets • Technology neutral • Already reported, familiar and clear, so data are relatively robust	• Concerns over gap between PHEV type approval emissions and real world emissions (e.g. due to charging behaviour)
C2	Zero emission range	• Provides an incentive to increase the zero emission range of LEVs	• For PHEVs, concerns over gap between type approval zero emission range and real world zero emission mileage undertaken (e.g. due to charging behaviour) • For ZEVs, this approach might exclude vehicles with a lower range that could in reality be very useful for city trips and so would be worthwhile incentivising • Less technology neutral (as it explicitly requires electrification) • While data on the zero emission range of vehicles will be available (measured under WLTP, recorded in certificate of conformity), they are not currently collated under the LDV CO_2 Regulations, so are potentially less robust
C3	Energy consumption	• Would provide an incentive to improve the efficiency of electric engines and fuel cells • Technology neutral	• Introduces complexity for the comparison of different powertrains • Less direct link to tailpipe CO_2 reductions • Risks incentivising vehicles which are not expected to have benefits towards the longer term GHG objectives • While data on the consumption of hydrogen for FCEVs are available (measured under WLTP, recorded in certificate of conformity), they are not currently collated under the LDV CO_2 Regulations, so are potentially less robust

Discussion: Options C2 and C3 were considered, as they both indicate a characteristic of an LEV that relates to its performance and which, at least in the long-term, would benefit from being improved. The zero emission range of an LEV is important for its consumer acceptance, while in the longer-term the energy consumption of all LEVs will need to be as low as possible in a low carbon, energy efficient economy. However, Option C1 performs better than both of these alternatives in the assessment for an LEV incentive in the context of a 2030 target. Option C1 is technologically neutral and relies on the same metric as used for the target setting. In addition, data on CO_2 emissions will also be used for the overall target, and so is subject to scrutiny in this context and so is considered to be reasonably robust. As it is also familiar to manufacturers, regulators and consumers, it would provide a consistent message. The novelty of Options C2 and C3 would introduce another variable to consider for regulatory purposes, for which the data has not been subject to as much scrutiny. Option C2 has the further disadvantage that it is less technologically neutral as only BEVs, FCEVs and PHEVs have a zero emission range. Also, this would not incentivise LEVs with a low range, although those can be beneficially used in zero-emission mode as city cars. While Option C3 is technologically neutral, the way in which energy is consumed differs between different powertrains, and so this option would introduce complexity as to how best to compare different powertrains. All options considered have a potential issue with PHEVs, as their use in practice, and so their CO_2 emissions, zero emission range and energy consumption, are highly dependent on the way in which they are used, particularly the type of trips taken and the user's charging behaviour.

Proposal: Take forward only Option C1.

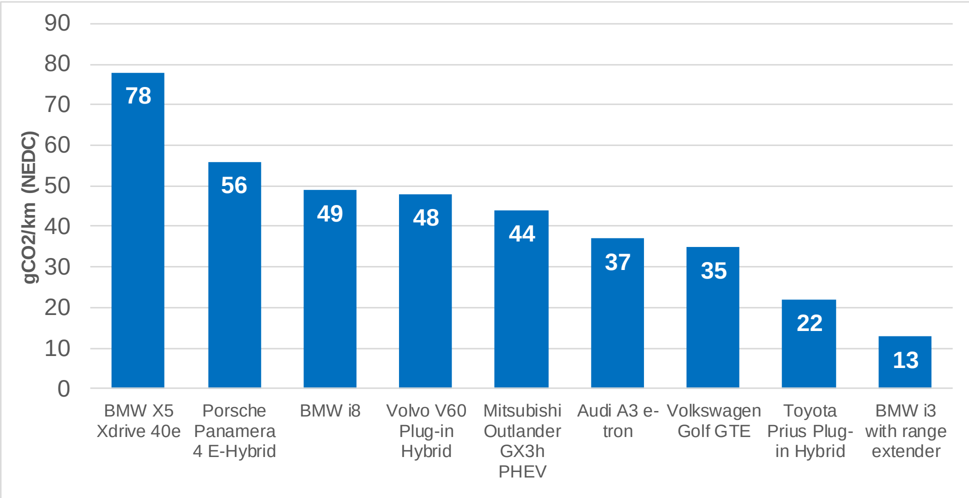
A1.2.1.2 The thresholds for defining an LEV

Options to set the thresholds that might be used to define LEVs are presented in Table 7.2, along with their pros and cons. As a result of the conclusion of the previous section, this section focuses only on options for setting CO_2 emission thresholds. A range of different thresholds is assessed from zero tailpipe CO_2 emissions, which effectively defines an LEV as either a BEV or a FCEV, to 50 gCO_2/km, which is the threshold used in the context of the current Regulations for defining a vehicle eligible for super-credits.

The identification of potential thresholds between these two extremes was based on an assessment of the CO_2 emissions of PHEVs currently on the market, and a consideration of the potential CO_2 emissions of such vehicles in the future, as projected by the PRIMES-TREMOVE model. Two potential approaches could be identified in this respect: one in which the same threshold is used for both 2025 and 2030; another in which there is a declining threshold. The latter has the advantage of incentivising improvements over time, but its added value in practice over using the same threshold would need to be assessed quantitatively. Figure 7.1 presents the CO_2 emissions of selected PHEVs currently on the market. It can be seen that many emit around 50 gCO_2km, while others emit less, e.g. around 35 gCO_2/km and even 22 gCO_2/km for the new 2017 Toyota Prius Prime PHEV and 13 gCO_2/km for the BMW i3 with range extender. This suggests that lower thresholds, of around 25-35 gCO_2/km might be appropriate for the next decade. Hence, an option of having a 25 gCO_2/km for both 2025 and 2030 is considered alongside an option where a threshold of 35 gCO_2/km is set for 2025, which declines to 25 gCO_2/km in 2030.

There are less data available on the CO_2 emissions of plug-in hybrid LCVs, the same thresholds were therefore initially applied to LCVs as to cars for consistency reasons (consistent also with the approach applied for supercredits in the existing regulations). The minimum thresholds were revised up from 25g/35g levels following the initial modelling results, since with only a single van category modelled in PRIMES-TREMOVE, a higher threshold was necessary to enable significant numbers of PHEVs to be able to qualify for the incentive options aimed beyond a simple ZEV mandate.

Figure 7.1: Examples of CO_2 emissions (NEDC) of PHEVs currently available on the market in the EU



Source: Update of data collected as part of the SR4 project (Ricardo Energy & Environment et al, 2016)

Table 7.2: Options for setting the CO_2 emission thresholds for defining an LEV

Options for the thresholds (T)*		Pros	Cons
T1	CO_2 emissions of zero at the tailpipe	• Strong signal to focus on ZEVs, which contribute most to tailpipe and real world CO_2 reductions and have zero air pollutant emissions	• No additional incentive provided for (low emitting) PHEVs, which may be important in the transition towards ZEVs
T2	CO_2 emissions less than or equal to 25 gCO_2/km (for 2025 and 2030)	• Recognises the potential of (low emitting) PHEVs to contribute to CO_2 reductions • CO_2 threshold sufficiently low to incentivise further improvements in PHEV performance (higher range, due to higher battery capacity/vehicle mass ratio)	• Reduces the focus on ZEVs, which have a larger CO_2 reduction potential • Risks incentivising vehicles having a bigger gap between test cycle and real world emissions
T3	CO_2 emissions less than or equal to 35 gCO_2/km in 2025 reducing to 25 gCO_2/km in 2030	• Idem T2, but provides an incentive to improve the CO_2 emissions performance of PHEVs over time	• Idem T2
T4	CO_2 emissions less than or equal to 50 gCO_2/km (for 2025 and 2030)	• Recognises the potential of most PHEVs to contribute to CO_2 reductions	• Would further reduce the focus on ZEVs, which have a larger CO_2 reduction potential • High threshold (status quo from current situation) risks over-incentivising PHEVs with high real world emissions • Does not incentivise improvements in most PHEVs, as many on the market already meet this threshold

Note: * All values are figures measured on the NEDC.

Discussion: The assessment demonstrates that the main difference between the options is that as the threshold increases there is less focus on ZEVs and more on PHEVs. PHEVs have the potential to contribute to CO_2 reduction and may be important in the transition to ZEVs. However, the higher the threshold, the greater the risk of incentivising PHEVs that do not deliver real-world emissions reductions.

Proposal: Take forward all four options T1-T4.

A1.2.1.3 Summary

In summary, the proposals from Section A1.2.1 are to take forward the following options for the criteria defining an LEV:

- CO_2 emissions of zero at the tailpipe (Option T1 in Table 7.2).
- CO_2 emissions less than or equal to 25 gCO_2/km (Option T2 in Table 7.2).
- CO_2 emissions less than or equal to 35 gCO_2/km in 2025 reducing to 25 gCO_2/km in 2030 (Option T3 in Table 7.2).
- CO_2 emissions less than or equal to 50 gCO_2/km (Option T4 in Table 7.2).

A1.2.2 Differentiating between LEVs

A1.2.2.1 Options for treating different types of LEV

As discussed in Section 1, different types of LEV have the potential to contribute differently to reducing tailpipe CO_2 emissions. There is therefore a clear rationale to incentivising LEVs according to their potential to reduce CO_2 emissions, in particular distinguishing ZEVs and other (non-ZEV) LEVs. Options to potentially differentiate between different types of LEV are presented in Table 7.3, along with their pros and cons. These are also linked to the stringency of the threshold, which was discussed in Table 7.2. For Option T1, where the threshold is zero gCO_2/km, Option D1 is the only option that makes sense. With higher thresholds in the LEV definition, a broader spectrum of PHEVs would be covered, making the case for option D2 stronger.

Table 7.3: Options for treating different types of LEV

Options for differentiating (or not) between different types of LEV (D)		Pros	Cons
D1	Do not differentiate between different types of ZEV/LEV		• It does not recognise the different contributions to CO2 reduction (between ZEV and non-ZEV; and between different PHEV). • It does not recognise the differences in the need for stimulating market uptake between types of LEV. • These concerns are more relevant where the thresholds are less stringent (e.g. under Option T4):
D2	Differentiate between different types of LEV, at least separating ZEV and non-ZEV	• Allows taking into account different needs for stimulating market uptake (more relevant in case of higher thresholds for defining LEV) • Allows accounting for different contributions to CO_2 reduction of different LEVs	

Discussion: Whether it is more appropriate to apply Option D1 or Option D2 is dependent on the choice of threshold. Option D1 is the only one that makes sense for threshold Option T1, whereas Option D2 allows counterbalancing the disadvantages of a higher threshold (e.g. Option T4).

Proposal: Take forward both options with the threshold options in the following combinations:

- LEV1: Option D2 and Option T3 (thresholds of 35 gCO_2/km in 2025 and 25 gCO_2/km in 2030);
- LEV2: Option D1 and Option T1 (threshold of 0 gCO_2/km);
- LEV3: Option D2 and Option T4 (threshold of 50 gCO_2/km); and
- LEV4: Option D1 and Option T2 (threshold of 25 gCO_2/km).

Depending on the outcome, the following option could also be assessed:

- *LEV5:* ***Option D1*** and Option T3 (thresholds of 35 gCO_2/km in 2025 and 25 gCO_2/km in 2030).

Option D2 needs further consideration of its details, specifically the determination of the form and the value of the credit.

A1.2.2.2 Sub-options for counting non-ZEV (under option D2)

Option D2 could be seen as a manufacturer being rewarded with a 'credit' for each LEV it sells, with the value of this credit being '1' for a ZEV, and less than '1' for other types of LEV. Table 7.4 considers two options for determining the value of a credit for LEVs that are not ZEVs.

Table 7.4: Options for counting non-ZEV (sub-options of Option D2)

Options for counting non-ZEV LEVs in the context of option D2		Pros	Cons
VC1	Count a non-ZEV as a ***fixed fraction*** of a ZEV, e.g. 0.5		• Does not distinguish between the different contributions to CO_2 reductions of different non-ZEVs
VC2	Count a non-ZEV LEV ***as a variable fraction*** of a ZEV depending on its CO_2 emissions	• Rewards vehicles on the basis of their CO_2 emissions, so direct link to overall objective • Distinguishes between the CO_2 reduction potentials of different non-ZEVs	

Discussion: Option VC2 links better to the overall target of reducing CO_2 emissions, while it has no relevant disadvantages over Option VC1.

Proposal: Give further consideration to Option VC2.

A1.2.2.3 Sub-options for determining the value of a non-ZEV LEV credit (under option VC2)

Under Option VC2, it needs to be considered how to calculate the value of the credit for a particular LEV (other than ZEV), options for which are presented in Table 7.5. In all cases, the credit is determined as a linear function based on the CO_2 emissions of the LEV. The options differ in terms of the reference point against which the CO_2 emissions of the LEV are compared (i.e. the denominator in the formula).

Option P1 has a variable reference point, which will not be known in advance, while under options P2 and P3 the denominator value is fixed in advance. In P2 this is the fleet-wide target and in P3 it is the LEV threshold used in the definition (which will be lower than the fleet-wide target).

Table 7.5: Options for calculating the value of a non-ZEV credit (sub-options of Option VC2)

Options for determining the value of a non-ZEV credit in Option VC2 (P)*		Pros	Cons
P1	$1 - \frac{CO_2 \text{ emissions of the LEV}}{\text{Fleet-wide average } CO_2 \text{ emissions in each year}}$	• As it relates the LEV credit directly to overall progress in emissions, there is an incentive to continually improve an LEV's CO_2 emissions to receive the same level of credit	• Regulatory uncertainty, as value of credit not known in advance • Limited differentiation between LEVs with different levels of emissions
P2	$1 - \frac{CO_2 \text{ emissions of the LEV}}{\text{Fleet-wide average } CO_2 \text{ emissions target}}$	• Provides regulatory certainty, as value of the credit for an LEV with a specified CO_2 emissions is known in advance	• Does not provide incentive to continually improve the CO_2 emissions of LEVs (as long as the target remains the same) • Limited differentiation between LEVs with different levels of emissions
P3	$1 - \frac{CO_2 \text{ emissions of the LEV}}{\text{Threshold used to define an LEV}}$	• Provides regulatory certainty, as value of the credit for an LEV with a specified CO_2 emissions is known in advance • More differentiation between LEVs with different levels of emissions	• Does not provide incentive to continually improve the CO_2 emissions of LEVs (as long as the LEV threshold/definition does not change)

Notes: * In each case, the equation proposes how the value of the LEV credit would be calculated

Discussion: Under Option P1, the value of a credit is not known in advance, and therefore it does not provide regulatory certainty for manufacturers. The only advantage would be that this Option provides for an incentive to continually improve an LEV's CO_2 emissions, but this could also be achieved by lowering the LEV thresholds over time (see Section A1.2.1.2). Option P3 has the advantage over Option P2 that it provides a greater differentiation between the credits allocated to LEVs with different (non-zero) levels of CO_2 emissions, and so provides more of an incentive to develop LEVs with lower CO_2 emissions.

Proposal: Option P3 to be taken forward.

A1.2.3 Incentivising LEVs

The first aspect of determining how to incentivise LEVs is the form that the incentive might take, followed by consideration of the entity to which the incentive should apply and finally it needs to be determined how the incentive should be applied. These are covered in the following sections.

Criteria for assessing options in this section are:

- Increase the uptake of vehicles that will provide benefits for the longer-term emissions reduction, but without weakening the 2030 target.
- Emissions reductions to be achieved as cost-effectively as possible, i.e. not disproportionately increase compliance costs.
- Fair treatment of manufacturers, including not penalising those that have taken early action to reduce their emissions.
- Minimise additional administrative burden.

- Regulatory certainty for manufacturers.

A1.2.3.1 Form that the incentive might take

The options for the form that the incentive might take and their main pros and cons are set out in Table 7.6 below.

Table 7.6: Options for the form that the incentive might take

Options for the form that the incentive might take (F)		Pros	Cons
F1	**Mandate**: mandatory minimum requirement with respect to LEV uptake (applying in addition to a fleet-wide CO_2 target)	• Does not affect the stringency of the overall CO_2 target • Provides a clear direction for all manufacturers to put LEVs on the market	• The mandate may only be delivered if other conditions are met which do not necessarily depend only on OEMs (infrastructure availability, consumer acceptance) • Reduces flexibility of manufacturers to choose how they meet the overall target
F2	**Credit-based system**: setting a benchmark relating to the number/share of LEVs, which is not mandatory as such, but is used to determine (emission) credits and/or debits with respect to the overall target	• Allows manufacturers to benefit from a reduction in the stringency of their overall CO_2 target (those that would have met the LEV mandate anyway) • (Compared to Option F1) Fairer to those manufacturers that have no/less need to introduce LEVs to meet targets • (Compared to Option F1) Provides more flexibility for manufacturers to choose how they meet their CO_2 target	• Risk of weakening the CO_2 target: especially if only relying on rewards (credits) and not on debits and if benchmark is set too low (significant effect of rewards) • Does not ensure that LEVs are taken up to the specified extent • (Compared to Option F1) Increases complexity of the regulatory approach

Discussion: Both options have their merits and warrant further analysis, allowing comparison with "no incentive" option (targets only). In-depth consideration of the risks (weakening of the targets, fairness, long-term objectives) will be very important.

Proposal: Take forward both options.

A1.2.3.2 Determining the value(s) for the mandate or benchmark

Under a mandate or credit-based system, the level of the incentive could be either expressed as the ***absolute*** number of LEV-equivalents in the new vehicle fleet or in ***relative*** terms, i.e. referring to the share of LEVs in the new fleet. Using an absolute number of vehicles would make the achievement of the objective dependent on the future size of the market, creating uncertainty around the overall emissions reduction and costs compared to the overall size of market, also at OEM-level. Therefore, this option is not taken forward and the further assessment only considers a system where the mandate or benchmark is expressed in terms of the **share of LEVs in the new fleet**.

For this, different options could be considered, starting from a given fleet-wide CO_2 target.

A first option would be to set the incentive at a level consistent with the cost-optimised level from the PRIMES-TREMOVE modelling for a given fleet-wide CO_2 target (Option VM1).

Alternative options would aim for a higher LEV uptake (Option VM2). The level of the LEVs mandate/benchmark could be informed by the cost-optimised LEV share indicated by PRIMES-TREMOVE under scenarios with a stricter fleet-wide CO_2 target.

The following higher LEV mandate/benchmark levels were targeted for exploration for Option VM2:

LEV incentive threshold	Non-ZEV credit type	Passenger Cars	Vans
T1	-	15%, 20%	15%, 20%
T2	-	25%, 30%	25%, 30%
T4	P3	25%, 30%	25%, 30%

Table 7.7: Options for determining the value of LEV incentive

Options for determining the value of the incentive		Pros	Cons
VM1	Set the mandate/benchmark at the level of uptake of LEVs indicated by PRIMES-TREMOVE scenario modelling for a given fleet-wide CO_2 target	• Represents cost-optimised level of LEV uptake	• Does not encourage the uptake of LEVs beyond levels that are 'cost-optimised', which may be necessary for cost-effectively reducing CO_2 emissions in the longer term
VM2	Set ***the mandate/benchmark at a higher level*** than the one indicated by PRIMES-TREMOVE for a given fleet-wide CO_2 target	Compared to VM1: • Reduces ICEV compliance costs as less CO_2 reductions would be needed from these • Higher level of LEV uptake	Compared to VM1: • Reduces overall cost-effectiveness

Discussion: Both options have potential benefits and disadvantages, largely in relation to the costs they impose and the CO_2 benefits they deliver.

Proposal: Take VM1 and VM2 forward for assessment.

As the higher mandate under VM2 is based on a higher LEV share, similar values should be considered for LCVs.

A1.2.3.3 Differentiating between OEMs

There are two obvious options for applying an LEV incentive across OEMs, which are set out in Table 7.8 below.

Table 7.8: Options for differentiating the incentives between OEMs

Options for differentiating the incentive between OEMS (O)		Pros	Cons
O1	Each manufacturer has the same level of incentive	• Rewards early movers, as the manufacturers that are already putting LEVs on the market will be closer to delivering the mandate than those that have not	
O2	Differentiated application for individual manufacturers	• Could be considered to be fairer for manufacturers that have not taken action to develop LEVs to date	• Need to decide on what basis the incentive should be distributed to different manufacturers (i.e. why manufacturers should be treated differently). • Risks penalising first movers.

Discussion: Option O2 has more issues. First, the basis on which the incentive should be distributed between different manufacturers would need to be decided. Logically, this would need to be based on some assessment of their potential to put LEVs on the market, but it is not evident how this might be assessed. Alternatively, the mandate could be differentiated according to the extent to which manufacturers have put LEVs on the market already. If a higher mandate was given to manufacturers that had already put LEVs on the market, this would effectively penalise early movers.

Proposal: Take forward only Option O1.

A1.2.3.4 Rewarding over-achievement / penalising under-achievement under a credit-based system (sub-options to Option F2)

A credit based system (Option F2) requires further consideration of the definition of the level of the reward (/ penalty) to be applied in the event of a manufacturer exceeding (/ not meeting) the 'benchmark' incentive level.

As noted in Table 7.6, a credit-based system (Option F2) brings the risk of weakening the CO_2 target. For example, in the case where a 2 gCO_2/km reduction in the overall target was given for every 1% overachievement of the benchmark, (Element Energy, 2016) estimated that continually exceeding the benchmark by 5% would reduce CO_2 emissions (from cars and vans) between 2005 and 2030 only by 25.9% instead of by 30% in the base case.

Hence, it is proposed to limit the reward to 5% overachievement and that the scale of the reward considered is not more than 2 g/km (which would be equivalent to 2.9% under the ‘central ambition’ scenario for 2030). Consequently, as set out in Table 7.9 below, it is proposed to assess options where manufacturers’ targets are adjusted by 1% and 2% for each % of over/underachievement of the LEV benchmarks.

Examples of the implications of these options are given in Table 7.9, for a case where a manufacturer's specific CO_2 target level is 70 g/km.

Table 7.9: Options for rewarding/penalising over/underachievement under a credit-based system

Options for rewarding overachievement and potentially penalising underachievement (R)		Pros	Cons	For a 5% over-achievement, 70 g/km target will be relaxed to:
R1	Reward a 1% overachievement of the LEV benchmark by relaxing the manufacturer's CO_2 target by 1%; reward limited to 5% overachievement of the benchmark	• Increased incentive to exceed the benchmark	• The overall target will be weakened (extent depends on the degree of overachievement)	73.5 gCO_2/km
R2	Reward a 1% overachievement ***and penalise a 1% underachievement*** of the LEV benchmark by relaxing / ***tightening*** the manufacturer's CO_2 target by 1%; reward limited to 5% overachievement of the benchmark	• Weakening of the overall CO_2 target resulting from overachievement of LEV benchmark is counteracted (to some extent) by the penalties for under-achievement • Increased incentive to deliver the benchmark	• Weakening of the target not excluded (extent depends on the degree of overachievement vs underachievement)	73.5 gCO_2/km
R3	Reward a 1% overachievement / penalise a 1% underachievement of the LEV benchmark by relaxing / tightening the manufacturer's CO_2 target by***2%***; reward limited to 5% overachievement of the benchmark	Compared to R2: • Increased incentive to exceed the benchmark	Compared to R2: • Increases risk of weakening the overall target	77.0 gCO_2/km
R4	Reward a 1% overachievement of the LEV benchmark by relaxing the manufacturer's CO_2 target by 1% and penalise a 1% underachievement of the LEV benchmark by tightening the manufacturer's CO_2 target by ***2%***; reward limited to 5% overachievement of the benchmark	Compared to R2: • Increased penalty further counteracts potential weakening of the target • Increased incentive to deliver the benchmark	Compared to R2: • Weakening of the target still not excluded	73.5 gCO_2/km

Discussion: The 'reward' element, while providing a further incentive to bring LEVs to the market, risks weakening the CO_2 target. The 'penalty' element increases the incentive to meet the benchmark share of LEV. Including both a 'reward' and a 'penalty' element reduces the risk of weakening the target. Increasing the size of the rewards and/or penalties increases the risks and potential benefits. The potential for a 10% weakening of the target under R3 (see Table 7.9) rules this option out.

Proposal: Take forward Options R1 and R2. Option R4 might also be considered further depending on the results of Option R2.

A1.2.3.5 Assessment of the options in PRIMES-TREMOVE

Options F1 and F2 can be assessed quantitatively in PRIMES-TREMOVE in the following way:

- *Mandate (F1):* In PRIMES-TREMOVE a constraint is set to require a minimum share of LEVs (overall, i.e. the mandate %) in combination with the LEV definition (e.g. <35gCO_2/km), and the LEV credit metric (discussed in Section A1.2.2).
- *Credit-based system (F2):* The credit-based system cannot be modelled at manufacturer-level in PRIMES-TREMOVE. However, scenarios can be explored as pairs of sensitivities:
  i. The first sensitivity explores the impacts of a net over-achievement of the mandate (i.e. up to 5% weakening resulting from LEV share 5% above the mandate level). In this case the minimum LEV share requirement in the PRIMES-TREMOVE model is set at the higher level (i.e. the over-exceedance), while the gCO_2/km target objective is relaxed by the corresponding level of reward.
  ii. The second sensitivity explores the impact of the assumed maximum under-achievement of the benchmark, i.e. the strengthening of the CO_2 targets resulting from this. In this case the LEV share objective is lowered to the maximum under-achievement level and made a maximum LEV share constraint. In addition, the overall gCO_2/km target objective is lowered /made stricter by the corresponding level of penalty.

  The other aspects are the same as for the *Mandate* option.

Within PRIMES-TREMOVE, the value of the LEVs (options D1/D2) will be implemented in the following way. For the sake of simplification, it is proposed that the threshold for the LEV share should be set at a level to the nearest 0.5% increment.

A. Accounting for the LEV credit: PRIMES-TREMOVE will 'value' LEVs according to the appropriate formulae (i.e. either all LEVs get a credit of 1 (Option D1) or are credited based on P3 (Option D2)), when optimising towards the targeted LEV share;

B. Setting the LEV target share: In order to calculate the LEV target share (i.e. the mandate or benchmark level) for Option P3, it is necessary to take into account the crediting formula, which is influenced by:

   a. The LEV threshold;

   b. The average PHEV performance as set out in the PRIMES-TREMOVE model; and

   c. The respective shares of ZEVs and PHEVs targeted for the mandate ambition.

A worked example is provided below for calculating the overall LEV share to be targeted in the model under Option D2 (/VC2/P3) with an LEV defined as having CO_2 emissions below 35 g/km, an average PHEV emission of 25 g/km and a share of 6% ZEV and 10% PHEV being targeted:

Model Target LEV Share = ZEV % + PHEV % * (1 - Av. PHEV g/km / LEV Threshold)

= 6% + 10% * (1 – 25 / 35) = **8.86%** → **9.0%** (nearest 0.5% increment)

The options to reward overachievement and penalise underachievement (R1, R2 and perhaps R4) can only be modelled in PRIMES-TREMOVE at the extremes. In other words, it is only possible to identify what the impacts would be of the maximum weakening/tightening of the targets (combined with the minimum/maximum LEV shares that would lead to penalising/rewarding) that might be delivered by these options.

Consequently, in order to model R2, the following runs will need to be undertaken using the chosen scenario:

- Assume that the benchmark is exceeded to the limit, i.e. 5%, which results in a weakening of the target of 5%; *and*
- Assume that the benchmark is not met, so that penalties are applied meaning that the target is made more stringent. In order to model this, the increased target to be modelled should be calculated based on the % share achieved by the 'natural' LEV share and the 1% tightening factor. For example, if a 3.5% lower LEV share was achieved the CO_2 target would be 3.5% lower for the 1%/1% penalty option (R2), and 7% lower for the 1%/2% option (R4).

A1.2.4 Summary of selected options

In summary, the following options were selected as regards the various elements for establishing LEV incentives:

- Type of incentive:
    - Mandate: (Option F1)
    - Credit based system (Option F2)

As regards modalities for implementation:

- Determining the value of the mandate/benchmark (i.e. share of LEVs in the new fleet):
    - Set the mandate/benchmark at the level of uptake of LEVs indicated by PRIMES-TREMOVE for a given fleet-wide CO_2 target (Option VM1)
    - Set the mandate/benchmark at a higher level of uptake of LEVs (Option VM2)
- Each manufacturer has the ***same level of incentive*** (Option O1).
- Differentiate between different types of LEV, at least separating ZEV and non-ZEV, where the thresholds are less stringent (Option D2); otherwise apply Option D1 (no differentiation between types of LEV), i.e. combining:
    - Option D2 and Option T3 (35 gCO_2/km reducing to 25 gCO_2/km);
    - Option D1 and Option T1 (0 gCO_2/km);
    - Option D2 and Option T4 (50 gCO_2/km); and
    - Option D1 and Option T2 (25 gCO_2/km); while:
    - Option D1 and Option T3 could be an alternative option.
- Under Option D2:
    - Count a non-ZEV ***as a variable fraction*** of a ZEV depending on its CO_2 emissions, where a ZEV counts as one LEV (Option VC2).
    - Determine the appropriate value of the LEV credit using the formula (Option P3):

$$1 - \frac{CO_2 \text{ emissions of the LEV}}{(\text{Threshold used to define an LEV})}$$

In order to be able to explore a credit-based system (Option F2), it is necessary to identify the extent of the reward, penalty and potential caps on these, that might be applied. The options to be explored are:

- Reward a 1% overachievement of the LEV benchmark by relaxing the manufacturer's overall CO_2 emissions by 1%; reward limited to 5% overachievement of the benchmark (Option R1)
- Reward a 1% overachievement and penalise a 1% underachievement of the LEV benchmark by relaxing / tightening the manufacturer's overall CO_2 emissions by 1%; reward limited to 5% overachievement of the benchmark (Option R2)

Based on the above, a series of potential LEV options were further explored.

A2 Appendix 2: NEDC-WLTP and WLTP-RW conversion factors by powertrain type and vehicle segment

This appendix provides the correlation factors used to convert NEDC-based CO2 emissions factors (in gCO2/km) to WLTP CO2 emissions factors for the purposes of the PRIMES-TREMOVE modelling, and also the assumed size of the WLTP to Real-world (WLTP-RW) gap. The development of correlation factors was carried out at JRC and is documented in (JRC, 2017a).

A2.1 Default NEDC-WLTP and WLTP-RW conversion factors

The following Table A1 summarises the default conversion factors used in the analysis, corresponding to the mode, segment and powertrain categories included in the PRIMES-TREMOVE model. The default assumption is that the WLTP-RW gap will remain constant from 2020 onwards (i.e. through to 2050).

Table A1: Summary of the default NEDC-WLTP and WLTP-RW conversion factors used in the analysis

Mode	Segment	Powertrain	NEDC-WLTP	WLTP-RW gap			
			All periods	2015	2020	2025	2030
Cars	Small	SI ICE	124.5%	110.0%	110.0%	110.0%	110.0%
Cars	Medium	SI ICE	114.5%	119.6%	119.6%	119.6%	119.6%
Cars	Large	SI ICE	106.7%	128.4%	128.4%	128.4%	128.4%
Cars	Small	CI ICE	126.2%	108.6%	108.6%	108.6%	108.6%
Cars	Medium	CI ICE	120.8%	113.4%	113.4%	113.4%	113.4%
Cars	Large	CI ICE	114.1%	120.1%	120.1%	120.1%	120.1%
Cars	Medium	CNG	135.9%	100.8%	100.8%	100.8%	100.8%
Cars	Medium	LPG	115.9%	118.2%	118.2%	118.2%	118.2%
Cars	Medium	E85	114.5%	119.6%	119.6%	119.6%	119.6%
Cars	Large	E85	106.7%	128.4%	128.4%	128.4%	128.4%
Cars	Small	SI Full Hybrid	136.5%	106.2%	106.2%	106.2%	106.2%
Cars	Medium	SI Full Hybrid	132.2%	109.7%	109.7%	109.7%	109.7%
Cars	Large	SI Full Hybrid	123.4%	117.5%	117.5%	117.5%	117.5%
Cars	Small	CI Full Hybrid	137.9%	105.1%	105.1%	105.1%	105.1%
Cars	Medium	CI Full Hybrid	133.8%	108.4%	108.4%	108.4%	108.4%
Cars	Large	CI Full Hybrid	129.8%	111.7%	111.7%	111.7%	111.7%
Cars	Small	SI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Medium	SI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Large	SI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Small	CI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Medium	CI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%

Mode	Segment	Powertrain	NEDC-WLTP	WLTP-RW gap			
			All periods	2015	2020	2025	2030
Cars	Large	CI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Small	SI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Medium	SI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Large	SI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Small	CI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Medium	CI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Large	CI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
Cars	Small	BEV	125.8%	115.3%	115.3%	115.3%	115.3%
Cars	Medium	BEV	128.3%	113.0%	113.0%	113.0%	113.0%
Cars	Large	BEV	129.9%	111.7%	111.7%	111.7%	111.7%
Cars	Small	FCEV	125.8%	115.3%	115.3%	115.3%	115.3%
Cars	Medium	FCEV	128.3%	113.0%	113.0%	113.0%	113.0%
Cars	Large	FCEV	129.9%	111.7%	111.7%	111.7%	111.7%
LCVs	All	SI ICE	121.5%	109.4%	109.4%	109.4%	109.4%
LCVs	All	CI ICE	130.5%	101.9%	101.9%	101.9%	101.9%
LCVs	All	CNG	135.9%	97.9%	97.9%	97.9%	97.9%
LCVs	All	LPG	115.9%	114.7%	114.7%	114.7%	114.7%
LCVs	All	E85	106.7%	124.7%	124.7%	124.7%	124.7%
LCVs	All	SI Full Hybrid	138.2%	104.9%	104.9%	104.9%	104.9%
LCVs	All	CI Full Hybrid	145.2%	99.9%	99.9%	99.9%	99.9%
LCVs	All	SI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%
LCVs	All	CI PHEV	100.0%	167.5%	167.5%	167.5%	167.5%
LCVs	All	SI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
LCVs	All	CI REEV	100.0%	167.5%	167.5%	167.5%	167.5%
LCVs	All	BEV	121.0%	119.8%	119.8%	119.8%	119.8%
LCVs	All	FCEV	121.0%	119.8%	119.8%	119.8%	119.8%

A2.2 Sensitivity on the evolution of the WLTP-RW gap from 2020-2030

The following Table A2 summarises the conversion factors used in the analysis for the sensitivity scenario, which assumes that the WLTP-RW gap will increase between 2020 and 2030 (and then remain constant to 2050).

Table A2: Summary of the NEDC-WLTP conversion factors and the alternative sensitivity on WLTP-RW conversion factors used in the analysis

Mode	Segment	Powertrain	NEDC-WLTP	WLTP-RW gap			
			All periods	2015	2020	2025	2030
Cars	Small	SI ICE	124.5%	110.0%	110.0%	112.6%	115.2%
Cars	Medium	SI ICE	114.5%	119.6%	119.6%	122.2%	124.8%
Cars	Large	SI ICE	106.7%	128.4%	128.4%	131.0%	133.6%
Cars	Small	CI ICE	126.2%	108.6%	108.6%	111.2%	113.8%
Cars	Medium	CI ICE	120.8%	113.4%	113.4%	116.0%	118.6%
Cars	Large	CI ICE	114.1%	120.1%	120.1%	122.7%	125.3%
Cars	Medium	CNG	135.9%	100.8%	100.8%	103.4%	106.0%
Cars	Medium	LPG	115.9%	118.2%	118.2%	120.8%	123.4%
Cars	Medium	E85	114.5%	119.6%	119.6%	122.2%	124.8%
Cars	Large	E85	106.7%	128.4%	128.4%	131.0%	133.6%
Cars	Small	SI Full Hybrid	136.5%	106.2%	106.2%	108.1%	110.0%
Cars	Medium	SI Full Hybrid	132.2%	109.7%	109.7%	111.6%	113.5%
Cars	Large	SI Full Hybrid	123.4%	117.5%	117.5%	119.4%	121.3%
Cars	Small	CI Full Hybrid	137.9%	105.1%	105.1%	107.0%	108.9%
Cars	Medium	CI Full Hybrid	133.8%	108.4%	108.4%	110.3%	112.1%
Cars	Large	CI Full Hybrid	129.8%	111.7%	111.7%	113.6%	115.5%
Cars	Small	SI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Medium	SI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Large	SI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Small	CI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Medium	CI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Large	CI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Small	SI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Medium	SI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Large	SI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Small	CI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Medium	CI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Large	CI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
Cars	Small	BEV	125.8%	115.3%	115.3%	117.9%	120.4%
Cars	Medium	BEV	128.3%	113.0%	113.0%	115.6%	118.2%

Mode	Segment	Powertrain	NEDC-WLTP	WLTP-RW gap			
			All periods	2015	2020	2025	2030
Cars	Large	BEV	129.9%	111.7%	111.7%	114.3%	116.9%
Cars	Small	FCEV	125.8%	115.3%	115.3%	117.9%	120.4%
Cars	Medium	FCEV	128.3%	113.0%	113.0%	115.6%	118.2%
Cars	Large	FCEV	129.9%	111.7%	111.7%	114.3%	116.9%
LCVs	All	SI ICE	121.5%	109.4%	109.4%	112.0%	114.6%
LCVs	All	CI ICE	130.5%	101.9%	101.9%	104.5%	107.1%
LCVs	All	CNG	135.9%	97.9%	97.9%	100.5%	103.1%
LCVs	All	LPG	115.9%	114.7%	114.7%	117.3%	119.9%
LCVs	All	E85	106.7%	124.7%	124.7%	127.3%	129.9%
LCVs	All	SI Full Hybrid	138.2%	104.9%	104.9%	106.8%	108.7%
LCVs	All	CI Full Hybrid	145.2%	99.9%	99.9%	101.8%	103.7%
LCVs	All	SI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
LCVs	All	CI PHEV	100.0%	167.5%	167.5%	180.7%	193.9%
LCVs	All	SI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
LCVs	All	CI REEV	100.0%	167.5%	167.5%	180.7%	193.9%
LCVs	All	BEV	121.0%	119.8%	119.8%	122.4%	125.0%
LCVs	All	FCEV	121.0%	119.8%	119.8%	122.4%	125.0%

A3 Appendix 3: Updated operation and maintenance costs used in the analysis of impacts on TCO

The Table A3 below summarises the updated operation and maintenance cost assumptions developed for the cost analysis during this project.

Table A3: Updated O&M cost assumptions for LDVs developed during the course of this project

				Updated O&M costs			
Year	**Mode**	**P-T Segment**	**Powertrain**	**Total Fixed O&M**	**Ownership**	**Maintenance**	**Insurance**
2015	Car	Small	ICE+Hybrids	**€ 963**	€ 115	€ 331	€ 517
2015	Car	Small	PHEV	**€ 1,084**	€ 115	€ 298	€ 671
2015	Car	Small	BEV	**€ 935**	€ 58	€ 232	€ 646
2015	Car	Small	FCEV	**€ 1,428**	€ 0	€ 248	€ 1,180
2015	Car	Medium	ICE+Hybrids	**€ 1,399**	€ 215	€ 535	€ 649
2015	Car	Medium	PHEV	**€ 1,478**	€ 215	€ 482	€ 782
2015	Car	Medium	BEV	**€ 1,266**	€ 108	€ 375	€ 784
2015	Car	Medium	FCEV	**€ 1,821**	€ 0	€ 401	€ 1,420
2015	Car	Large	ICE+Hybrids	**€ 2,292**	€ 345	€ 715	€ 1,232
2015	Car	Large	PHEV	**€ 2,367**	€ 345	€ 644	€ 1,379
2015	Car	Large	BEV	**€ 2,107**	€ 173	€ 501	€ 1,434
2015	Car	Large	FCEV	**€ 2,822**	€ 0	€ 536	€ 2,285
2015	LCV	All	ICE+Hybrids	**€ 2,322**	€ 140	€ 1,015	€ 1,167
2015	LCV	All	PHEV	**€ 2,472**	€ 140	€ 914	€ 1,418
2015	LCV	All	BEV	**€ 2,234**	€ 70	€ 711	€ 1,454
2015	LCV	All	FCEV	**€ 2,990**	€ 0	€ 761	€ 2,228
2020	Car	Small	ICE+Hybrids	**€ 963**	€ 115	€ 331	€ 517
2020	Car	Small	PHEV	**€ 998**	€ 115	€ 298	€ 585
2020	Car	Small	BEV	**€ 862**	€ 58	€ 232	€ 573
2020	Car	Small	FCEV	**€ 939**	€ 0	€ 248	€ 691
2020	Car	Medium	ICE+Hybrids	**€ 1,399**	€ 215	€ 535	€ 649
2020	Car	Medium	PHEV	**€ 1,404**	€ 215	€ 482	€ 708
2020	Car	Medium	BEV	**€ 1,198**	€ 108	€ 375	€ 716
2020	Car	Medium	FCEV	**€ 1,246**	€ 0	€ 401	€ 844
2020	Car	Large	ICE+Hybrids	**€ 2,292**	€ 345	€ 715	€ 1,232
2020	Car	Large	PHEV	**€ 2,283**	€ 345	€ 644	€ 1,295
2020	Car	Large	BEV	**€ 2,017**	€ 173	€ 501	€ 1,344
2020	Car	Large	FCEV	**€ 2,028**	€ 0	€ 536	€ 1,491
2020	LCV	All	ICE+Hybrids	**€ 2,322**	€ 140	€ 1,015	€ 1,167
2020	LCV	All	PHEV	**€ 2,331**	€ 140	€ 914	€ 1,278
2020	LCV	All	BEV	**€ 2,098**	€ 70	€ 711	€ 1,318
2020	LCV	All	FCEV	**€ 2,209**	€ 0	€ 761	€ 1,448

				Updated O&M costs			
Year	**Mode**	**P-T Segment**	**Powertrain**	**Total Fixed O&M**	**Ownership**	**Maintenance**	**Insurance**
2025	Car	Small	ICE+Hybrids	**€ 963**	€ 115	€ 331	€ 517
2025	Car	Small	PHEV	**€ 968**	€ 115	€ 298	€ 555
2025	Car	Small	BEV	**€ 892**	€ 115	€ 232	€ 545
2025	Car	Small	FCEV	**€ 904**	€ 58	€ 248	€ 598
2025	Car	Medium	ICE+Hybrids	**€ 1,399**	€ 215	€ 535	€ 649
2025	Car	Medium	PHEV	**€ 1,375**	€ 215	€ 482	€ 679
2025	Car	Medium	BEV	**€ 1,272**	€ 215	€ 375	€ 683
2025	Car	Medium	FCEV	**€ 1,246**	€ 108	€ 401	€ 737
2025	Car	Large	ICE+Hybrids	**€ 2,292**	€ 345	€ 715	€ 1,232
2025	Car	Large	PHEV	**€ 2,244**	€ 345	€ 644	€ 1,255
2025	Car	Large	BEV	**€ 2,129**	€ 345	€ 501	€ 1,284
2025	Car	Large	FCEV	**€ 2,050**	€ 173	€ 536	€ 1,341
2025	LCV	All	ICE+Hybrids	**€ 2,322**	€ 140	€ 1,015	€ 1,167
2025	LCV	All	PHEV	**€ 2,285**	€ 140	€ 914	€ 1,232
2025	LCV	All	BEV	**€ 2,111**	€ 140	€ 711	€ 1,260
2025	LCV	All	FCEV	**€ 2,134**	€ 70	€ 761	€ 1,302
2030	Car	Small	ICE+Hybrids	**€ 963**	€ 115	€ 331	€ 517
2030	Car	Small	PHEV	**€ 957**	€ 115	€ 298	€ 544
2030	Car	Small	BEV	**€ 881**	€ 115	€ 232	€ 534
2030	Car	Small	FCEV	**€ 935**	€ 115	€ 248	€ 572
2030	Car	Medium	ICE+Hybrids	**€ 1,399**	€ 215	€ 535	€ 649
2030	Car	Medium	PHEV	**€ 1,363**	€ 215	€ 482	€ 666
2030	Car	Medium	BEV	**€ 1,261**	€ 215	€ 375	€ 671
2030	Car	Medium	FCEV	**€ 1,322**	€ 215	€ 401	€ 706
2030	Car	Large	ICE+Hybrids	**€ 2,292**	€ 345	€ 715	€ 1,232
2030	Car	Large	PHEV	**€ 2,224**	€ 345	€ 644	€ 1,236
2030	Car	Large	BEV	**€ 2,106**	€ 345	€ 501	€ 1,261
2030	Car	Large	FCEV	**€ 2,177**	€ 345	€ 536	€ 1,296
2030	LCV	All	ICE+Hybrids	**€ 2,322**	€ 140	€ 1,015	€ 1,167
2030	LCV	All	PHEV	**€ 2,265**	€ 140	€ 914	€ 1,211
2030	LCV	All	BEV	**€ 2,090**	€ 140	€ 711	€ 1,240
2030	LCV	All	FCEV	**€ 2,161**	€ 140	€ 761	€ 1,260

A4 Appendix 4: Additional results and data tables

A4.1 Chapter 3, 5 and 6: Options for ambition, timing and incentives to stimulate the uptake of low emission vehicles

A4.1.1 Calculation of cumulative cost-effectiveness and Benefit:Cost Ratios

An assessment of the cumulative costs and benefits of different scenario runs was conducted using the outputs of the PRIMES-TREMOVE model. Since the model outputs annualised capital costs, and the fuel cost benefits resulting from the regulations would be accumulated in the period following the target date, a 2020-2040 time-period was selected for the cumlative impact analysis to capture the major effects of the proposed policy designs being modeled.

Cost-effectiveness:

PRIMES-TREMOVE provides the following fleet-level annualised cost outputs in 5 year intervals, which were used to calculate cumulative costs for each scenario run over the 2020-2040 period:

- Capital costs
- Fuel costs
- Variable non-fuel costs
- Fixed operation and maintenance costs
- Infrastructure payments (i.e. xEV charging, hydrogen, etc.).

The net change in these individivindividual cumulative cost componets was first calculated relative to the baseline (REF) scenario. The final cost-effectiveness indicator (in €/tonne CO_2 reduced) was then calculated from the corresponding cumulative WTW GHG emissions savings versus the baseline over the same period.

Cost-Benefit Analysis:

Cost benefit analysis (CBA) is a systematic approach to estimating the strengths and weaknesses of alternative options and determine an objective comparison of different types of impacts. The societal costs of impacts (i.e. externalities) that are not directly captured, such as air pollution, GHG emissions, noise, congestion and accidents can be quantified in monetary terms using external costs to allow them to be compared with direct financial costs in impact assessment.

The PRIMES-TREMOVE model also outputs external costs for air pollution, noise, congestion and accidents, which are used in the cost-benefit analysis. However, the cost of GHG emissions is not calculated in the model, and this was therefore done in post-processing using central estimates for the external costs of GHG emissions, as summarised in Table A4 below, to calculate the total cumulative costs of GHG emissions over the 2020-2040 period.

From these figures the total net cost impacts of different scenarios could be calculated based on the combined direct costs and the externalities. In addition, a Benefit:Cost Ratio (BCR) was calculated for each scenario:

$$\textbf{Benefit:Cost Ratio (BCR)} = \frac{\text{Sum of all components with net € savings}}{\text{Sum of all components with net € costs}}$$

Note: the BCR is NOT the same as a simple ratio of net direct and external cost elements.

Table A4: Projected external costs of climate change (in €/tonne CO_2e)

	Projected external cost of GHG Emissions, 2016 €/tonne								
Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Lower value	48	50.0	54.1	58	62	66.9	72.3	77.8	83.8
Central value	**90**	**93.7**	**101.5**	**108.7**	**116.3**	**125.4**	**135.5**	**145.9**	**157.1**
Upper value	168	174.9	189.4	202.9	217.2	234	252.9	272.4	293.2

Source: Values for 2010 from the Updated Handbook on External Costs of Transport (Ricardo-AEA, 2014), extrapolated to 2050 using PRIMES-TREMOVE GDP projections from the 2016 Reference scenario.

A4.1.2 Costs, cost-effectiveness and cost-benefit analysis of options for Chapters 3, 5 and 6

The following Table A5 to Table A10 provide a summary of the cumulative cost, cost-effectiveness and cost:benefit analysis for the main scenario options explored using PRIMES-TREMOVE modelling in Chapters 3, 5 and 6.

Table A5: Summary of the cost-effectiveness and cost-benefit analysis of different options for ambition level and timing compared to the baseline scenario

	Change in cumulative costs and WTW GHG emissions for 2020-2040 period, compared to the baseline (REF) scenario									
	Direct Costs to Society (B€)	WTW CO_2e abatement (Mt)	Direct €/tCO_2e	GHG Cost €/tCO_2e	Other External Cost €/t CO_2e	Total GHG Costs (B€)	Other External Costs (B€)	Total External Costs (B€)	**Total (Direct + External) Costs (B€)**	Benefit:Cost Ratio (BCR)
L-25-MNM	99.5	-1,066	93.3	127.3	-45.9	-135.7	-49.0	-184.7	**-85.2**	1.22
C-25-MNM	114.7	-1,188	96.6	127.0	-42.4	-150.8	-50.4	-201.1	**-86.5**	1.18
H-25-MNM	160.3	-1,616	99.2	126.3	-37.8	-204.2	-61.1	-265.2	**-104.9**	1.14
68NL-25-MNM	175.3	-1,810	96.9	125.5	-32.8	-227.2	-59.3	-286.5	**-111.1**	1.13
V-25-MNM	214.8	-2,084	103.1	125.9	-35.3	-262.3	-73.5	-335.8	**-121.0**	1.12
C-30-MNM	103.2	-1,120	92.1	127.4	-44.8	-142.7	-50.2	-192.9	**-89.8**	1.21
L-25-MNM	99.5	-1,066	93.3	127.3	-45.9	-135.7	-49.0	-184.7	**-85.2**	1.22
L-25-MNM-HICE	186.2	-1,012	184.0	127.6	-75.8	-129.1	-76.7	-205.7	**-19.5**	1.04
C-25-MNM	114.7	-1,188	96.6	127.0	-42.4	-150.8	-50.4	-201.1	**-86.5**	1.18
C-25-MNM-HICE	203.4	-1,161	175.1	127.1	-67.3	-147.6	-78.1	-225.7	**-22.3**	1.04
C-25-MNM-LxEV	90.1	-1,234	73.0	126.9	-36.3	-156.6	-44.8	-201.4	**-111.3**	1.24
C-25-MNM-VLxEV	84.2	-1,390	60.6	126.8	-31.2	-176.2	-43.3	-219.6	**-135.4**	1.27
C-25-MNM-LO	27.7	-1,287	21.5	126.7	-19.4	-163.1	-25.0	-188.0	**-160.3**	1.38
H-25-MNM	160.3	-1,616	99.2	126.3	-37.8	-204.2	-61.1	-265.2	**-104.9**	1.14
H-25-MNM-HICE	244.8	-1,598	153.2	126.3	-54.5	-201.8	-87.0	-288.8	**-44.1**	1.05
H-25-MNM-LxEV	118.5	-1,578	75.1	126.4	-31.7	-199.4	-50.0	-249.4	**-130.9**	1.20
H-25-MNM-VLxEV	94.5	-1,576	60.0	126.4	-28.5	-199.2	-45.0	-244.1	**-149.6**	1.24
H-25-MNM-LO	56.2	-1,598	35.2	126.3	-19.1	-201.9	-30.5	-232.4	**-176.2**	1.29

Note: The Benefit:Cost ratio is calculated based on the individual sub-components, i.e. fuel cost savings = benefit, manufacturing cost increase = cost, etc. It is NOT the same as a simple ratio of net direct and external cost elements. "*Direct Costs*" includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "*Other External Costs*" includes air quality pollutant emissions, noise, accidents and congestion.

Table A6: Summary of the cost-effectiveness and cost-benefit analysis of different sensitivity scenarios from Chapter 3 and 6 compared to the baseline scenario

	Change in cumulative costs and WTW GHG emissions for 2020-2040 period, compared to the baseline (REF) scenario									
	Direct Costs to Society (B€)	WTW CO_2e abatement (Mt)	Direct €/t CO_2e	GHG Cost €/t CO_2e	Other External Cost €/t CO_2e	Total GHG Costs (B€)	Other External Costs (B€)	Total External Costs (B€)	**Total (Direct + External) Costs (B€)**	Benefit:Cost Ratio (BCR)
C-25-MNM	114.7	-1,188	96.6	127.0	-42.4	-150.8	-50.4	-201.1	**-86.5**	1.18
C-25-MNM-RW	161.2	-945	170.6	127.8	-72.6	-120.8	-68.6	-189.3	**-28.1**	1.07
C-25-MNM-DSL	122.7	-1,104	111.1	127.1	-66.9	-140.4	-73.9	-214.2	**-91.6**	1.22
C-25-MNM-DSL2	137.4	-1,012	135.8	127.2	-98.2	-128.7	-99.4	-228.1	**-90.7**	1.25
L-25-MNM-LFuel*	114.6	-1,177	97.4	127.4	-55.8	-149.9	-65.7	-215.6	**-100.9**	1.33
C-25-MNM-LFuel*	145.1	-1,474	98.4	126.6	-48.3	-186.7	-71.2	-257.9	**-112.8**	1.25
H-25-MNM-LFuel*	217.5	-2,001	108.7	126.0	-46.7	-252.0	-93.4	-345.4	**-128.0**	1.17
C-25-MNM-NMD	114.7	-1,188	96.6	127.0	-42.4	-150.8	-50.4	-201.1	**-86.5**	1.18
C-25-MNM-OFF	9.1	-1,487	6.1	126.0	-8.0	-187.3	-12.0	-199.2	**-190.1**	1.36

Note: The Benefit:Cost ratio is calculated based on the individual sub-components, i.e. fuel cost savings = benefit, manufacturing cost increase = cost, etc. It is NOT the same as a simple ratio of net direct and external cost elements. * Relative to the baseline scenario also with low fuel prices (REF-LFuel). "*Direct Costs"* includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "*Other External Costs*" includes air quality pollutant emissions, noise, accidents and congestion.

Table A7: Summary of the cumulative costs, cost-effectiveness and cost-benefit analysis of different options from Chapter 5 for LEV incentives and sensitivities on these compared to the baseline scenario

	Change in cumulative costs and WTW GHG emissions for 2020-2040 period, compared to the baseline (REF) scenario									
	Direct Costs to Society (B€)	WTW CO_2e abatement (Mt)	**Direct Cost €/tCO_2e**	GHG Cost €/tCO_2e	Other External Cost €/tCO_2e	Total GHG Costs (B€)	Other External Costs (B€)	Total External Costs (B€)	**Total (Direct + External) Costs (B€)**	**Benefit:Cost Ratio (BCR)**
C-25-MNM	114.7	-1,188	96.6	127.0	-42.4	-150.8	-50.4	-201.1	**-86.5**	**1.18**
C-25-MNM-L1	185.9	-1,143	162.7	127.1	-63.7	-145.3	-72.8	-218.2	**-32.2**	**1.06**
C-25-MNM-L1F	244.4	-1,053	232.1	127.4	-87.7	-134.1	-92.3	-226.4	**18.0**	**0.96**
C-25-MNM-L1FL	103.5	-1,272	81.4	126.8	-34.8	-161.3	-44.2	-205.6	**-102.0**	**1.20**

Table A8: Impact of LEV scenarios from Chapter 5 with different cost assumptions and mandates on cumulative costs, cost-effectiveness and cost-benefit analysis (where the overall target was set in accordance with the *'central ambition'* scenario, i.e. C-25-MNM)

	Change in cumulative costs and WTW GHG emissions for 2020-2040 period, compared to the baseline (REF) scenario									
	Direct Costs to Society (B€)	WTW CO_2e abatement (Mt)	**Direct Cost €/tCO_2e**	GHG Cost €/tCO_2e	Other External Cost €/tCO_2e	Total GHG Costs (B€)	Other External Costs (B€)	Total External Costs (B€)	**Total (Direct + External) Costs (B€)**	**Benefit:Cost Ratio (BCR)**
C-25 MNM	114.7	-1,188	96.6	127.0	-42.4	-150.8	-50.4	-201.1	**-86.5**	**1.18**
C-25 MNM-LxEV	90.1	-1,234	73.0	126.9	-36.3	-156.6	-44.8	-201.4	**-111.3**	**1.24**
-L2_15-LxEV	166.5	-1,188	140.2	127.0	-55.6	-150.9	-66.0	-216.8	**-50.4**	**1.11**
-L4_25-LxEV	201.4	-1,145	175.9	127.2	-71.9	-145.7	-82.3	-228.0	**-26.6**	**1.06**
-L3_25-LxEV	297.9	-1,091	272.9	127.5	-94.6	-139.1	-103.2	-242.4	**55.5**	**0.89**
C-25 MNM-VLxEV	84.2	-1,390	60.6	126.8	-31.2	-176.2	-43.3	-219.6	**-135.4**	**1.27**
-L2_15-VLxEV	203.1	-1,305	155.6	127.1	-58.8	-166.0	-76.8	-242.8	**-39.7**	**1.08**
-L4_25-VLxEV	218.7	-1,293	169.1	127.2	-66.4	-164.4	-85.9	-250.3	**-31.6**	**1.06**
-L3_25-VLxEV	327.0	-1,212	269.9	127.5	-90.3	-154.5	-109.4	-263.8	**63.2**	**0.88**
-L2_20-VLxEV	132.1	-1,341	98.5	127.0	-42.9	-170.3	-57.6	-227.9	**-95.8**	**1.19**
-L4_30-VLxEV	171.1	-1,338	127.8	127.1	-54.6	-170.1	-73.1	-243.1	**-72.1**	**1.14**
-L3_30-VLxEV	206.8	-1,276	162.0	127.2	-61.4	-162.4	-78.4	-240.8	**-34.0**	**1.07**

Note: The Benefit:Cost ratio is calculated based on the individual sub-components. It is NOT the same as a simple ratio of net direct and external cost elements. "*Direct Costs*" includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs.

Table A9: Impact of LEV scenarios from Chapter 5 with different cost assumptions and mandates on cumulative costs, cost-effectiveness and cost-benefit analysis (where the overall target was set in accordance with the *'low ambition'* scenario, i.e. L-25-MNM)

	Change in cumulative costs and WTW GHG emissions for 2020-2040 period, compared to the baseline (REF) scenario									
	Direct Costs to Society (B€)	WTW CO_2e abatement (Mt)	**Direct Cost €/tCO_2e**	GHG Cost €/tCO_2e	Other External Cost €/tCO_2e	Total GHG Costs (B€)	Other External Costs (B€)	Total External Costs (B€)	**Total (Direct + External) Costs (B€)**	**Benefit:Cost Ratio (BCR)**
L-25 MNM	99.5	-1,066	93.3	127.3	-45.9	-135.7	-49.0	-184.7	**-85.2**	**1.22**
L-25 MNM-LxEV*										
-L2_15-LxEV	156.7	-1,111	141.1	127.4	-60.4	-141.5	-67.1	-208.6	**-51.8**	**1.12**
-L4_25-LxEV	184.1	-1,081	170.4	127.4	-74.1	-137.7	-80.1	-217.7	**-33.6**	**1.08**
-L3_25-LxEV	301.0	-1,011	297.6	127.8	-105.8	-129.2	-107.0	-236.2	**64.7**	**0.86**
L-25 MNM-VLxEV*										
-L2_15-VLxEV	194.4	-1,278	152.1	127.2	-60.3	-162.6	-77.0	-239.6	**-45.2**	**1.09**
-L4_25-VLxEV	233.4	-1,271	183.6	127.2	-71.0	-161.7	-90.3	-252.0	**-18.6**	**1.04**
-L3_25-VLxEV	329.6	-1,195	275.9	127.6	-94.1	-152.4	-112.4	-264.8	**64.9**	**0.88**
-L2_20-VLxEV	128.1	-1,314	97.5	127.0	-42.9	-166.9	-56.4	-223.3	**-95.1**	**1.20**
-L4_30-VLxEV	151.3	-1,318	114.7	127.1	-50.9	-167.5	-67.1	-234.6	**-83.4**	**1.17**
-L3_30-VLxEV	214.2	-1,253	171.0	127.3	-64.3	-159.4	-80.6	-240.0	**-25.8**	**1.05**

Note: The Benefit:Cost ratio is calculated based on the individual sub-components, i.e. fuel cost savings = benefit, manufacturing cost increase = cost, etc. It is NOT the same as a simple ratio of net direct and external cost elements. * No scenario runs were conducted with low and very low cost curves for xEVs. "*Direct Costs"* includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "*Other External Costs*" includes air quality pollutant emissions, noise, accidents and congestion.

Table A10: Impact of LEV scenarios from Chapter 5 with different cost assumptions and mandates on cumulative costs, cost-effectiveness and cost-benefit analysis (where the overall target was set in accordance with the *'high ambition'* scenario, i.e. H-25-MNM)

	Change in cumulative costs and WTW GHG emissions for 2020-2040 period, compared to the baseline (REF) scenario								
	Direct Costs to Society (B€)	WTW CO_2e abatement (Mt)	**Direct Cost €/tCO_2e**	GHG Cost €/tCO_2e	Other External Cost €/tCO_2e	Total GHG Costs (B€)	Other External Costs (B€)	Total External Costs (B€)	**Total (Direct + External) Costs (B€)**	**Benefit:Cost Ratio (BCR)**
H-25 MNM	160.3	-1,616	99.2	126.3	-37.8	-204.2	-61.1	-265.2	**-104.9**	**1.14**
H-25 MNM-LxEV	118.5	-1,578	75.1	126.4	-31.7	-199.4	-50.0	-249.4	**-130.9**	**1.20**
-L2_15-LxEV	171.7	-1,490	115.3	126.6	-43.8	-188.6	-65.2	-253.8	**-82.1**	**1.13**
-L4_25-LxEV	166.1	-1,531	108.5	126.6	-44.8	-193.8	-68.5	-262.3	**-96.2**	**1.14**
-L3_25-LxEV	240.5	-1,457	165.1	126.9	-58.1	-184.9	-84.6	-269.5	**-29.0**	**1.04**
H-25 MNM-VLxEV	94.5	-1,576	60.0	126.4	-28.5	-199.2	-45.0	-244.1	**-149.6**	**1.24**
-L2_15-VLxEV	176.0	-1,591	110.6	126.4	-41.0	-201.1	-65.3	-266.4	**-90.4**	**1.14**
-L4_25-VLxEV	219.1	-1,630	134.4	126.3	-49.1	-205.8	-80.1	-285.9	**-66.8**	**1.10**
-L3_25-VLxEV	259.4	-1,546	167.8	126.5	-55.9	-195.6	-86.5	-282.1	**-22.7**	**1.04**
-L2_20-VLxEV	144.1	-1,614	89.3	126.3	-34.4	-203.7	-55.6	-259.3	**-115.2**	**1.18**
-L4_30-VLxEV	159.9	-1,627	98.3	126.3	-38.9	-205.5	-63.3	-268.8	**-108.9**	**1.17**
-L3_30-VLxEV	171.5	-1,592	107.7	126.4	-39.4	-201.2	-62.7	-263.9	**-92.4**	**1.14**

Note: The Benefit:Cost ratio is calculated based on the individual sub-components, i.e. fuel cost savings = benefit, manufacturing cost increase = cost, etc. It is NOT the same as a simple ratio of net direct and external cost elements. "*Direct Costs"* includes annualised investments for vehicle purchases, fuel costs, variable non-fuel costs, fixed operation and maintenance costs, and energy infrastructure investment costs. "*Other External Costs*" includes air quality pollutant emissions, noise, accidents and congestion.

A4.2 Chapter 4: Options for distribution of effort amongst manufacturers

A4.2.1 Assessment of impacts on competition between manufacturers

Table A11: Increased 2030 manufacturing costs relative to the baseline for passenger cars for different distribution parameters and slopes, values presented as absolute (€) and relative (%) to average prices

C-25-MNM, 2030	Mass (RegSlope)	Mass 60%	Mass 80%	Mass 100%	Footprint 60%	Footprint 80%	Footprint 100%	Uniform Reduction	Uniform Target
Additional manufacturing cost, €									
Smaller Vehicles	1,170	955	1,036	1,130	1,018	1,133	1,261	909	755
Advanced Tech Average	960	928	942	954	912	916	922	927	900
Average Vehicles	1,042	995	1,014	1,035	954	958	963	1,022	943
Advanced Tech Larger	996	1,066	1,035	1,005	1,091	1,067	1,048	1,107	1,171
Laggard Larger Vehicles	1,708	2,546	2,127	1,806	3,497	3,211	2,969	1,209	4,345
Total	**1,022**	**1,023**	**1,021**	**1,020**	**1,035**	**1,033**	**1,035**	**1,025**	**1,051**
Additional manufacturing cost as a percentage of average vehicle price									
Smaller Vehicles	6.7%	5.4%	5.9%	6.4%	5.8%	6.5%	7.2%	5.2%	4.3%
Advanced Tech Average	4.5%	4.3%	4.4%	4.4%	4.2%	4.3%	4.3%	4.3%	4.2%
Average Vehicles	4.5%	4.3%	4.4%	4.5%	4.1%	4.2%	4.2%	4.4%	4.1%
Advanced Tech Larger	2.8%	3.0%	3.0%	2.9%	3.1%	3.0%	3.0%	3.2%	3.3%
Laggard Larger Vehicles	2.3%	3.5%	2.9%	2.5%	4.8%	4.4%	4.0%	1.6%	5.9%
Total	**4.0%**	**3.9%**	**3.9%**	**4.0%**	**3.9%**	**3.9%**	**4.0%**	**3.9%**	**3.9%**

Notes: The impacts of different DoE options are presented for different "stylised" manufacturers (or manufacturer groups) to represent groups of manufacturers with similar characteristics.

Table A12: Increased 2030 manufacturing costs relative to the baseline for LCVs for different distribution parameters and slopes, values presented as absolute (€) and relative (%) to average prices

C-25-MNM, 2030	Mass (RegSlope)	Mass 60%	Mass 80%	Mass 100%	Footprint 60%	Footprint 80%	Footprint 100%	Uniform Reduction	Uniform Target
Additional manufacturing cost, €									
Smaller LCV	594	492	533	579	428	444	460	588	385
Larger LCV	652	689	673	657	783	799	815	654	742
Larger LCV with xEV	648	798	726	664	911	861	815	651	1,110
Total	**622**	**622**	**619**	**620**	**644**	**641**	**639**	**621**	**670**
Additional manufacturing cost as a percentage of average vehicle price									
Smaller LCV	2.35%	1.95%	2.11%	2.29%	1.70%	1.76%	1.82%	2.33%	1.53%
Larger LCV	2.02%	2.13%	2.08%	2.03%	2.43%	2.47%	2.53%	2.03%	2.30%
Larger LCV with xEV	1.73%	2.13%	1.94%	1.78%	2.44%	2.30%	2.18%	1.74%	2.97%
Total	**2.10%**	**2.04%**	**2.06%**	**2.09%**	**2.07%**	**2.07%**	**2.08%**	**2.10%**	**2.11%**

Notes: The impacts of different DoE options are presented for different "stylised" manufacturers (or manufacturer groups) to represent groups of manufacturers with similar characteristics.

A4.2.2 Supporting information on xEV model launch and strategy announcements

Ricardo routinely collects information on xEV model launch and strategy announcements. Figure A1 to Figure A2 below provides a summary, compiled from information collected up to the end of June 2017, of the anticipated xEV model availability in for the main different manufacturer groups by 2025. Overall it is estimated that xEV models will be available for around half of the vehicle models responsible for the vast majority of car sales in Europe, and over a third of LCV models (although it is not clear whether all GVW/length variants would be available for the announced models).

Just over the period of this project there have been a significant number of announcements from all manufacturers on planned model launches, notably also from OEMs who have previously not launched any notable xEVs previously, such as Mazda[27], JLR[28] and Subaru[29]. Announcements from the latter two manufacturers suggest that at least half their model line-up will include xEV versions by 2025.

Whilst manufacturers such as GM, Honda, Toyota, and even Renault-Nissan have relatively lower shares of announced xEV models, these OEMs have significant existing experience in electrified powertrains, from a range of hybrid, fuel-cell and pure battery-electric models (notably Renault-Nissan are global market leaders in BEVs). Therefore, these OEMs should be better positioned, than otherwise suggested by model announcements, to expand their offering significantly also by 2025 and beyond.

Manufacturers that do not appear have significantly developed strategies in place for xEV deployment to date include Suzuki, Mazda, and FCA Group (where most of the model announcements are in lower-volume premium/sports models, and not in their main mass-market brands responsible for most sales). These manufacturers may therefore find it more difficult to achieve more ambitions CO_2 reduction targets, or comply with possible LEV mandates (discussed further in Section 5.3.4), in the absence of flexibilities such as trading.

Recent analysis by (UBS, 2017) has also assessed the relative positioning of key manufacturers, also factoring in current investment levels and relative impacts on their average CO_2 emissions, as is summarised in Table A13 below. This analysis also includes Tesla, which only produces pure electric

27 http://www.autonews.com/article/20161116/OEM04/311169999/mazda-plans-diesel-cx-5-ev-plug-in-hybrid-under-fuel-efficiency-push
28 http://www.caradvice.com.au/500650/jaguar-to-launch-plug-in-hybrids-before-electric-i-pace-launches-in-2018
29 http://www.autoblog.com/2017/05/22/subaru-phev-plug-in-hybrid-pure-ev/

vehicles. Although Tesla is currently classified as a small volume manufacturer in Europe, its mass-market targeted 'Model 3' vehicle, available from mid-2017 in the USA currently has very large numbers of vehicle order reservations (~400,000), and it has ambitions to become a major automotive player in the next decade. To date, Volvo and JLR are the only current mainstream car manufacturers that are anticipated to have 100% of its vehicle line-up fully electrified before 2025[30].

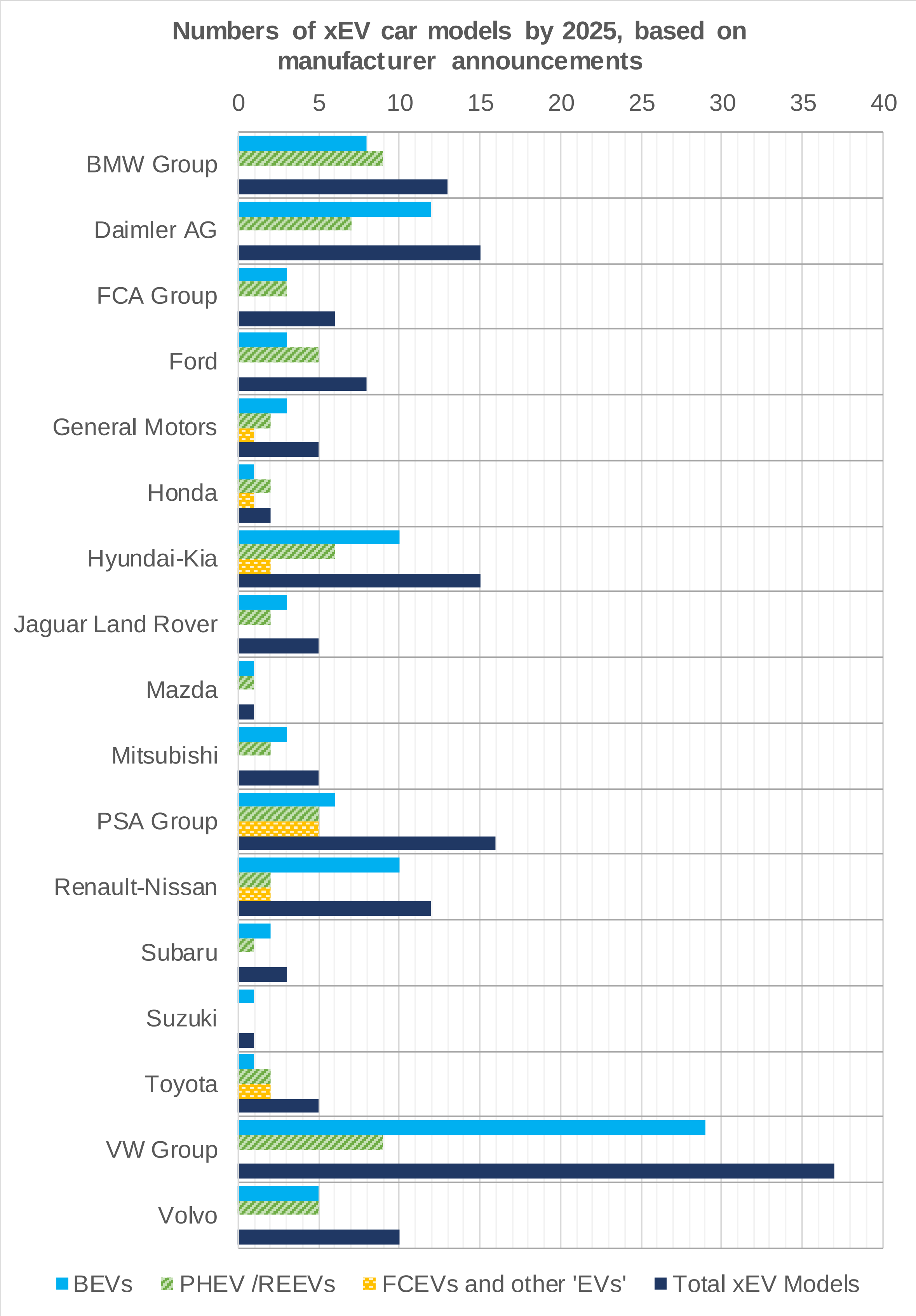
Table A13: OEM EV heat map of the best and worst positioned players for different criteria

OEM	EV sales potential	Investment focus on EV	Potential CO_2 benefit	Residual value risk	ACEA Member?
Tesla	Very high	Very high	N/A	Low	No
Daimler	Very high	High	High	High	Yes
JLR	Very high	Medium	High	Low	Yes
Volvo	Very high	Medium	High	Low	Yes
BMW	Very high	Medium	High	High	Yes
VW	High	High	High	High	Yes
Renault	High	Medium	High	Medium	Yes
Nissan	High	High	Low	Low	No
Toyota	High	Medium	Medium	Medium	Yes
PSA	High	Low	High	Low	Yes
Hyundai	Medium	Medium	Medium	Low	No
Ford	Medium	Medium	Medium	Medium	Yes
General Motors	Medium	Medium	Medium	Medium	Yes
Kia	Medium	Low	Low	Low	No
Mazda	Medium	Low	Medium	Low	No
Honda	Low	Medium	Low	Medium	No
FCA	Low	Low	Low	Low	Yes
Subaru	Low	Low	Low	Low	No
Suzuki	Low	Low	Low	Low	No

Source: Reproduced from (UBS, 2017), slightly modified by Ricardo Energy & Environment.

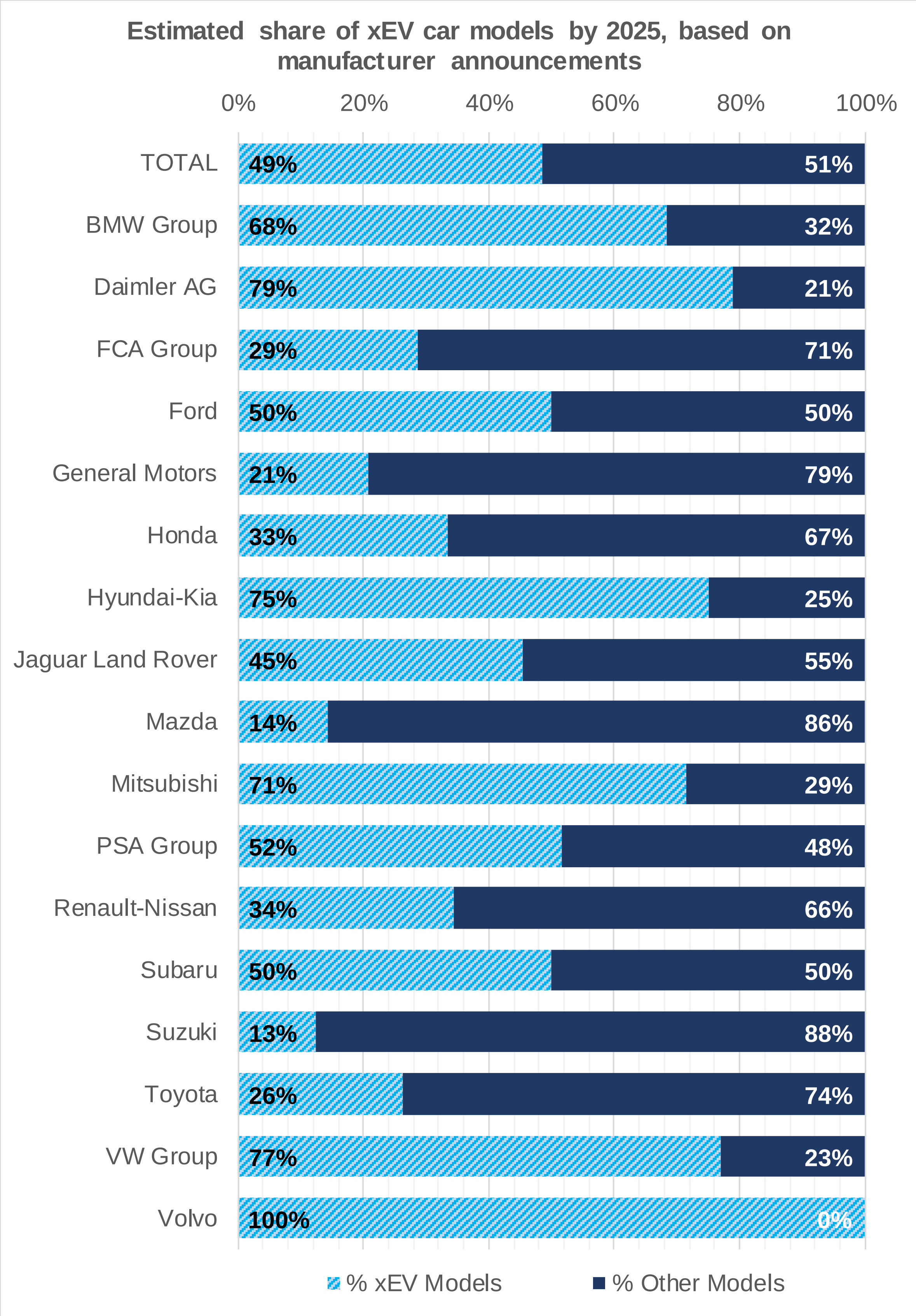
30 https://www.autocar.co.uk/car-news/new-cars/all-volvo-models-become-electrified-2019, and https://www.autocar.co.uk/car-news/industry/jaguar-land-rover-electrify-model-range-2020

Figure A1: Summary anticipated xEV car model numbers by manufacturer for 2025



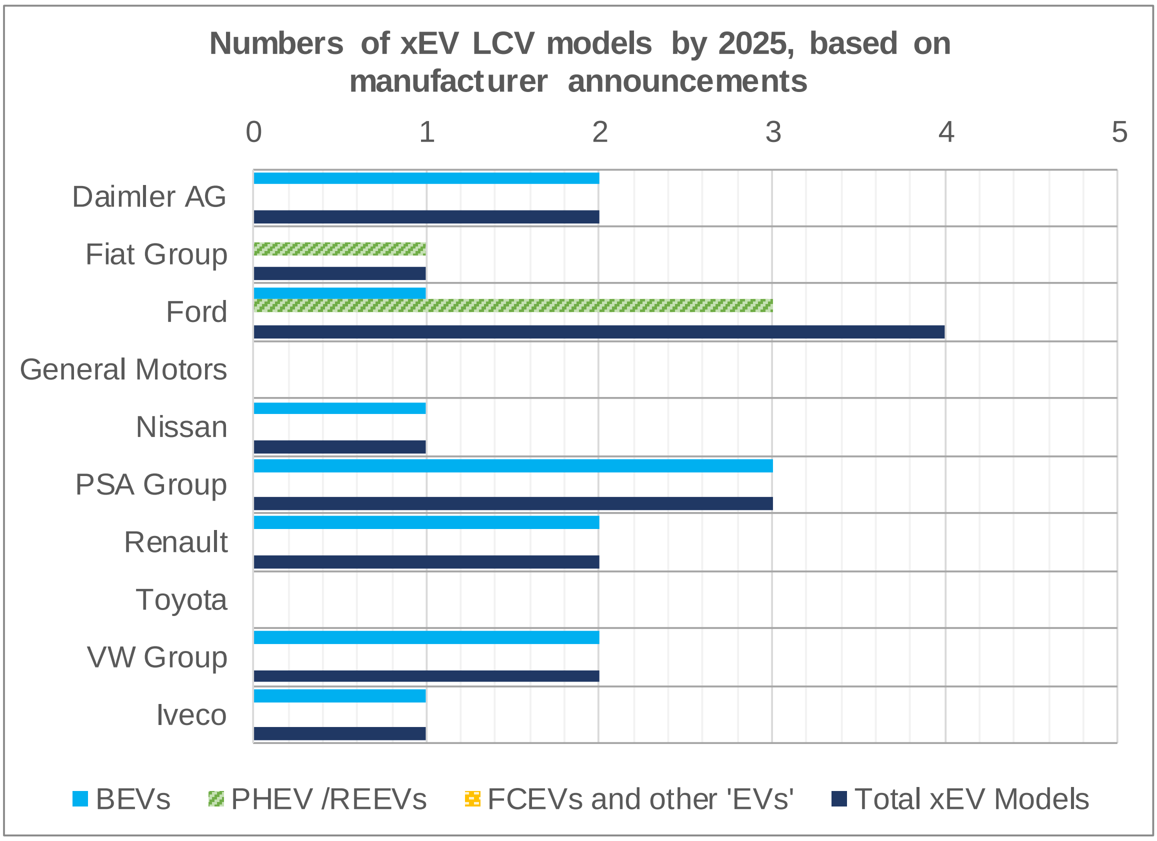
Source: Ricardo Energy & Environment analysis based on manufacturer announcements.

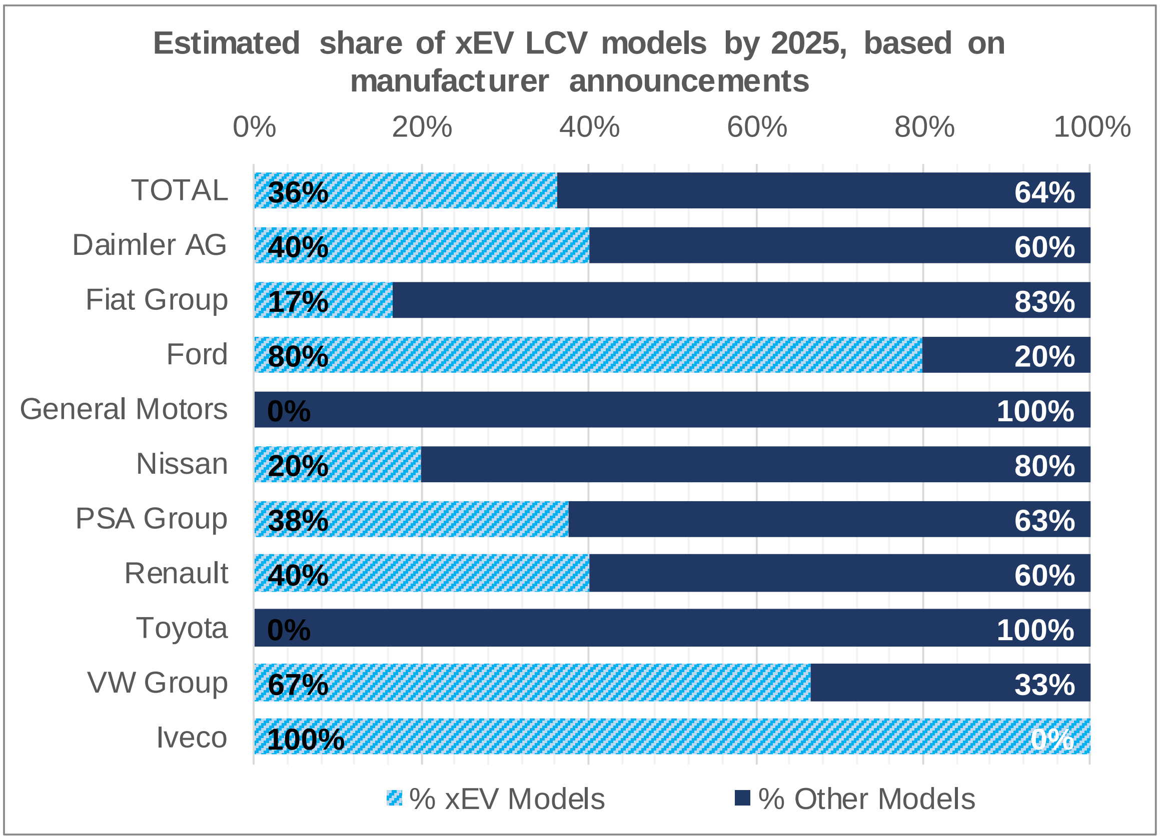
Figure A2: Summary of estimated xEV model shares of all models, by manufacturer for 2025



Source: Ricardo Energy & Environment analysis based on manufacturer announcements.

Figure A3: Summary of anticipated xEV LCV model numbers and estimated shares of all models, by manufacturer for 2025





Source: Ricardo Energy & Environment analysis based on manufacturer announcements.

A4.3 Chapter 5: Options for incentives to stimulate the market uptake of zero- and low-emission vehicles

A4.3.1 Impacts on LEV uptake

Table A14: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for cars (where the overall target was set in accordance with the *'low ambition'* scenario, i.e. L-25-MNM)

Scenario	Summary	LEV Mandate (set)	% in 2030			Change* in implied ICEV /HEV target (gCO_2/km)
			ZEVs	PHEVs	Total xEVs	
L-25-MNM	No LEV incentive	n/a	8.1%	9.3%	17.4%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	14.5%	7.5%	22.0%	+7.2
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	16.1%	10.3%	26.4%	+14.6
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	20.5%	8.2%	28.7%	+19.3
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	15.9%	9.6%	25.5%	+11.8
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	17.7%	9.7%	27.4%	+15.4
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	20.1%	9.1%	29.2%	+19.0
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	19.9%	7.1%	27.0%	+15.2
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	21.8%	9.8%	31.6%	+24.1
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	26.0%	7.3%	33.3%	+28.0

Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario L-25 MNM.

Table A15: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for LCVs (where the overall target was set in accordance with the *'low ambition'* scenario, i.e. L-25-MNM)

Scenario	Summary	LEV Mandate (set)	% in 2030			Change* in implied ICEV /HEV target (gCO_2/km)
			ZEVs	PHEVs	Total xEVs	
L-25-MNM	No LEV incentive	n/a	3.6%	13.9%	17.5%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	15.0%	5.7%	20.7%	+10.3
-L4_25-LxEV	40/40; ZEV/PHEV = 1; low xEV costs	25%	9.2%	15.8%	25.0%	+17.3
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	24.0%	2.7%	26.7%	+25.8
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	15.0%	8.6%	23.6%	+16.0
-L4_25-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	25%	9.9%	15.0%	24.9%	+16.6
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	23.7%	3.9%	27.6%	+27.2
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	19.9%	4.8%	24.7%	+20.2
-L4_30-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	30%	15.3%	15.0%	30.3%	+29.4
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	29.2%	1.9%	31.1%	+34.5

Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario L-25 MNM.

Table A16: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for cars (where the overall target was set in accordance with the *'central ambition'* scenario, i.e. C-25-MNM)

Scenario	Summary	LEV Mandate (set)	% in 2030			Change* in implied ICEV /HEV target (gCO_2/km)
			ZEVs	PHEVs	Total xEVs	
C-25-MNM	No LEV incentive	n/a	9.0%	10.8%	19.8%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	14.6%	8.4%	23.0%	+4.9
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	16.1%	10.9%	27.0%	+10.7
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	20.0%	9.0%	29.0%	+14.4
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	16.2%	9.8%	26.0%	+8.5
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	18.1%	9.9%	28.0%	+11.9
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	20.1%	9.5%	29.6%	+14.6
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	19.9%	7.6%	27.5%	+11.6
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	21.9%	10.0%	31.9%	+19.0
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	25.9%	7.7%	33.6%	+22.9

Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario C-25 MNM.

Table A17: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for LCVs (where the overall target was set in accordance with the *'central ambition'* scenario, i.e. C-25-MNM)

Scenario	Summary	LEV Mandate (set)	% in 2030			Change* in implied ICEV /HEV target (gCO_2/km)
			ZEVs	PHEVs	Total xEVs	
C-25-MNM	No LEV incentive	n/a	3.7%	15.0%	18.7%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	14.9%	6.8%	21.7%	+9.4
-L4_25-LxEV	40/40; ZEV/PHEV = 1; low xEV costs	25%	8.5%	16.6%	25.1%	+14.0
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	23.9%	3.0%	26.9%	+23.8
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	15.0%	9.4%	24.4%	+14.5
-L4_25-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	25%	9.5%	15.7%	25.2%	+14.0
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	23.4%	4.6%	28.0%	+25.7
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	19.9%	5.6%	25.5%	+18.8
-L4_30-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	30%	14.5%	15.3%	29.8%	+25.8
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	29.3%	2.4%	31.7%	+35.9

Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario C-25 MNM.

Table A18: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for cars (where the overall target was set in accordance with the *'high ambition'* scenario, i.e. H-25-MNM)

Scenario	Summary	% in 2030				Change* in implied ICEV /HEV target (gCO_2/km)
		LEV Mandate (set)	ZEVs	PHEVs	Total xEVs	
H-25-MNM	No LEV incentive	n/a	12.3%	15.7%	28.0%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	15.4%	13.4%	28.8%	+1.9
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	14.6%	14.5%	29.1%	+2.0
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	17.8%	13.7%	31.5%	+5.6
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	18.4%	11.8%	30.2%	+4.1
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	18.7%	11.9%	30.6%	+4.7
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	18.4%	12.0%	30.4%	+4.3
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	20.1%	10.6%	30.7%	+5.2
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	21.4%	11.0%	32.4%	+7.9
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	24.2%	10.1%	34.3%	+11.1

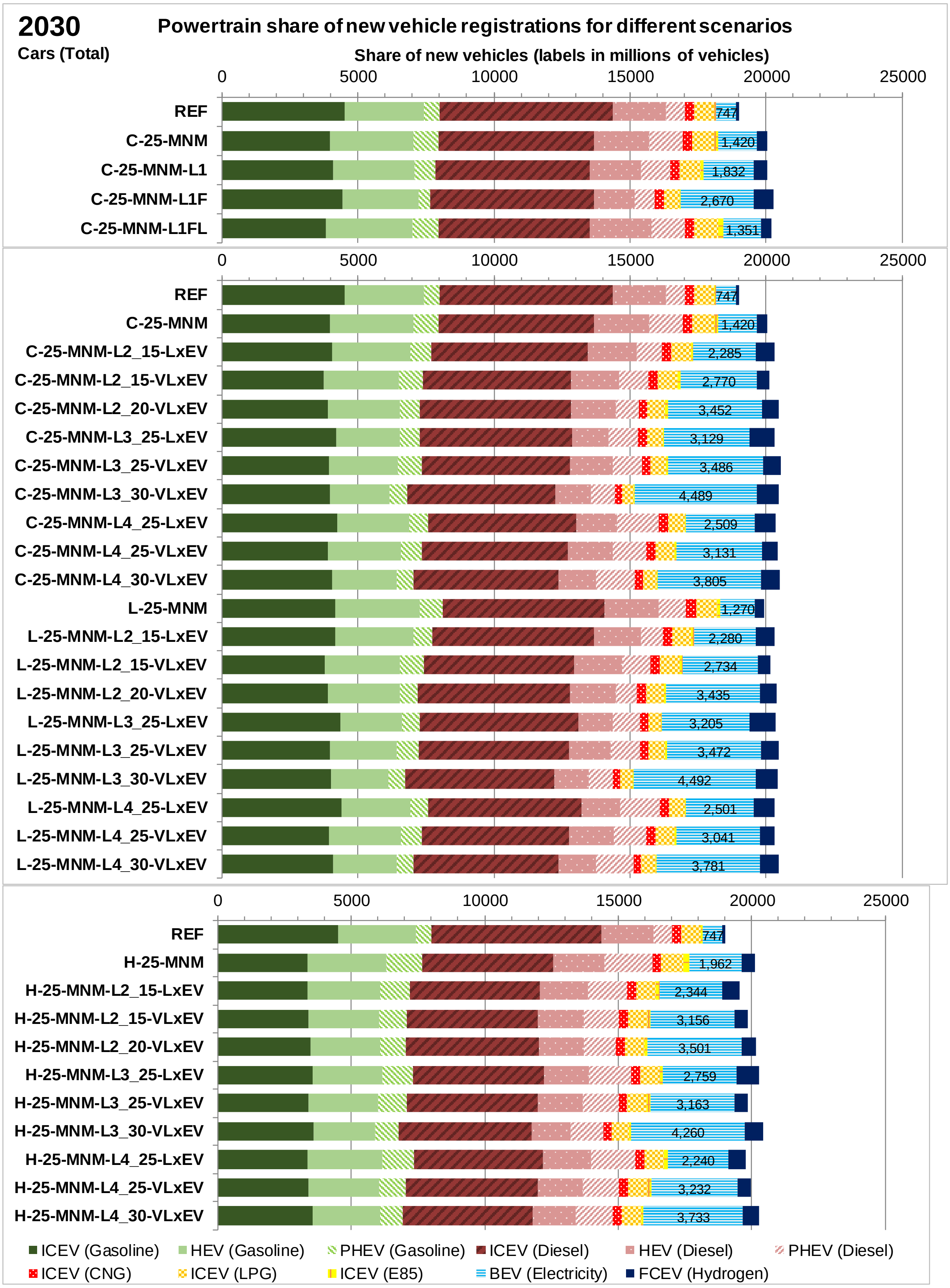
Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario H-25 MNM.

Table A19: Impact of LEV scenarios with different cost assumptions and mandates on ZEV and PHEV uptake for LCVs (where the overall target was set in accordance with the *'high ambition'* scenario, i.e. H-25-MNM)

Scenario	Summary	LEV Mandate (set)	% in 2030			Change* in implied ICEV /HEV target (gCO_2/km)
			ZEVs	PHEVs	Total xEVs	
H-25-MNM	No LEV incentive	n/a	5.5%	24.7%	30.2%	n/a
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	15.1%	15.0%	30.1%	+3.4
-L4_25-LxEV	40/40; ZEV/PHEV = 1; low xEV costs	25%	11.7%	24.1%	35.8%	+13.7
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	21.9%	10.3%	32.2%	+10.1
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	14.7%	16.6%	31.3%	+5.1
-L4_25-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	25%	16.8%	18.7%	35.5%	+14.3
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	21.7%	10.8%	32.5%	+10.4
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	20.1%	11.2%	31.3%	+7.1
-L4_30-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	30%	23.1%	17.0%	40.1%	+27.9
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	27.8%	6.2%	34.0%	+16.0

Notes: * The implied ICEV/HEV target in the final column of the table is presented relative to the scenario H-25 MNM.

Figure A4: Powertrain share of different options for LEV incentives for 2030



A4.3.2 Impacts on the effectiveness of reducing TTW and WTW CO_2

Table A20: Impact of LEV scenarios with different cost assumptions and mandates on TTW and WTW CO_2 (where the overall target was set in accordance with the *'low ambition'* scenario, i.e. L-25-MNM)

Scenario	Summary	2030 LEV Mandate	Reduction versus 2005	Reduction versus REF	
			TTW CO_2	TTW CO_2	WTW CO2
L-25-MNM	No LEV incentive, Central costs	n/a	28.6%	5.5%	4.9%
L-25-MNM-LxEV*	Low xEV costs	n/a			
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	30.0%	7.3%	5.4%
LEV4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	29.6%	6.9%	4.9%
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	30.1%	7.4%	4.6%
L-25-MNM-VLxEV*	***Very*** low xEV costs	n/a			
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	31.4%	9.2%	6.5%
LEV4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	31.0%	8.7%	6.1%
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	31.4%	9.1%	5.7%

Scenario	Summary	2030	Reduction versus 2005	Reduction versus REF	
		LEV Mandate	TTW CO_2	TTW CO_2	WTW CO2
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	31.1%	8.8%	6.9%
LEV4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	30.9%	8.5%	6.6%
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	31.2%	8.9%	6.3%

Notes: * No scenario runs were conducted with low and very low cost curves for xEVs.

Table A21: Impact of LEV scenarios with different cost assumptions and mandates on WTT and WTW CO2 (where the overall target was set in accordance with the *'high ambition'* scenario, i.e. H-25-MNM)

Scenario	Summary	2030 LEV Mandate	Reduction versus 2005	Reduction versus REF	
			TTW CO_2	TTW CO_2	WTW CO_2
H-25-MNM	No LEV incentive, Central costs	n/a	32.6%	10.8%	9.6%
H-25-MNM-LxEV	Low xEV costs	n/a	32.5%	10.7%	9.2%
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	32.5%	10.6%	8.5%
LEV4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	32.5%	10.6%	8.6%
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	32.8%	11.0%	8.2%
H-25-MNM-VLxEV	***Very*** low xEV costs	n/a	32.6%	10.7%	9.1%
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	33.5%	12.0%	9.4%
LEV4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	33.9%	12.5%	9.6%
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	33.6%	12.1%	8.8%

Scenario	Summary	2030	Reduction versus 2005	Reduction versus REF	
		LEV Mandate	TTW CO_2	TTW CO_2	WTW CO_2
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	33.2%	11.6%	9.5%
LEV4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	33.4%	11.8%	9.5%
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	33.4%	11.8%	9.4%

A4.3.3 Impacts on transport externalities

Table 7.10: Impact of LEV scenarios with different cost assumptions and mandates on externalities (where the overall target was set in accordance with the *'low ambition'* scenario, i.e. L-25-MNM)

Scenario	Summary	2030 LEV Mandate	% reduction in 2030 relative to baseline (REF)						
			Acci-dents	Noise	Cong-estion	Air Pollution	WTW GHG	Total Cost	Total (excl. GHG costs)*
L-25-MNM	No LEV incentive, Central costs	n/a	0.0%	-3.9%	-0.2%	-4.6%	-4.8%	**-1.1%**	**-0.4%**
L-25-MNM-LxEV*	Low xEV costs	n/a							
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	0.0%	-8.7%	-0.1%	-10.0%	-5.4%	**-1.5%**	**-0.8%**
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	-0.2%	-12.1%	-0.3%	-12.9%	-4.7%	**-1.7%**	**-1.1%**
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	-0.7%	-13.6%	-0.6%	-14.3%	-4.0%	**-2.0%**	**-1.6%**
L-25-MNM-VLxEV**	***Very*** low xEV costs	n/a							
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	0.0%	-12.6%	-0.1%	-13.7%	-6.3%	**-1.9%**	**-1.0%**
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	-0.2%	-16.0%	-0.1%	-16.9%	-5.5%	**-2.0%**	**-1.3%**
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	-0.6%	-16.8%	-0.5%	-17.2%	-4.7%	**-2.2%**	**-1.7%**
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	0.3%	-10.7%	0.2%	-11.0%	-7.0%	**-1.6%**	**-0.6%**
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	0.2%	-13.3%	0.1%	-13.8%	-6.5%	**-1.8%**	**-0.8%**
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	-0.1%	-14.1%	-0.1%	-14.1%	-6.1%	**-1.9%**	**-1.1%**

Notes: *Total of all external costs, excluding GHG costs. ** No scenario runs were conducted with low and very low cost curves for xEVs.

Table 7.11: Impact of LEV scenarios with different cost assumptions and mandates on externalities (where the overall target was set in accordance with the *'high ambition'* scenario, i.e. H-25-MNM)

Scenario	Summary	2030 LEV Mandate	% reduction in 2030 relative to baseline (REF)						
			Acci-dents	Noise	Cong-estion	Air Pollution	WTW GHG	Total Cost	Total (excl. GHG costs)*
H-25-MNM	No LEV incentive, Central costs	n/a	0.1%	-9.7%	-0.2%	-9.8%	-9.5%	**-2.2%**	**-0.8%**
H-25-MNM-LxEV	Low xEV costs	n/a	0.4%	-10.0%	0.1%	-10.4%	-9.1%	**-2.0%**	**-0.6%**
-L2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	0.1%	-11.3%	-0.1%	-12.0%	-8.4%	**-2.1%**	**-0.8%**
-L4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	0.2%	-12.4%	0.0%	-12.6%	-8.5%	**-2.1%**	**-0.8%**
-L3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	-0.2%	-14.6%	-0.3%	-15.7%	-8.0%	**-2.4%**	**-1.3%**
H-25-MNM-VLxEV	***Very*** low xEV costs	n/a	0.6%	-11.2%	0.3%	-11.1%	-9.0%	**-1.9%**	**-0.4%**
-L2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	0.3%	-14.3%	0.2%	-14.5%	-9.3%	**-2.2%**	**-0.8%**
-L4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	0.2%	-16.6%	0.2%	-17.5%	-8.8%	**-2.3%**	**-1.0%**
-L3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	0.0%	-16.8%	0.0%	-17.4%	-8.5%	**-2.4%**	**-1.2%**
-L2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	0.5%	-13.2%	0.3%	-13.2%	-9.4%	**-2.1%**	**-0.6%**
-L4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	0.4%	-14.2%	0.3%	-14.2%	-9.3%	**-2.1%**	**-0.7%**
-L3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	0.4%	-14.0%	0.2%	-14.0%	-9.3%	**-2.2%**	**-0.7%**

Notes: *Total of all external costs, excluding GHG costs.

A4.3.4 Impacts on manufacturing cost and total cost of ownership

Table A22: Impact of LEV scenarios with different cost assumptions and mandates on average manufacturing costs and Total Cost of Ownership (TCO) per vehicle for passenger cars (where the overall target was set in accordance with the *'central ambition'* scenario, i.e. C-25-MNM)

Scenario	Summary	2030 LEV Mandate	Average 2025 Cost				Average 2030 Cost			
			Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user	Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user
C-25-MNM	No LEV incentive	n/a	380	-152	-263	-329	1,020	-878	-818	-947
C-25-MNM-LxEV	Low xEV costs	n/a	215	-247	-352	-362	654	-1,133	-1,044	-1,039
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	166	-199	-353	-333	586	-1,071	-1,036	-1,013
LEV4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	186	-23	-244	-238	556	-784	-876	-869
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	185	72	-183	-195	526	-574	-771	-778
C-25-MNM-VLxEV	***Very*** low xEV costs	n/a	-2	-369	-462	-396	262	-1,349	-1,245	-1,099
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	-43	-361	-483	-385	249	-1,355	-1,256	-1,101
LEV4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	-64	-163	-371	-272	203	-1,229	-1,194	-1,037
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	-62	-165	-363	-278	171	-1,115	-1,132	-984
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	-101	-209	-417	-306	181	-1,269	-1,230	-1,062
LEV4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	-71	-70	-319	-225	147	-927	-1,033	-890
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	-91	125	-204	-132	106	-741	-939	-806

Notes: All costs are calculated relative to those from the baseline (REF) scenario, hence can be positive (increased cost) or negative (decreased cost).

Table A23: Impact of LEV scenarios with different cost assumptions and mandates on average manufacturing costs and Total Cost of Ownership (TCO) per vehicle for passenger cars (where the overall target was set in accordance with the *'low ambition'* scenario, i.e. L-25-MNM)

Scenario	Summary	2030 LEV Mandate	Average 2025 Cost				Average 2030 Cost			
			Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user	Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user
L-25-MNM	No LEV incentive	n/a	115	-100	-200	-201	419	-802	-723	-708
L-25-MNM-LxEV	Low xEV costs	n/a								
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	-53	-70	-231	-172	146	-783	-784	-692
LEV4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	-23	7	-174	-129	204	-340	-511	-478
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	7	268	-13	-5	217	-63	-355	-361
L-25-MNM-VLxEV	***Very*** low xEV costs	n/a								
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	-241	-248	-360	-232	-116	-984	-934	-746
LEV4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	-233	-106	-276	-154	-114	-810	-836	-662
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	-230	-3	-209	-107	-117	-645	-741	-589
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	-273	-27	-257	-124	-139	-854	-878	-692
LEV4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	-229	131	-139	-33	-107	-407	-600	-471
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	-231	358	-5	73	-120	-195	-487	-377

Notes: All costs are calculated relative to those from the baseline (REF) scenario, hence can be positive (increased cost) or negative (decreased cost). It is judged highly unlikely that xEV costs would reach low or very low levels for Low Ambition in the absence of an LEV mandate, hence these options were not modelled.

Table A24: Impact of LEV scenarios with different cost assumptions and mandates on average manufacturing costs and Total Cost of Ownership (TCO) per vehicle for passenger cars (where the overall target was set in accordance with the *'high ambition'* scenario, i.e. H-25-MNM)

Scenario	Summary	2030 LEV Mandate	Average 2025 Cost				Average 2030 Cost			
			Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user	Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user
H-25-MNM	No LEV incentive	n/a	747	-78	-241	-420	1,812	-565	-639	-1,022
H-25-MNM-LxEV	Low xEV costs	n/a	526	-247	-386	-481	1,310	-994	-998	-1,183
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	486	-272	-427	-486	1,272	-965	-997	-1,170
LEV4_25-LxEV	25/25; ZEV/PHEV = 1; low xEV costs	25%	499	-236	-396	-462	1,276	-985	-1,005	-1,179
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	460	-69	-309	-378	1,132	-938	-1,014	-1,149
H-25-MNM-VLxEV	***Very*** low xEV costs	n/a	193	-465	-581	-547	791	-1,428	-1,360	-1,331
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	179	-513	-623	-565	794	-1,420	-1,356	-1,329
LEV4_25-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	25%	160	-460	-595	-531	768	-1,430	-1,367	-1,331
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	157	-438	-578	-522	785	-1,432	-1,363	-1,333
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	116	-462	-615	-535	730	-1,456	-1,395	-1,342
LEV4_30-VLxEV	25/25; ZEV/PHEV = 1; ***very*** low xEV costs	30%	85	-312	-531	-446	649	-1,391	-1,378	-1,303
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	73	-282	-507	-434	547	-1,316	-1,360	-1,263

Notes: All costs are calculated relative to those from the baseline (REF) scenario, hence can be positive (increased cost) or negative (decreased cost).

Table A25: Impact of LEV scenarios with different cost assumptions and mandates on average manufacturing costs and Total Cost of Ownership (TCO) per vehicle for LCVs (where the overall target was set in accordance with the *'central ambition'* scenario, i.e. C-25-MNM)

			Average 2025 Cost				Average 2030 Cost			
Scenario	**Summary**	**2030 LEV Mandate**	**Manuf-acturing**	**TCO Societal**	**TCO 1st End-user**	**TCO 2nd End-user**	**Manuf-acturing**	**TCO Societal**	**TCO 1st End-user**	**TCO 2nd End-user**
C-25-MNM	No LEV incentive	n/a	355	-962	-1,083	-809	620	-2,037	-2,184	-1,582
C-25-MNM-LxEV	Low xEV costs	n/a	240	-979	-1,093	-804	358	-2,163	-2,253	-1,602
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	310	-462	-816	-638	485	-1,366	-1,774	-1,323
LEV4_25-LxEV	40/40; ZEV/PHEV = 1; low xEV costs	25%	346	-661	-898	-694	501	-1,717	-1,958	-1,435
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	513	243	-387	-395	724	-394	-1,152	-964
C-25-MNM-VLxEV	***Very*** low xEV costs	n/a	85	-956	-1,072	-775	135	-2,025	-2,125	-1,501
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	115	-577	-880	-661	210	-1,502	-1,813	-1,317
LEV4_25-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	35%	145	-726	-931	-696	170	-1,881	-2,030	-1,445
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	251	53	-500	-441	332	-752	-1,332	-1,037
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	226	-35	-556	-473	266	-1,105	-1,567	-1,174
LEV4_30-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	40%	232	-394	-722	-577	270	-1,390	-1,696	-1,253
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	411	721	-89	-199	454	-148	-939	-807

Notes: All costs are calculated relative to those from the baseline (REF) scenario, hence can be positive (increased cost) or negative (decreased cost).

Table A26: Impact of LEV scenarios with different cost assumptions and mandates on average manufacturing costs and Total Cost of Ownership (TCO) per vehicle for LCVs (where the overall target was set in accordance with the *'low ambition'* scenario, i.e. L-25-MNM)

			Average 2025 Cost				Average 2030 Cost			
Scenario	**Summary**	**2030 LEV Mandate**	**Manuf-acturing**	**TCO Societal**	**TCO 1st End-user**	**TCO 2nd End-user**	**Manuf-acturing**	**TCO Societal**	**TCO 1st End-user**	**TCO 2nd End-user**
L-25-MNM	No LEV incentive	n/a	232	-810	-889	-655	426	-1,688	-1,783	-1,282
L-25-MNM-LxEV	Low xEV costs	n/a								
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	237	-204	-555	-453	342	-932	-1,317	-992
LEV4_25-LxEV	40/40; ZEV/PHEV = 1; low xEV costs	25%	294	-372	-617	-495	399	-1,194	-1,443	-1,074
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	455	500	-123	-205	632	128	-638	-601
L-25-MNM-VLxEV	***Very*** low xEV costs	n/a								
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	39	-349	-637	-482	90	-1,051	-1,346	-983
LEV4_25-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	35%	47	-575	-739	-547	57	-1,395	-1,537	-1,094
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	188	306	-240	-252	239	-249	-831	-684
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	173	276	-259	-262	140	-682	-1,111	-846
LEV4_30-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	40%	203	-45	-404	-356	209	-784	-1,129	-861
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	349	947	153	-24	362	236	-530	-515

Notes: All costs are calculated relative to those from the baseline (REF) scenario, hence can be positive (increased cost) or negative (decreased cost). It is judged highly unlikely that xEV costs would reach low or very low levels for Low Ambition in the absence of an LEV mandate, hence these options were not modelled.

Table A27: Impact of LEV scenarios with different cost assumptions and mandates on average manufacturing costs and Total Cost of Ownership (TCO) per vehicle for LCVs (where the overall target was set in accordance with the *'high ambition'* scenario, i.e. H-25-MNM)

Scenario	Summary	2030 LEV Mandate	Average 2025 Cost				Average 2030 Cost			
			Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user	Manuf-acturing	TCO Societal	TCO 1st End-user	TCO 2nd End-user
H-25-MNM	No LEV incentive	n/a	877	-1,291	-1,616	-1,258	1,582	-2,389	-2,912	-2,217
H-25-MNM-LxEV	Low xEV costs	n/a	669	-1,416	-1,698	-1,290	1,091	-2,808	-3,175	-2,339
LEV2_15-LxEV	0/0; ZEV = 1; PHEV = 0; low xEV costs	15%	694	-1,041	-1,513	-1,183	1,153	-2,219	-2,830	-2,137
LEV4_25-LxEV	40/40; ZEV/PHEV = 1; low xEV costs	25%	806	-990	-1,444	-1,154	1,204	-2,241	-2,804	-2,123
LEV3_25-LxEV	50/50; ZEV = 1; PHEV < 1; low xEV costs	25%	798	-580	-1,240	-1,026	1,236	-1,636	-2,468	-1,926
H-25-MNM-VLxEV	***Very*** low xEV costs	n/a	431	-1,314	-1,637	-1,230	691	-2,863	-3,172	-2,304
LEV2_15-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	15%	406	-1,312	-1,665	-1,246	696	-2,704	-3,076	-2,245
LEV4_25-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	35%	484	-916	-1,401	-1,095	717	-2,444	-2,884	-2,131
LEV3_25-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	25%	464	-859	-1,400	-1,090	733	-2,203	-2,764	-2,062
LEV2_20-VLxEV	0/0; ZEV = 1; PHEV = 0; ***very*** low xEV costs	20%	459	-840	-1,392	-1,086	718	-2,365	-2,871	-2,126
LEV4_30-VLxEV	40/40; ZEV/PHEV = 1; ***very*** low xEV costs	40%	586	-485	-1,127	-936	778	-1,909	-2,516	-1,914
LEV3_30-VLxEV	50/50; ZEV = 1; PHEV < 1; ***very*** low xEV costs	30%	555	-268	-1,047	-884	764	-1,751	-2,479	-1,894

Notes: All costs are calculated relative to those from the baseline (REF) scenario, hence can be positive (increased cost) or negative (decreased cost).

A5 Appendix 5: Additional information from the social equity analysis

A5.1 Sensitivities on the economic lifetimes of vehicles

The following figures present the sensitivity analysis for different economic lifetimes for the vehicles (7, 5 and 4 years, respectively).

Figure A5: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 7 years

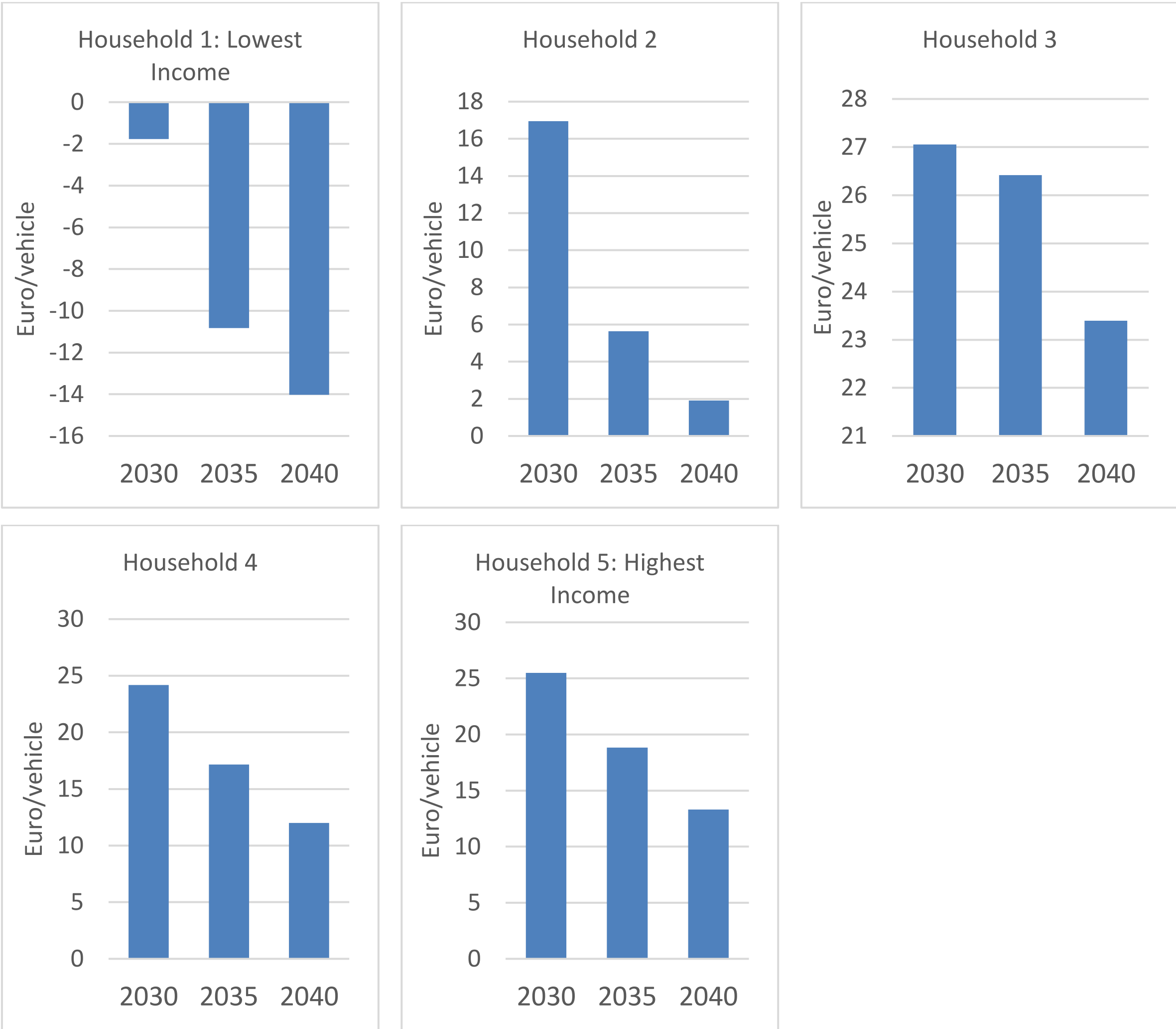


Figure A6: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 5 years

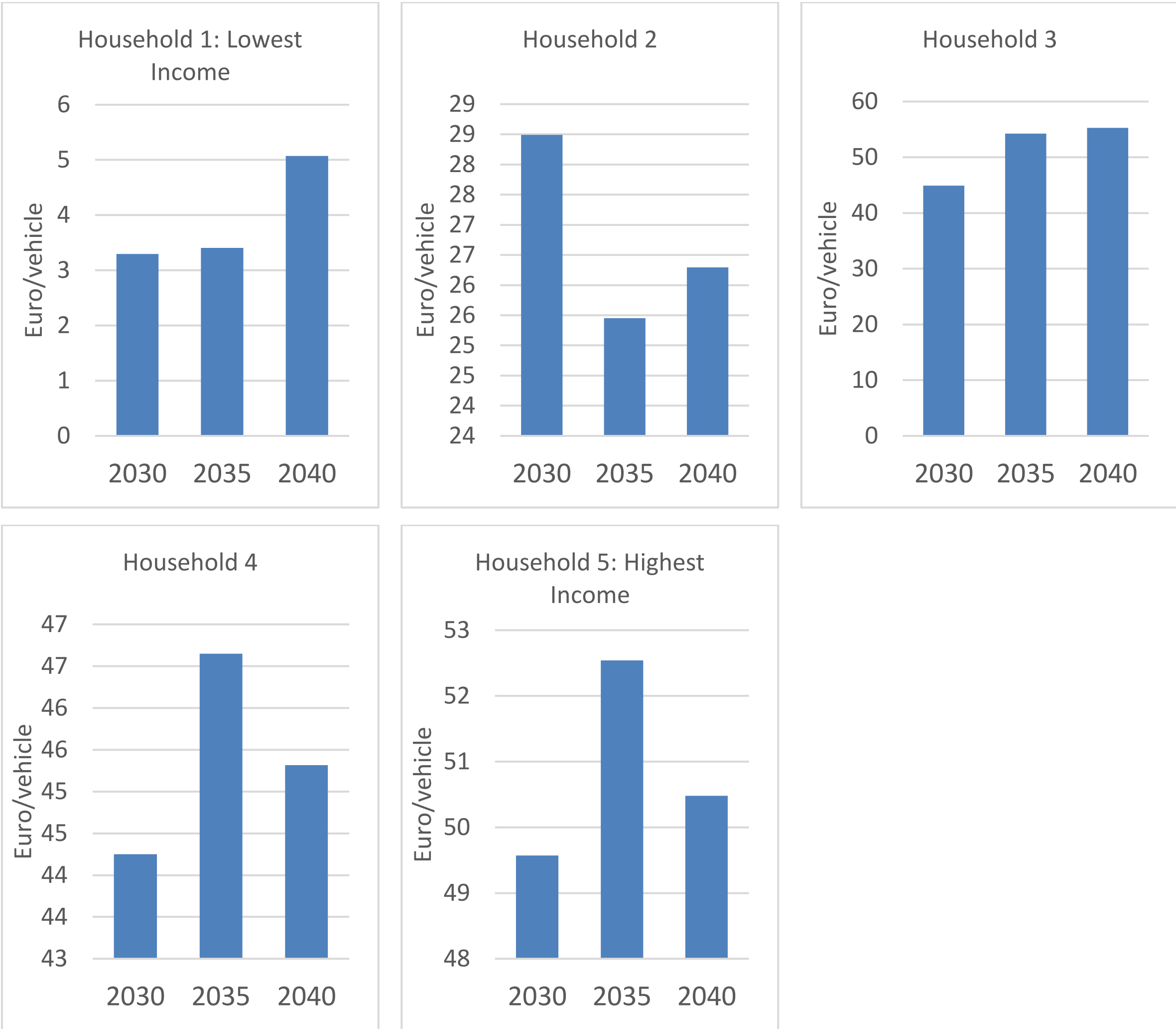
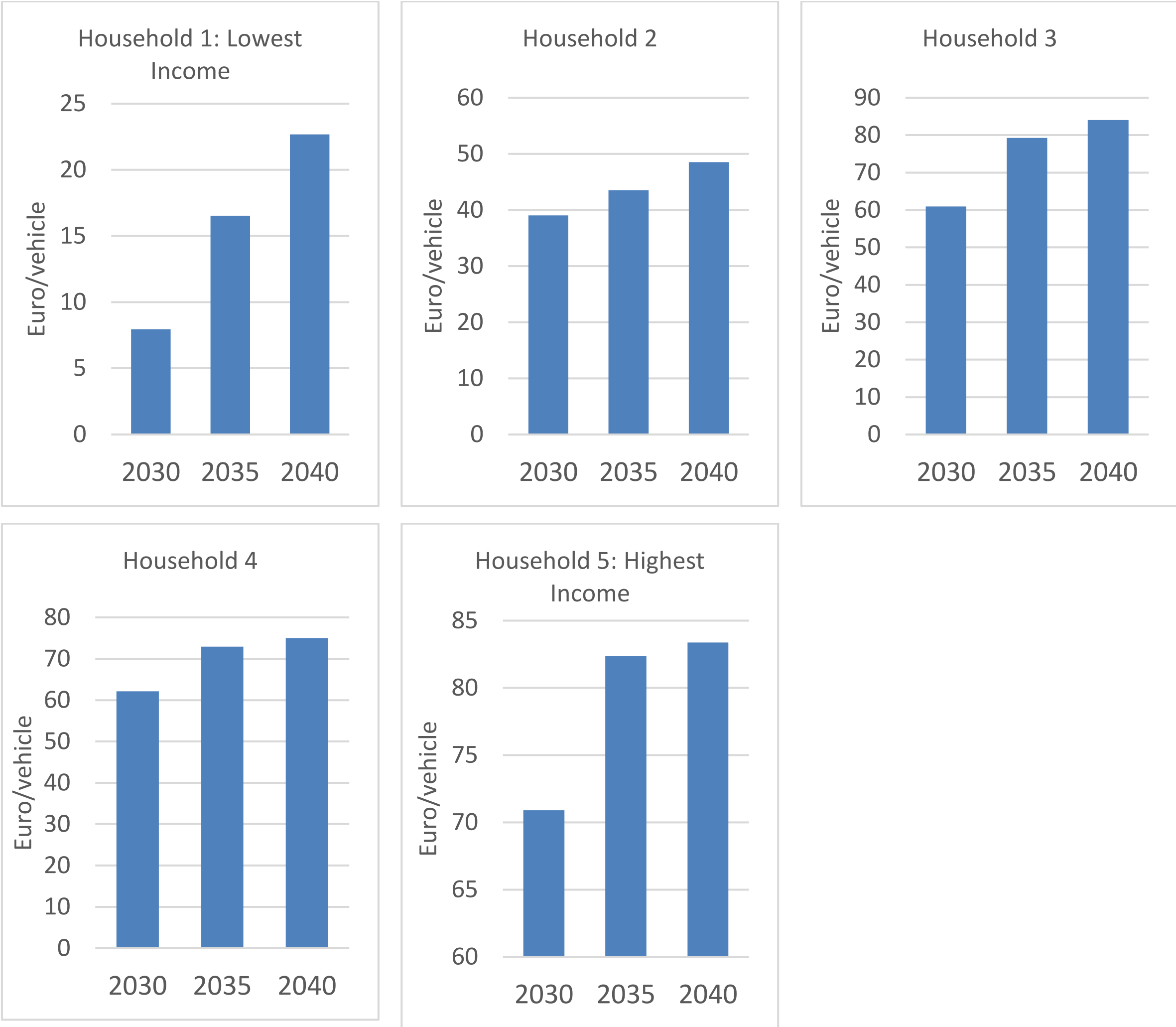


Figure A7: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 4 years



A5.2 Sensitivity analysis over discount rates

The analysis considers two counterfactual cases: a high and a low discount rate case. Both cases assume that the economic lifetime of the car is 7 years. The discount rates assumed are presented in Table A28. The purpose of this analysis is to test how sensitive are the results when differentiating the discount rates over the household categories. The discount rates have been assumed to decrease as the income increases (see Table A28).

The impacts are positive for the two household categories with the lowest income when assuming low discount rates. The lower discount rate undervalues the annuity payment for the vehicle price compared to the annual fuel savings, which justifies the negative values shown in graphs (i.e. savings)

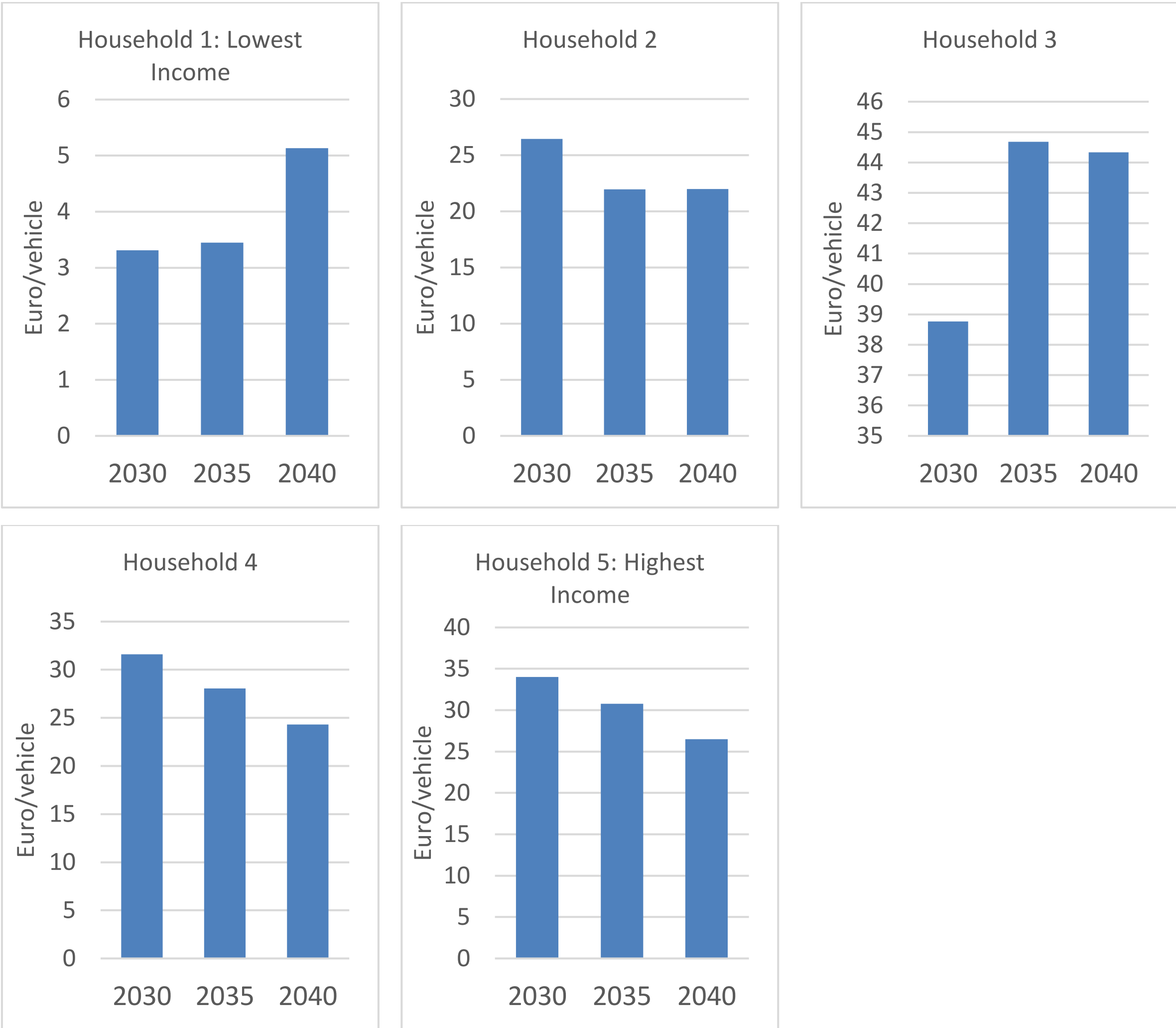
Table A28: Assumed discount rates by household class for the sensitivity runs over the duration of the economic lifetime of cars

Household Income class	Central	High case	Low case
Household 1: Lowest Income	23%	30%	18%
Household 2	20%	26%	15%
Household 3	17%	22%	13%

Household Income class	Central	High case	Low case
Household 4	13%	16%	10%
Household 5: Highest Income	10%	13%	8%

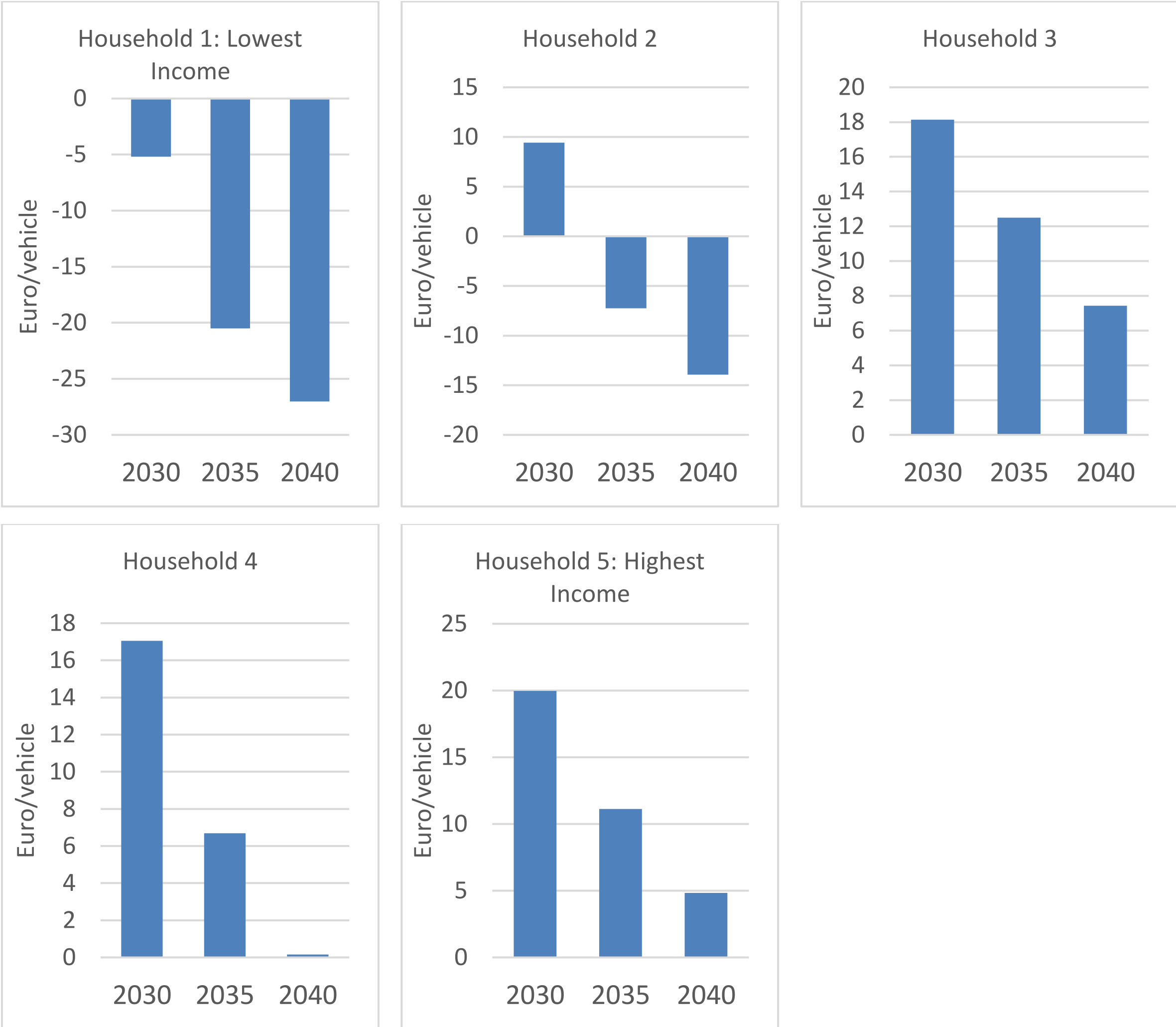
Under a high discount rate case, all household classes experience losses. However, low income classes again experience the lowest negative impact (in the order of €3 to €5 per vehicle per annum per household for the lowest income household). Losses increase by an order of magnitude for all the remaining household categories.

Figure A8: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 7 years, HIGH discount rates



The sensitivity analysis over the discount rates is presented in the following.

Figure A9: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 7 years, LOW discount rates



A5.3 Sensitivity analysis over depreciation of vehicles through the years

As has been already depicted, the low-income households benefit from the implementation of more optimistic targets (relative to the baseline scenario), as they are able to purchase more fuel-efficient second-hand cars without a significant increase in the vehicle price. The higher-income households face the higher vehicle price and sustain the depreciation of their vehicle.

This section aims to assess the impact of the assumption on the vehicle depreciation rate over the years. The sensitivities are based on the seven-year economic lifetime case with central discount rates. All the above-mentioned cases are quantified using a "central case" assumptions on depreciation rates. Table A29 presents a 'high" and a "low" case with varying depreciation rates. Low depreciation refers to a case where second-hand cars retain their original price for longer time-periods; in other words, cars do not lose their value abruptly.

Table A29: Assumed depreciation rates of vehicles over the age cohorts for the sensitivity runs

Age cohort	Central Depreciation	High Depreciation	Low Depreciation
New registrations	1	1	1
0-5 years	0.8	0.75	0.9
5-10 years	0.65	0.55	0.75
> 10 years	0.15	0.1	0.3

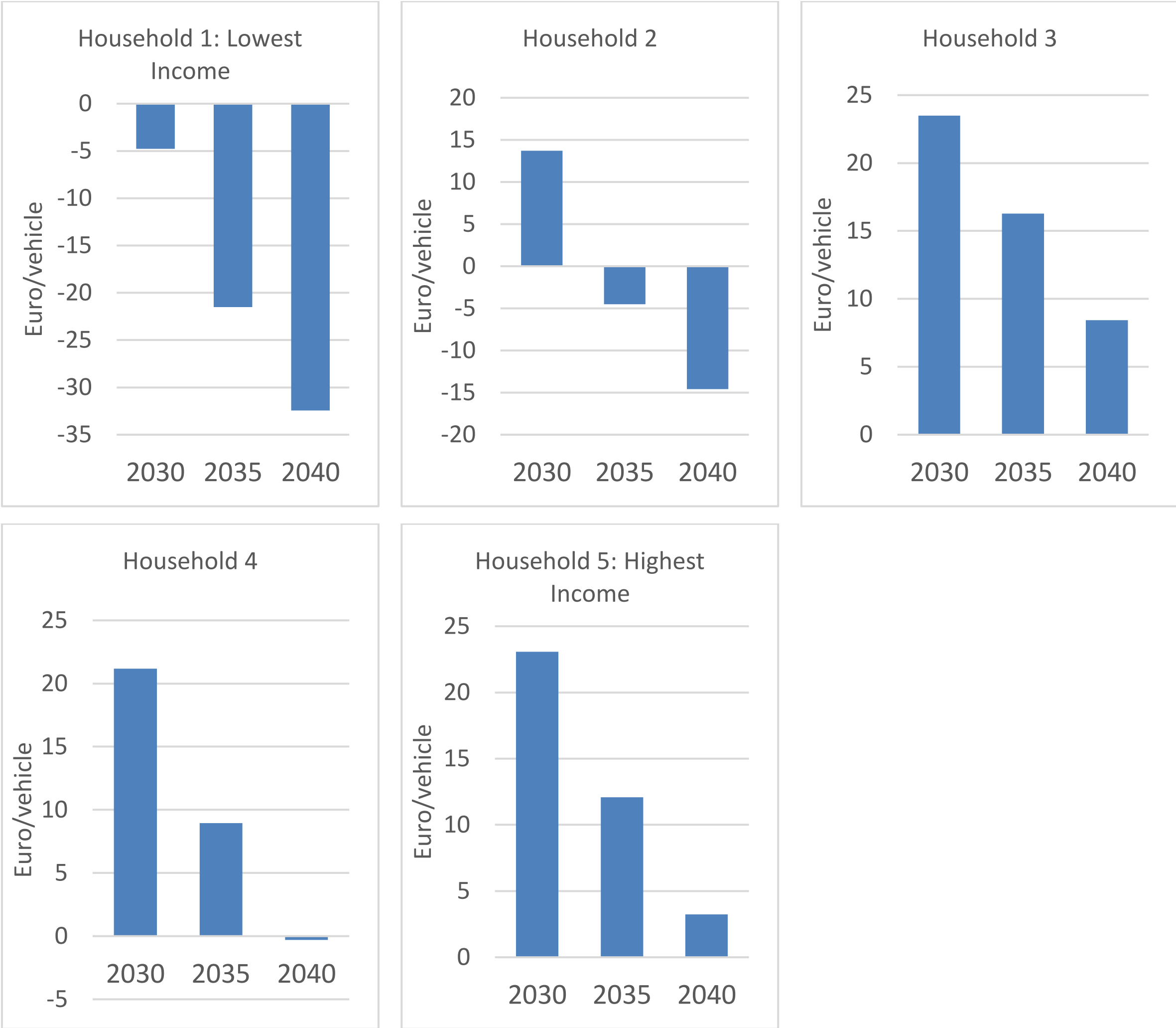
The values presented in Table A29 denote the depreciation rate $Deprec_a$ relative to the age cohort a. Then the vehicle price $Vehprice_a$ per age cohort is calculated as shown:

$$Vehprice_a = Deprec_a \cdot Vehprice_{New}$$

The higher depreciation yields additional annual savings for the households that mainly purchase old second-hand cars. In that case, second-hand car prices are becoming cheaper, while at the same time the owners benefit from the fuel savings. Hence, the impact of higher depreciation rate is obvious to all income classes. However, the order of magnitude of the benefit increases as the income of the household decreases.

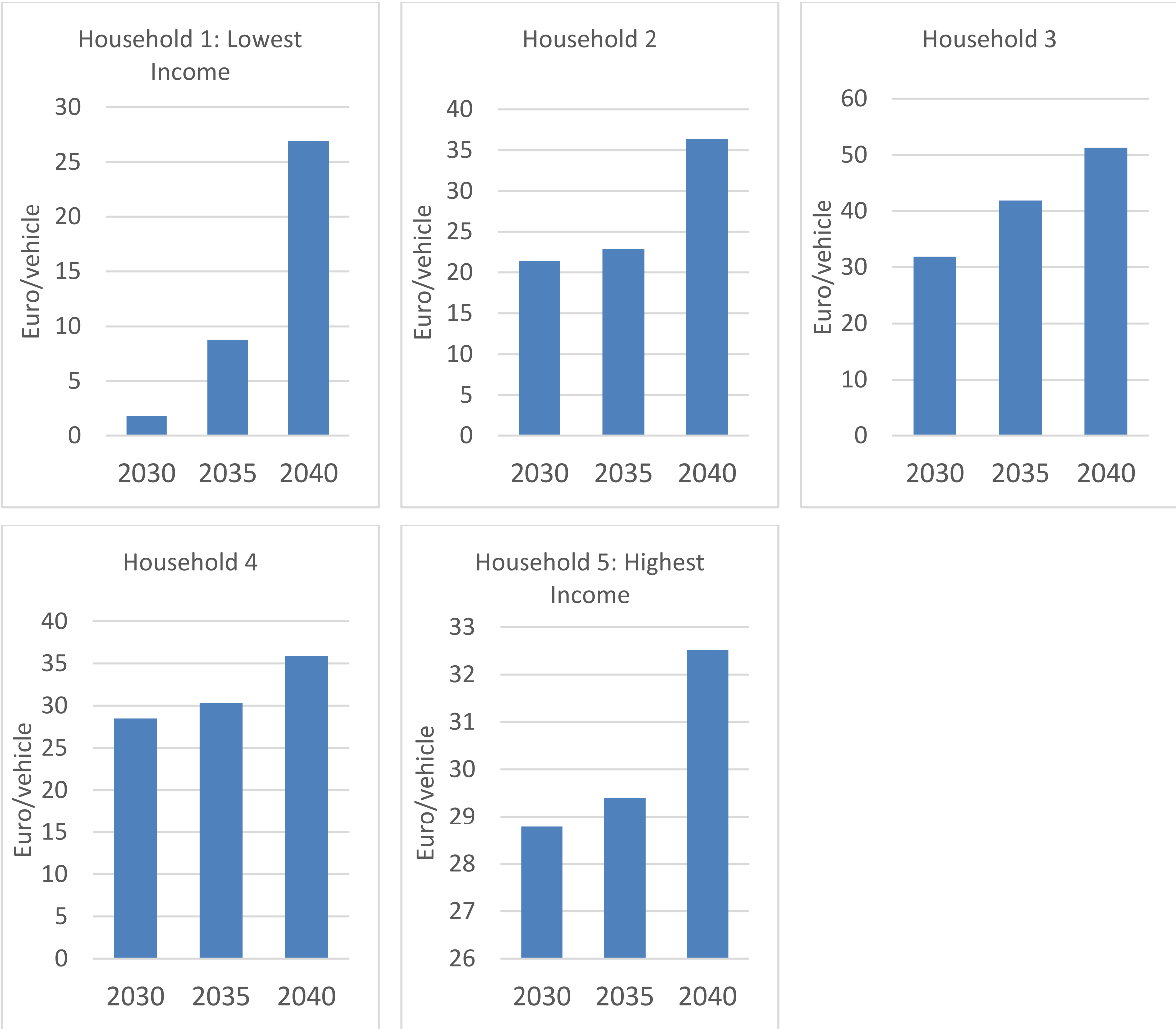
In contrast, low depreciation rates yield negative impacts on the low-income households given that they do not benefit that much from lower second-hand vehicle prices. Indeed, all households bear negative impacts, as all of them purchase a portion of second-hand cars. However, the impacts on all households tend to be at the same order of magnitude when approaching 2040 when more second-hand cars registered new in 2030 penetrate the market.

Figure A10: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 7 years, Central discount rates, HIGH Depreciation



A comparison is presented on the savings/additional costs for the C-25-MNM scenario assuming low depreciation rates for second hand cars.

Figure A11: Savings/Additional cost per household category in the C-25-MNM scenario relative to Baseline ("-" means savings): Economic lifetime assumed 7 years, Central discount rates, LOW Depreciation



A comparison is presented on the savings/additional costs that different household categories face on the three level of ambition scenarios.

Figure A12: Savings/Additional cost for the "Household 2" category in the L-25-MNM, C-25-MNM and H-25-MNM scenarios relative to Baseline ("-" means savings): Economic lifetime assumed 10 years, Central discount rates, Central Depreciation

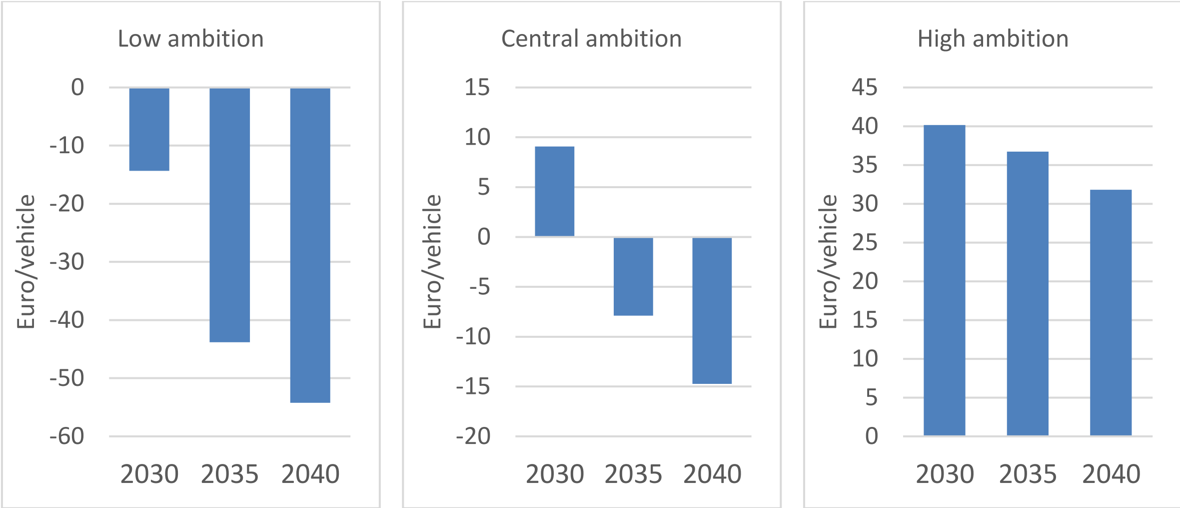


Figure A13: Savings/Additional cost for the "Household 3" category in the L-25-MNM, C-25-MNM and H-25-MNM scenarios relative to Baseline ("-" means savings): Economic lifetime assumed 10 years, Central discount rates, Central Depreciation

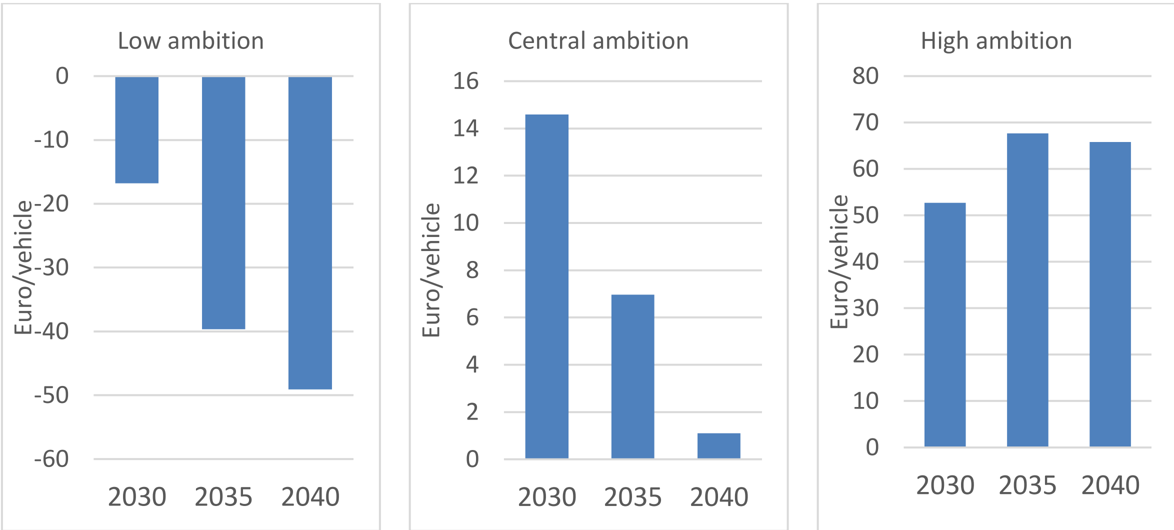
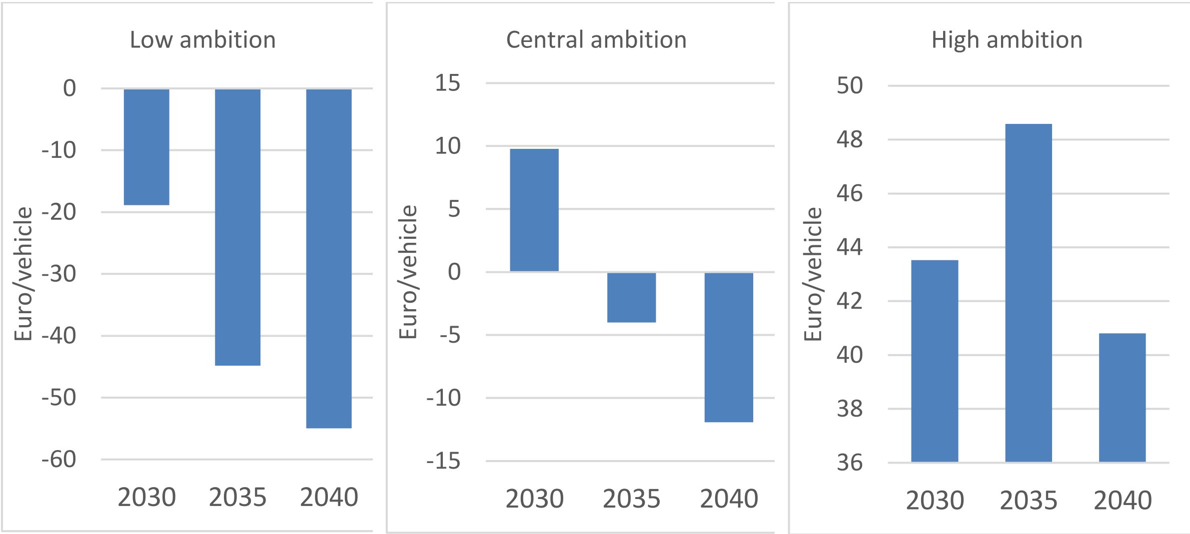


Figure A14: Savings/Additional cost for the "Household 4" category in the L-25-MNM, C-25-MNM and H-25-MNM scenarios relative to Baseline ("-" means savings): Economic lifetime assumed 10 years, Central discount rates, Central Depreciation



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