Ricardo
Energy & Environment

Europe's Clean Mobility Outlook: Scenarios for the EU light-duty vehicle fleet, associated energy needs and emissions, 2020-2050

Final Report for ePURE

ED11522 | Issue Number 3 | Date 06/06/2018
Ricardo in Confidence

Customer:

ePURE

Customer reference:

N/A

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06 June 2018

Ricardo Energy & Environment reference:

Ref: ED11522 - Issue Number 3

Executive Summary

This study, commissioned by ePURE assesses the potential contribution of low carbon fuels in decarbonising conventionally fuelled light duty vehicles (LDVs, i.e. passenger cars and vans) from 2020-2050 in the context of the European Commission's 2nd Clean Mobility Package (CMP)[1], and the EU's medium- and long-term GHG reduction targets.

The 2nd CMP sets target reductions for tailpipe emissions of CO_2 from new LDVs post 2020, but does not address the decarbonisation of fuels used in vehicles. This is currently covered by the Fuel Quality Directive (FQD), which requires a 6% reduction in the GHG intensity of fuels between 2010 and 2020, but there are no plans to extend this target post-2020. Instead, it is proposed that decarbonisation of fuels is addressed in the proposed revised Renewable Energy Directive (RED II), through targets/caps for the inclusion of low carbon fuels and minimum GHG savings requirements.

Existing analysis shows that one way the reductions in GHG emissions from new cars and vans required by the 2nd CMP can be met is by a high penetration of electric vehicles (xEVs) into the fleet. **However, when considering approaches to decarbonising the sector, a technology-neutral approach is important.** This study therefore examines the contributions that other elements of a strategy to reduce GHG emissions from light duty vehicles could make – namely, decarbonisation of the fuel supply through the use of sustainable biofuels (as well as other low carbon fuels). **The study therefore broadens the scope of emissions from a narrow (tailpipe/tank to wheel approach) to a Well-to-Wheel approach. It does not, however, consider other emissions associated with the vehicle lifecycle (vehicle production and end of life emissions) in its scope.**

To explore this, **three scenarios of powertrain fuel development were considered**, that all meet the future improvement trajectory for the proposed post-CO_2 regulatory targets for new cars and vans:

- Low xEV powertrain deployment scenario (LOxEV).
- Medium xEV powertrain deployment scenario (MIDxEV).
- High xEV powertrain deployment scenario (HIxEV).

The impact of these scenarios on the composition of the LDV fleet, energy consumption and GHG emissions was then assessed using the SULTAN model, developed by Ricardo Energy & Environment. **GHG emissions were assessed on both a 'tail-pipe'/ Tank-to-Wheel (TTW) basis and a fuel life-cycle/ Well-to Wheel (WTW) basis.** Impacts of these three scenarios were assessed for:

- **A reference fuel scenario,** where biofuel substitution shares are assumed to remain constant post-2020 at the levels defined in European Commission's 2016 Reference Scenario (European Commission, 2016a).
- **A Low Carbon Fuel scenario (LCF1)** where biofuel production continues to rise post-2020, at a level considered to reflect realistic rates of development within the industry. Assumptions are relatively conservative compared to those in some other some recent analyses, e.g. (P Baker et al, 2017).

Figure E1 clearly demonstrates the important contribution that increased use of low carbon fuels could make to reducing the GHG emissions from LDVs in 2030. For all potential xEV uptake rates, additional low carbon fuels reduce TTW GHG emissions further (compared to 2005[2]) by at least four percentage points. Impacts on WTW emissions from the introduction of more low carbon fuels are similar, with the increase in low carbon fuels further improving GHG savings by three percentage points. **The additional savings generated by the increased use of low carbon fuels, mean that even with low electrification rates, reductions achieved under a low carbon fuels scenario are greater than a scenario with high electrification but no increased use of low carbon fuels. This is true even if electricity decarbonises more rapidly than in the reference scenario (scenario EGL in Figure E1).**

Similar results are obtained for 2050, confirming that **increased future deployment of sustainable low carbon fuels could make an important contribution to reducing the GHG emissions from LDVs in both the medium and long-term**. Importantly, the analysis showed that the EU's long-term

[1] https://ec.europa.eu/transport/modes/road/news/2017-11-08-driving-clean-mobility_en

[2] The EU's 2030 climate and energy framework (European Commission, 2017c) sets an objective to reduce GHG emissions in non-ETS sectors by 30%, relative to 2005, by 2030.

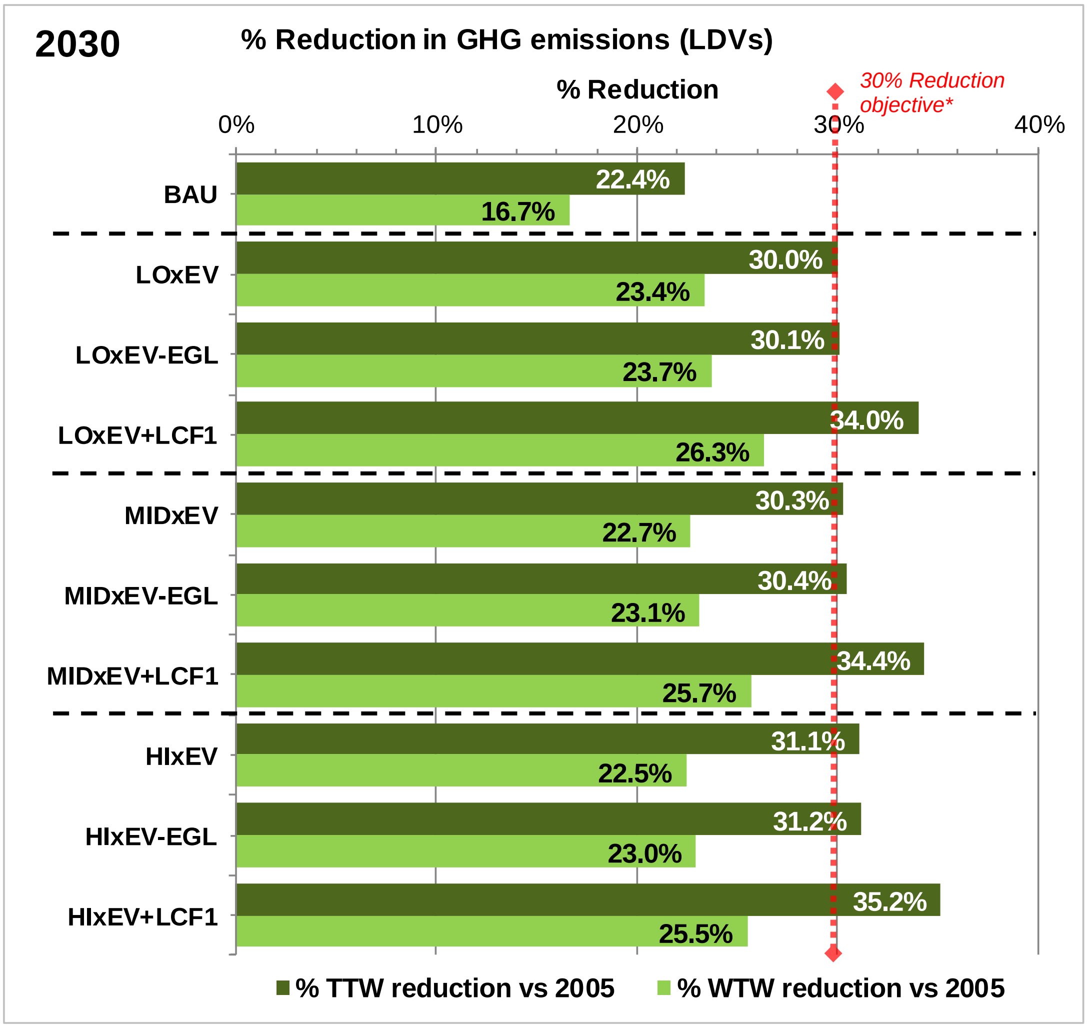
transport GHG reduction objectives are unlikely to be achieved without additional measures beyond the rate of CO_2 reduction set in the post-2020 CO_2 regulation proposals.

Utilisation of low carbon fuels could therefore provide additional GHG emission reductions that would otherwise not be achieved, and/or mitigate for potential uncertainty in the longer-term GHG intensity of electricity used by plug-in electric LDVs, as well as availability of key resources needed for xEVs, and/or their higher manufacturing emissions.

For a given trajectory of improvement in regulatory tailpipe gCO_2/km emissions, conventional fuel consumption and GHG emissions reductions are relatively insensitive to different assumptions on xEV uptake. This is because with higher xEV shares, the improvement trajectory can be met with lower rates of improvement to conventional and regular hybrid powertrains can be lower, and this offsets the reductions in conventional fuel use caused by a shift to xEV.

Additional sensitivity modelling to examine the impact of an increased share of 1G bioethanol in the low carbon fuels scenario (offset by a reduction in FAME biodiesel), illustrated that additional direct (TTW) and WTW GHG emissions savings could be possible in this case.

Figure E1: Reduction in LDV GHG emissions in 2030 compared to 2005



Notes: * The EU has an objective for 2030 to reduce EU non-ETS sector GHG emissions by 30%, relative to 2005.

Key:

BAU	European Commission's 2016 Reference Scenario	**LOxEV**	Low xEV deployment
LCF1	Increase Low Carbon Fuels	**MIDxEV**	Intermediate xEV deployment
EGL	low GHG intensity electricity	**HIxEV**	High xEV deployment

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Abbreviation	Description
1G	First generation [biofuels produced mainly from crop-based feedstocks]
2G	Second generation/advanced [biofuels produced mainly from non-feed crop-based feedstocks]
BAU	Business As Usual
BEV or EV	Battery Electric Vehicle
Biogasoline	Generic term for renewable fuels which can be blended with conventional gasoline including bioethanol and syngasoline
CI engines	Compression-ignition engines
CO_2	Carbon dioxide
E20	Petrol fuel containing 20% bioethanol on a volumetric basis
ECF	European Climate Foundation
eFuel	A term often used for so-called 'power-to-liquids' (PtL) fuels produced using (ideally renewable) electricity and captured/ waste CO_2 streams to produce syngas, followed by a Fisher-Tropsch processes to produce synthetic liquid fuels
ESD	Effort Sharing Decision[3]
ETS	Emissions Trading System[4]
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse gas
HEV	Hybrid Electric Vehicle (non-plug-in)
HVO	Hydrotreated Vegetable Oil
ILUC	Indirect Land Use Change
LCV	Light Commercial Vehicle
LDV	Light Duty Vehicle (i.e. cars and LCVs)
LUC	Land Use Change (direct or indirect)
MS	Member State (of the European Union)
NEDC	New European Driving Cycle
PHEV	Plug-in Hybrid Electric Vehicle
REEV or REX	Range-Extended Electric Vehicle
Syndiesel	Synthetic diesel is produced from syngas using the Fischer-Tropsch process. It is a 'drop-in' replacement for conventional diesel, as it has similar properties
Syngasoline	Synthetic gasoline is produced from syngas using the Fischer-Tropsch process. It is a 'drop-in' replacement for conventional gasoline as it has similar properties.
Syngas	Synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide. It can be produced by gasifiying biomass.
TTW	Tank-to-Wheel analysis – i.e. 'tailpipe' emissions
WLTP	Worldwide Harmonised Light-duty Test Procedure
WTW	Well-to-Wheel analysis on a life-cycle basis
xEV	Generic grouping of BEV, PHEV, REEV or FCEV powertrain types. Does NOT include HEV (conventional/non-plug-in hybrid electric vehicles)

[3] http://ec.europa.eu/clima/policies/effort/index_en.htm
[4] http://ec.europa.eu/clima/policies/ets/index_en.htm

1 Introduction

ePURE commissioned Ricardo Energy & Environment to assess the potential contribution of low carbon fuels in decarbonising conventionally fuelled light duty vehicles (LDVs, i.e. cars and vans) from 2020-2050 in the context of the European Commission's 2nd Clean Mobility Package (CMP), and the EU's medium- and long-term GHG reduction targets.

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's climate and energy policy framework for 2030, which has been agreed by Member States (MS), sets an economy-wide GHG reduction target of 40% compared to 1990 levels by 2030. This target is split between the ETS (Emissions Trading System[5]) and non-ETS sectors and translates to a reduction of 30% for non-ETS sectors by 2030 (compared to 2005). The Commission's White Paper on Transport sets out two targets for transport emissions: a 20% reduction from 2008 levels by 2030, and a 60% reduction from 1990 levels by 2050.

In November 2017, the European Commission launched the 2nd Clean Mobility Package (CMP) (European Commission, 2017), setting out CO_2 standards for new cars and vans for 2021 to 2030, which would mean that average CO_2 emissions for new vehicles would have to be 30% lower in 2030, compared to 2021 (European Commission, 2017a)[6]. Furthermore, additional measures included:

- Updates to the Clean Vehicles Directive to promote clean mobility solutions in public procurement;
- An action plan and investment solutions for the EU deployment of alternative fuels infrastructure;
- The revision of the Combined Transport Directive, which promotes the combined use of different modes for freight transport (e.g. lorries and trains);
- The Directive on Passenger Coach Services, to stimulate the development of long distance bus connections;
- An EU battery initiative of strategic importance to the EU's integrated industrial policy.

While analysis shows that one way the required reductions in GHG emissions from new cars and vans can be met is by a high penetration of electric vehicles into the fleet, ePURE wish to ensure that a technology neutral view is adopted when considering approaches to decarbonising the sector. Consequently, ePURE commissioned this study to look at the contributions that other elements of a strategy to reduce *both* TTW and WTW GHG emissions from light duty vehicles could make – namely, improvements in the fuel consumption of conventional vehicles and decarbonisation of the fuel supply through the use of sustainable biofuels.

The decarbonisation of fuels used in vehicles is currently covered by the Fuel Quality Directive (FQD), which required a 6% reduction in the GHG intensity of fuels between 2010 and 2020, but there are no plans to extend this target post-2020. Instead, it is proposed that decarbonisation of fuels is addressed in the proposed revised Renewable Energy Directive (RED II). Currently, EU policy on low carbon fuels is in a state of flux; proposals were put forward by the Commission in the recast of the Renewable Energy Directive (RED) on targets for renewables in transport, a strengthening of the cap on crop-based biofuels and minimum GHG savings going forward. However, these were not agreed by the Council, nor the European Parliament, who both came up with alternative proposals. The proposed Directive is at the time of writing the subject of trilogue negotiations, meaning that policy on renewable transport fuels for the post-2020 period is still unclear.

Specifically, this study looks at the potential impacts, on the whole LDV fleet/vehicle parc, of scenarios for the uptake of new alternatively fuelled LDVs and low carbon fuel substitution rates on:

- Composition of different powertrain/fuel types in the overall EU light-duty vehicle fleet.
- Energy consumption – the breakdown/volumes for conventional and low carbon fuels.
- GHG emissions (tailpipe, or tank-to-wheel, and well-to-wheel).

The work has been completed using Ricardo's well-regarded SULTAN model (see Box 1 below), with a high-level overview of the methodology outlined in Figure 1.1.

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[5] http://ec.europa.eu/clima/policies/ets/index_en.htm

[6] A transition has been taking place in the regulatory test-cycle / test procedures from the NEDC (upon which the 2020/21 targets are based) to WLTP (Worldwide Harmonised Light duty vehicle Test Procedure). Due to the uncertainty in the correlation between NEDC and WLTP at 2021, the post-2020 CO_2 targets will be set relative to the final WLTP values. There is therefore uncertainty on what the final gCO_2/km targets will be.

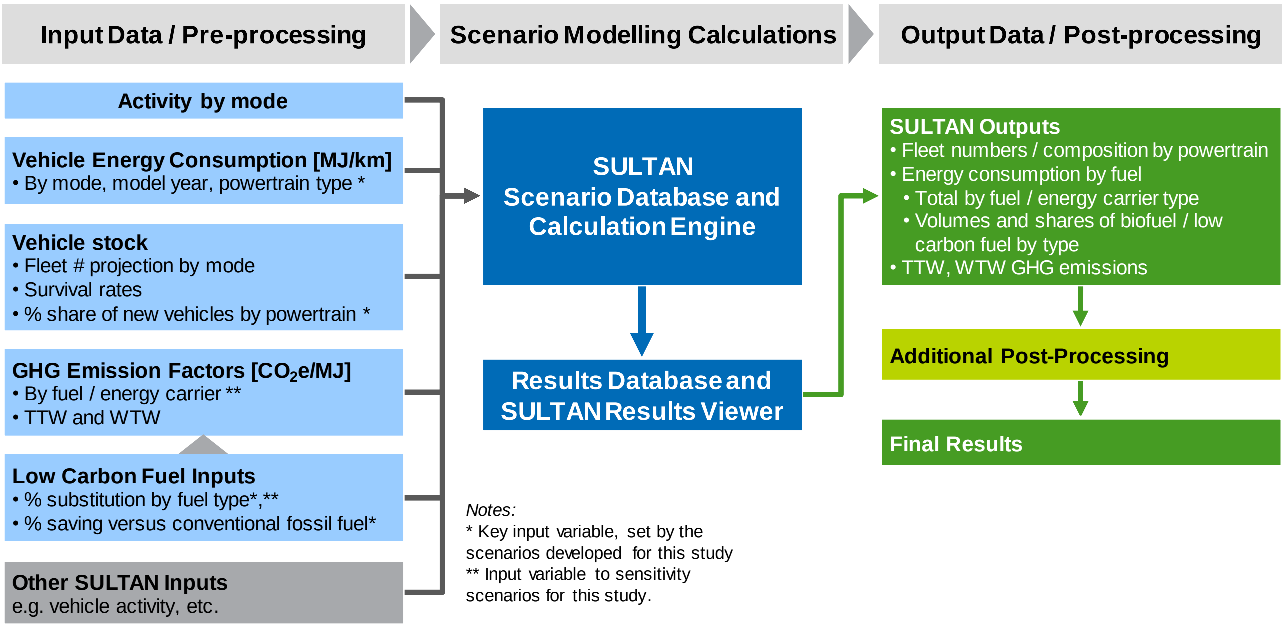
The scenarios of the deployment of different powertrains and low carbon fuels availability which were modelled, are described in Section 2 of the report. Section 3 gives results regarding fleet composition, energy consumption, low carbon fuels (including biofuels) consumption and tank-to-wheel/well-to-wheel greenhouse gas emissions. The results from sensitivity analysis, based on differing carbon intensity assumptions for electricity and differences in the composition of biofuels available are also presented. Finally, some key findings from the analysis are discussed.

Box 1: Overview of the SULTAN model

In previous work for the European Commission's Directorate General on Climate Action (DG CLIMA) (the EU Transport GHG: Routes to 2050 projects[7]), Ricardo Energy & Environment developed the sustainable transport illustrative scenarios tool called SULTAN (SUstainabLe TrANsport). The tool uses a simplified stock-modelling approach and information on transport activity, emission factors, and fuel efficiency to develop estimates for net energy consumption and emissions from different transport modes. The model has most recently been enhanced, and updated to the Commission's 2016 Reference scenario, as part of (as yet unpublished) work for DG CLIMA considering transport's potential contribution to the EU's 2030 decarbonisation objectives. It has also been further utilised in a number of other UK and European projects, e.g.:

- Analysing the potential impacts of different ultra-low emission vehicle (ULEV) measures/incentives on emissions from European passenger cars (for Greenpeace and T&E).
- Evaluating the potential energy, GHG, NOx and PM emissions impacts of different low emission vehicle uptake scenarios in London (for Transport for London).
- Evaluating the potential fuel consumption and GHG impacts of uptake of cost-effective lightweighting by heavy duty vehicles (for DG Climate Action).
- Evaluating the wider impacts of scenarios for High EV uptake in Europe to 2050, in comparison to alternatives with more significant use of low carbon fuels (private customer).

Figure 1.1: Illustration of the SULTAN modelling framework employed as part of the study



[7] http://www.eutransportghg2050.eu/

2 Scenario development

2.1 Baseline scenario

The current baseline (BAU) scenario in the SULTAN model is consistent with the European Commission's 2016 Reference Scenario (European Commission, 2016a). This reference scenario has been used as a basis for the modelling analysis for a wide range of EC impact assessments, including those informing the Effort Sharing Decision (European Commission, 2016), the European Strategy on Low Emission Mobility (European Commission, 2016d) and for the proposals for future light duty vehicle (LDV) CO_2 regulations and amendments to the Clean Vehicle Directive (CVD) announced in the 2nd Clean Mobility Package (CMP) (European Commission, 2017).

The baseline, business-as-usual (BAU) well-to-wheels (WTW) GHG emissions profile for all transport modes not included in the EU ETS[8] is illustrated in Figure 2.1 below. These figures illustrate the ongoing importance of light duty vehicles (cars and vans/LCVs – light commercial vehicles) to EU transport emissions going forwards.

Figure 2.1: Breakdown in WTW GHG emissions in non-ETS transport sectors, baseline (BAU) scenario

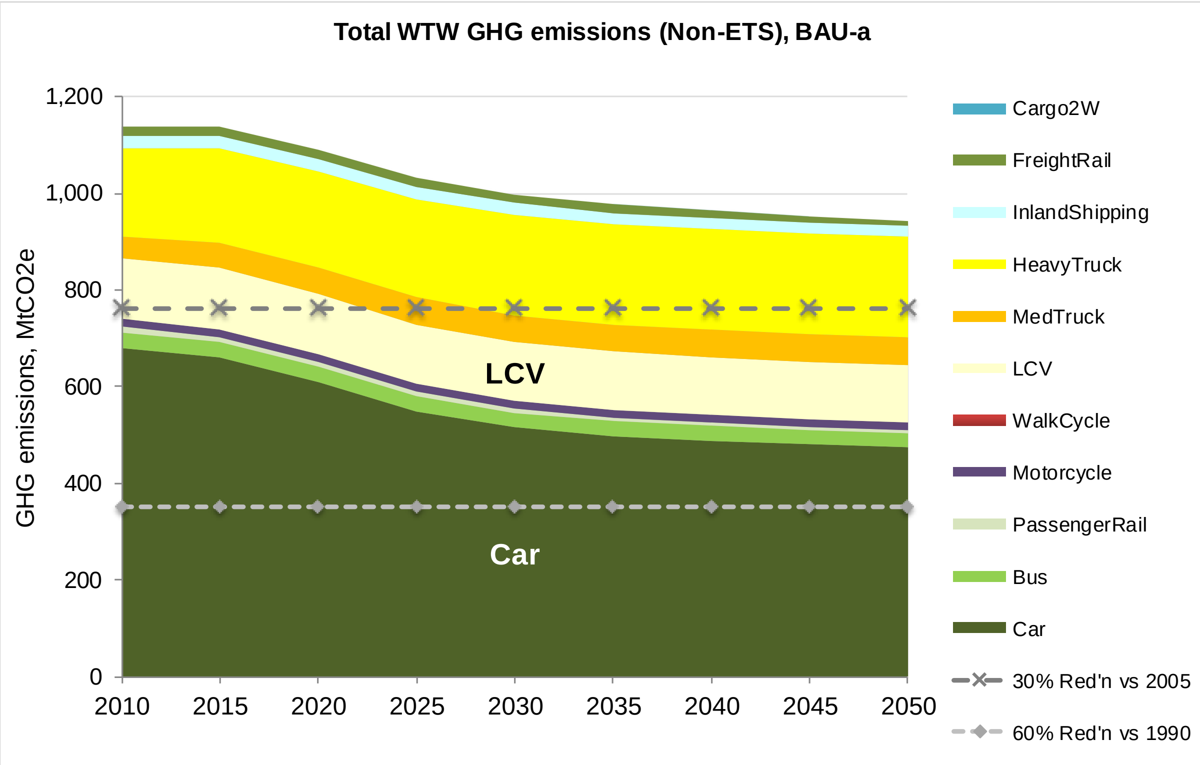


Figure 2.2 and Figure 2.3 illustrate the new vehicle powertrain shares for cars and LCVs in the baseline scenario, and the breakdown of energy consumption by fuel type. In the baseline scenario, the xEV powertrain share only reaches ~16.5% for passenger cars, and ~14.5% for LCVs by 2050 (in the absence of post-2020 CO_2 reduction targets), as illustrated in Figure 2.2. In addition, the overall energy consumption of LDVs flattens off after 2020 as improvements in vehicle efficiency are balanced by increases in activity (vehicle-km) (Figure 2.3).

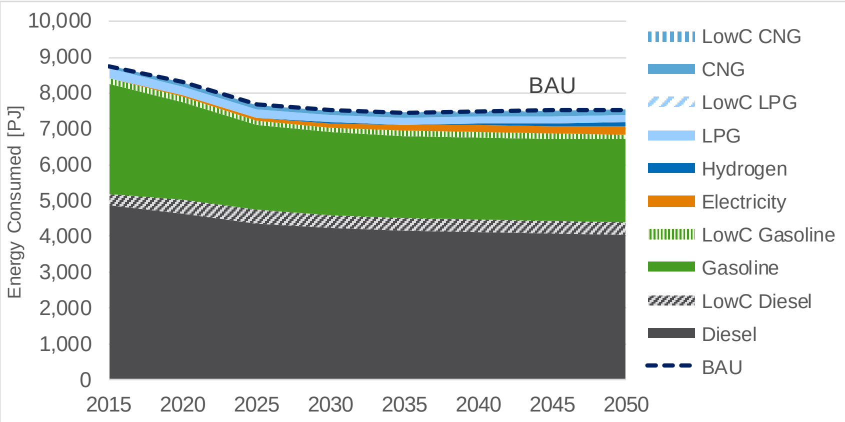
[8] These non-ETS modes include: all road transport modes (including passenger cars, light commercial vehicles (LCVs, i.e. including vans), buses and coaches, heavy duty lorries (aka trucks), motorcycles and other 2/3 wheeled vehicles), rail passenger and freight transport, and inland shipping. Maritime shipping and aviation are NOT included.

Figure 2.2: Powertrain deployment in new vehicles for cars and LCVs in the baseline (BAU) scenario

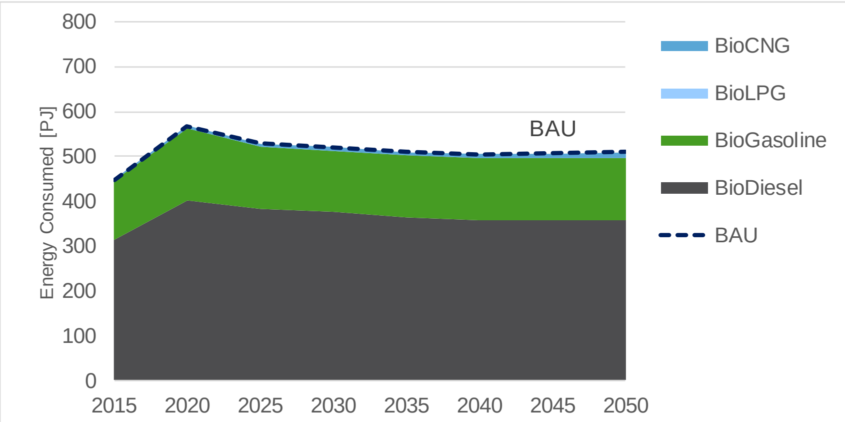
Note: xEV = FCEV + EV + PHEV

Figure 2.3: Total LDV energy/biofuel consumption by fuel type, baseline (BAU) scenario

Total energy consumption (including biofuels)



Biofuel consumption



2.2 Scenarios for powertrain deployment

Three alternative scenarios for xEV powertrain deployment were developed, as set out in Table 2.1, and detailed further below, and in Appendix A1. These scenarios have been developed to encompass a potential range of xEV deployment levels for a given overall trajectory for regulated emissions from new vehicles in gCO_2/km (given the estimated available technical potential for improvements).

Table 2.1: Overview of the modelled powertrain deployment scenarios

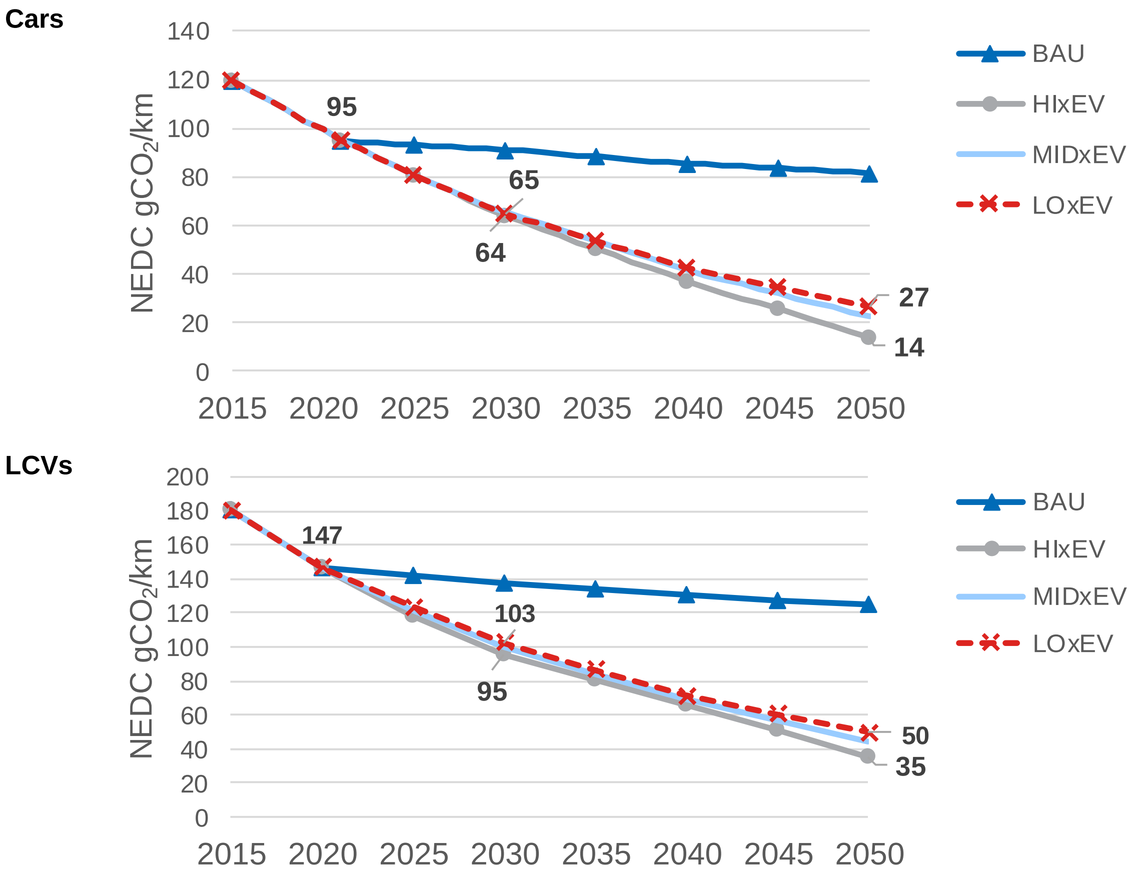
#	Scenario name	Summary of scenario definition
1	**Low xEV powertrain deployment scenario (LOxEV)**	This scenario has been developed to follow a trajectory consistent with reaching the low-end of projections for xEV deployment for 2030 and 2050, whilst still achieving an average new vehicle gCO_2/km trajectory consistent with the European Commission's post-2020 CO_2 regulation proposals, extrapolated through to 2050.
2	**Medium xEV powertrain deployment scenario (MIDxEV)**	This scenario has been developed to follow a level of xEV deployment and efficiency improvement to conventional powertrains intermediate between the LOxEV and HIxEV scenarios.
3	**High xEV powertrain deployment scenario (HIxEV)**	This scenario has been developed to follow a trajectory consistent with medium-high projections for xEV deployment for 2030 and 2050, reaching 100% xEV deployment by 2050. Improvements to conventional and hybrid vehicle efficiency is frozen after 2025. Even so, the rate of improvement in average vehicle gCO_2/km is slightly higher than the LOxEV and MIDxEV scenarios after 2030.

The European Commission has made proposals for improvements in the post-2020 gCO_2/km emissions for LDVs (30% improvement on 2021 emission levels by 2030). In addition, there have previously been indications on the likely longer-term objectives for LDVs, informed by Commission modelling for meeting long-term policy objectives (i.e. equivalent to ~25 gCO_2/km for cars and ~60 gCO_2/km for vans on an NEDC basis) (Ricardo Energy & Environment et al., 2018), however, there are no official targets or proposals for these at this point.

The post-2020 gCO_2/km reduction trajectories used as a constraint for the definition of the high, medium and low xEV powertrain deployment scenarios (HIxEV, MIDxEV and LOxEV respectively) have been set up to be broadly consistent with the proposed 2030 target objectives, and extrapolated to 2050 at a similar rate at of annual improvement as a minimum. These improvements are indicative, given the change in regulatory testing protocol/cycles from NEDC (upon which the 2020/21 targets were set) to WLTP[9] (upon which the future targets will be defined). These assumptions on gCO_2/km trajectories are used together with the new vehicle powertrain shares to define the energy efficiency improvements (in MJ/km) by powertrain needed to meet targets. The gCO_2/km trajectories for the different scenarios are summarised in Figure 2.4 below. The HIxEV scenario was defined to achieve 100% xEV share of new cars by 2050 (and 90% for new vans), which resulted in a greater than required level of improvement in average gCO_2/km emissions out to 2050, even with the average relative efficiency of conventional and hybrid powertrain vehicles frozen from 2025 onwards.

The evolution in powertrain shares for new passenger cars and vans (LCVs) is summarised in Figure 2.5 and Figure 2.6 below. In addition, the total passenger car xEV market share trajectories for the three scenarios are shown in comparison with the range of forecasts and projections identified in the literature in Figure 2.7 (also summarised in Appendix A1). The scenarios developed for this project fall within the middle-low part of the range from the literature, with higher xEV shares more consistent with higher overall rates of reduction in average new vehicle emissions (i.e. greater than the trajectory consistent with a 30% reduction in gCO_2/km between 2021 and 2030 from the EC's proposals).

Figure 2.4: New vehicle TTW (tailpipe) gCO_2/km trajectories for the different scenarios



[9]For more information on WLTP (Worldwide Harmonised Light-duty Test Procedure), see: http://wltpfacts.eu/what-is-wltp-how-will-it-work/

Figure 2.5: xEV powertrain scenarios, new passenger cars

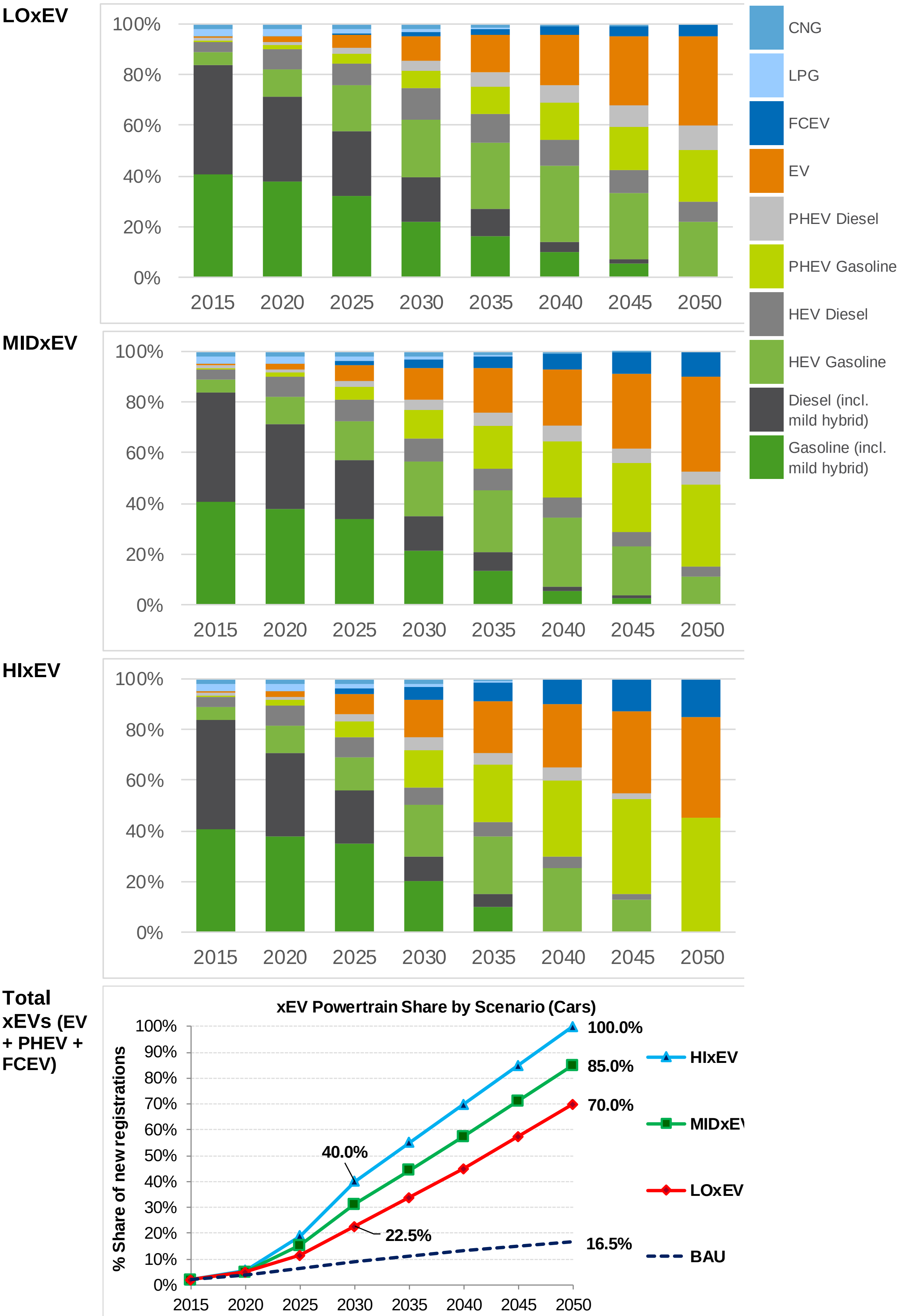


Figure 2.6: xEV powertrain scenarios, new light commercial vehicles

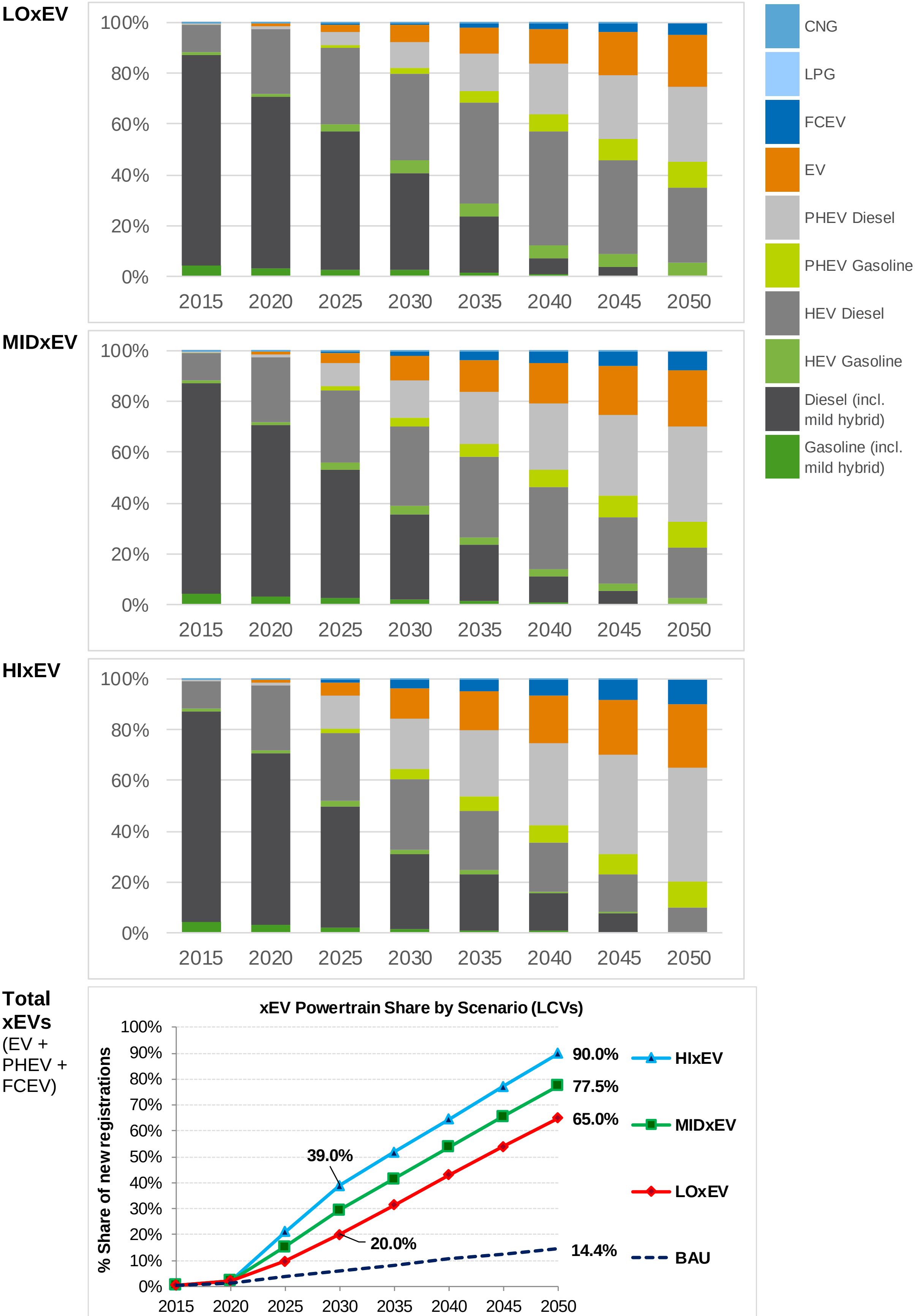
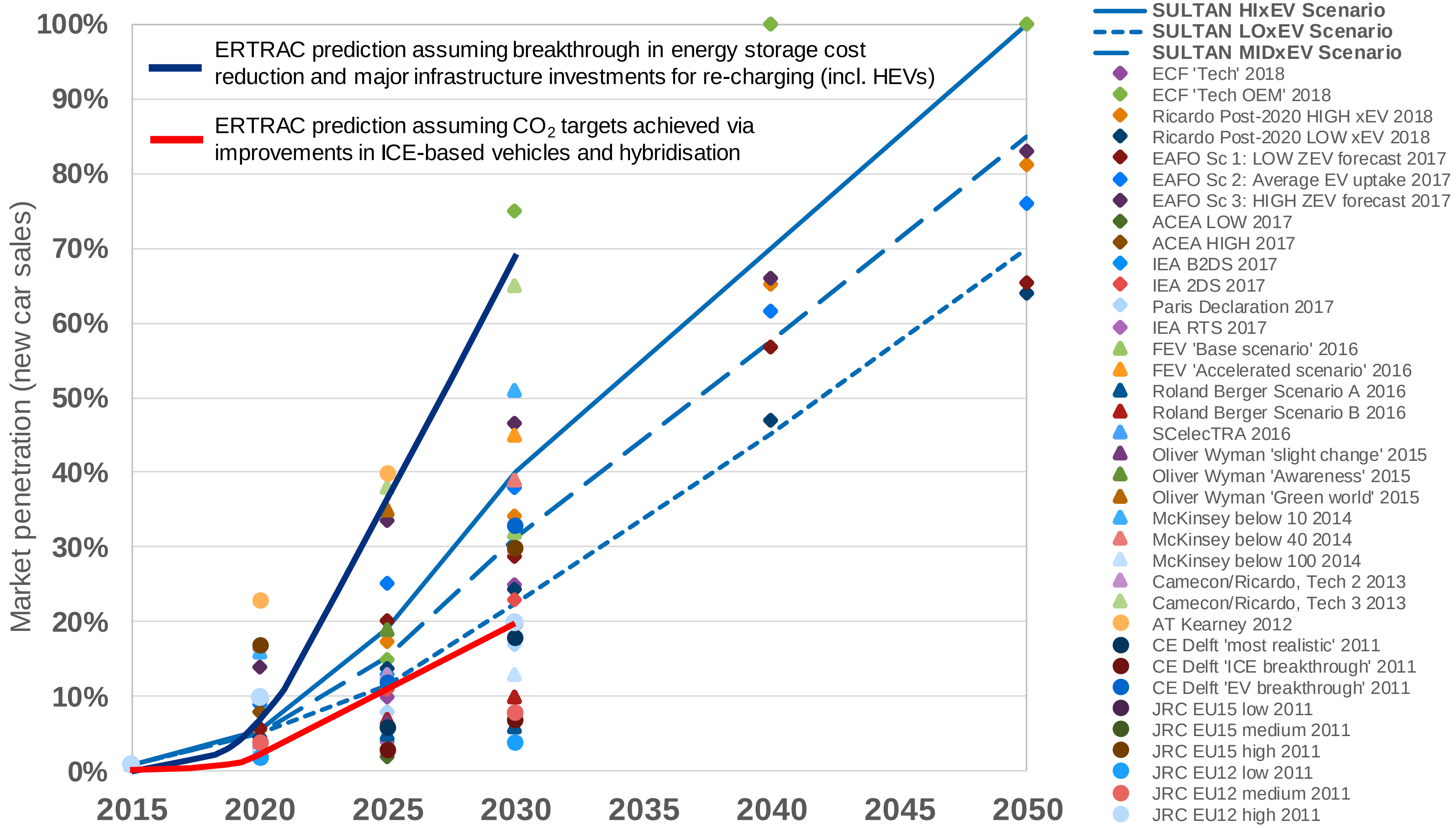


Figure 2.7: xEV powertrain scenarios, comparison with forecasts from the literature for passenger cars



Notes: xEVs = BEVs, PHEVs, REEVs and FCEVs.

2.3 Scenarios for low carbon fuels availability

Three alternative scenario assumptions were developed for the modelling, which are summarised in the following table, and are detailed further in the following report sections. The assumptions for these scenarios were defined and agreed in discussion with ePURE and validated by Ricardo experts based on a review of recent data sources.

Table 2.2: Overview of the modelled low carbon fuel substitution scenario assumptions

#	Scenario name	Summary of scenario definition
1	**Baseline biofuel shares (Default)**	This scenario assumes the same substitution shares for biofuel deployment as in the baseline (BAU) scenario, which is the default assumption for comparison with the Low Carbon Fuel scenarios.
2	**Low Carbon Fuels main scenario (LCF1)**	This scenario is based upon estimates for the total potential availability of different Low Carbon Fuels for road transport with ~flat availability of 1G biofuels post-2030. Deployment of E20+ optimised passenger cars is assumed to begin post-2020, coupled with a wide availability of high-octane E20 by 2030 and E25 by 2050.
3	**Low Carbon Fuels sensitivity scenario (LCF2)**	This scenario provides a sensitivity for Low Carbon Fuels uptake, with an assumed declining share of 1G FAME (from crop-based sources) post-2020, and a corresponding increase in 1G bioethanol availability. Assumptions for high-octane E20 and E25 are similar.

2.3.1 Low Carbon Fuels main scenario (LCF1)

2.3.1.1 Availability of biofuels

A scenario for the future availability of biofuels was constructed based on a number of sources which have looked at the potential for biofuels in the EU in the short (2020) medium (2030) and long term (2040) to 2050), including (Joint Research Centre, 2014; Sub Group on Advanced Biofuels (Sustainable Transport Forum), 2017; E4Tech, 2017; IEA, 2017; P Baker et al, 2017). Starting from current consumption of biofuels, the scenario is intended to provide an optimistic yet realistic picture of biofuels development; so, for example, development of gasification technologies was less rapid than proposed in e.g. SGAB 2017. This is because, while second generation technologies are moving to a commercialisation stage, progress has consistently been slower than forecast in the past. While gasification technologies can be used to produce both diesel and gasoline substitutes, it was considered that the main output from these technologies would be syndiesel (a 'drop-in' replacement for conventional diesel), as this typically has a higher economic value than syngasoline (a 'drop-in' replacement for conventional gasoline).

The scenario also takes account of proposed policy developments in biofuels post-2020 under RED II; although these are uncertain as the proposed directive is still the subject of negotiation. In the case of crop-based biofuels, which are identified separately in the scenario, the 7% cap was kept. Full details of the scenario and the assumptions underpinning it are given in Appendix 1.

Overall (Figure 2.8 and Figure 2.9), the availability of biofuels increases from about 20 Mtoe in 2020 (834 PJ) to 30 Mtoe (994 PJ) in 2030 and 42 Mtoe (1334 PJ) in 2050. Production of 1G bioethanol increases to 2030, making use of currently under-utilised production capacity. Production is assumed to remain constant thereafter, although overall quantities of bioethanol increase as 2G lignocellulosic production is assumed to become well established by 2030, and to grow substantially in the period to 2030. In the case of fatty-acid methyl ester (FAME) biodiesel, production falls from current levels as waste oil and vegetable oil feedstocks are used to produce Hydrotreated Vegetable Oil (HVO) a drop-in replacement for diesel, rather than FAME. Quantities of oil feedstocks for FAME and HVO production are limited – both by the assumed crop cap, and the fact that waste oil feedstocks are a finite resource, and they are assumed to be increasingly used in HVO rather than FAME. Significant HVO production capacity is being developed for this in Europe, and it is assumed that it will be produced preferentially to FAME as it is fungible. As discussed above, gasification followed by processes such as Fischer-

Tropsch, are assumed to become established in the period 2020 to 2030, with production more than doubling in the period to 2050.

By 2030 a small amount of eFuels (0.2 Mtoe) produced from surplus/curtailed renewable electricity generation in the EU is available from demonstration plants; this is assumed to grow to 2 Mtoe by 2050.

Figure 2.8: Availability of biofuels substituting for gasoline in the LCF main scenario (LCF1)

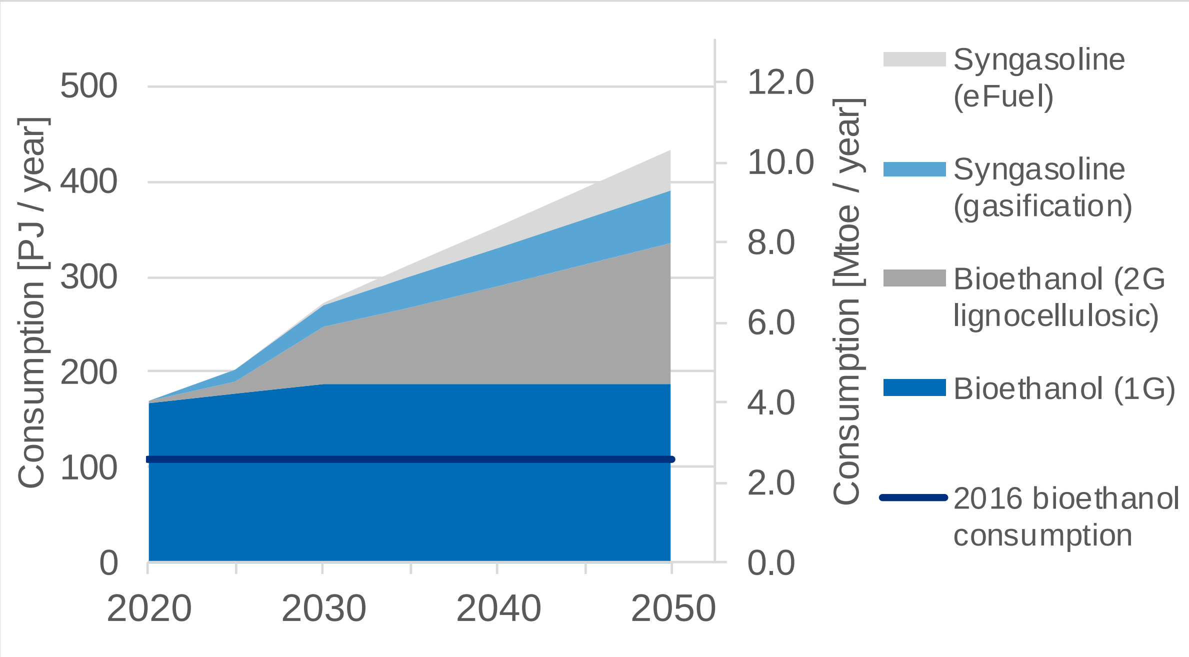
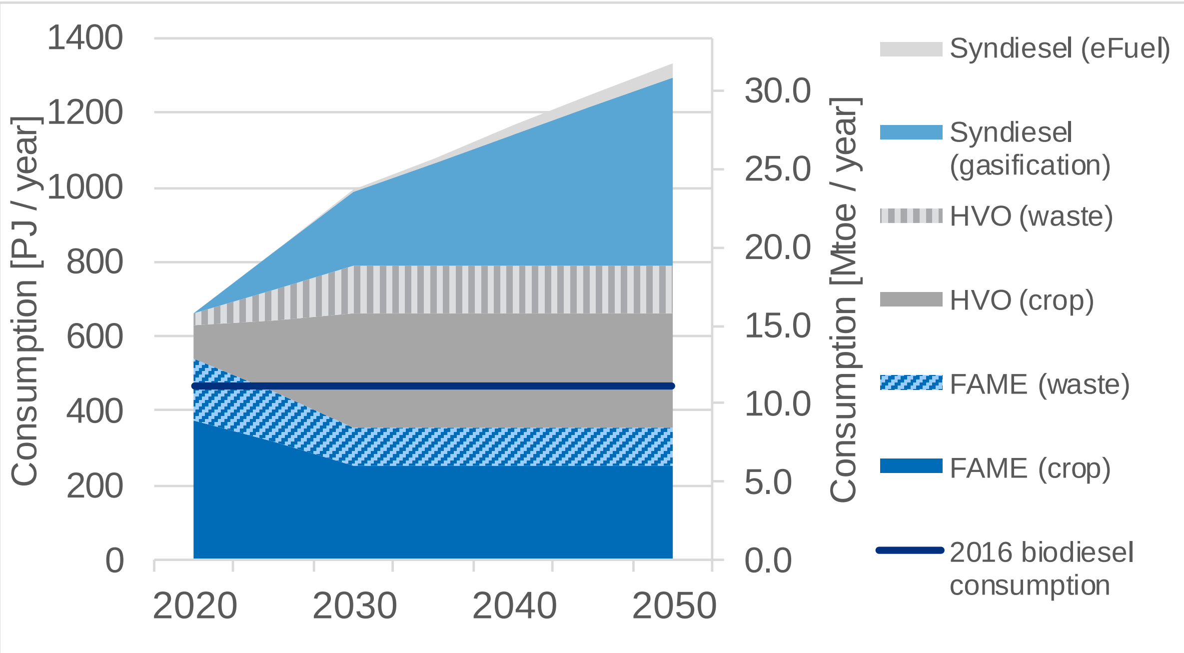


Figure 2.9: Availability of biofuels substituting for diesel in the LCF1 main scenario (LCF1)



2.3.1.2 Carbon intensity of biofuels

Well-to-Tank (WTT) greenhouse gases emissions (GHG) for individual biofuels are shown in Figure 2.10, with the basis of the values given in Table 2.3. In general, a reduction in WTT emissions from all biofuels is assumed over the period 2030 to 2050 as the decarbonisation of the economy, including electricity generation, leads to a reduction in the carbon footprint of inputs to the production process (e.g. fertilisers for crops, methanol for FAME), fuels used to transport and cultivate feedstocks, and distribute finished fuels, as well as electricity used in the production process and dispensing of fuels. For crop-based biofuels, improvements in yields can also contribute to reductions in overall emissions. In the case of bioethanol production, capture of the CO_2 stream from fermentation and its subsequent utilisation in other processes, can also significantly reduce emissions.

Overall (Figure 2.11), this means that the biofuels substituting for gasoline can deliver a 70% GHG saving by 2020, rising to 79% by 2030 and 84% by 2050, and biofuels substituting for diesel a 63% saving in 2020, rising to 68% by 2030, and to 76% by 2050.[10]

Table 2.3: Derivation of WTT GHG emissions for biofuels

Biofuel	Assumptions
Ethanol (1G)	Current emissions from ethanol produced by ePURE members (which accounts for about 80% of current EU consumption) are 28.3 gCO_2/MJ, a 66% saving compared to fossil fuels, and have shown a substantial reduction over the last few years. This trend in reduced emissions is assumed to continue and reach 25.1 gCO_2/MJ (70% saving) in 2020 and 18.8 gCO_2/MJ (80% saving[11]) in 2030. These are target values that ePURE members have made a commitment to. From 2030 to 2050, emissions are assumed to reduce by a further 10%.
Ethanol (2G)	The value for 2020 and 2030 of 13.7g CO_2/MJ is the 'typical' value proposed in RED II for wheat straw ethanol, which due to a decarbonising economy falls by 15% by 2050.
FAME	In 2020 crop-based FAME is assumed to achieve a 50% GHG saving giving emissions of 42 gCO_2/MJ and waste-based FAME to have average emissions of 10 gCO_2/MJ. By 2030, FAME production is assumed to be 70% crop-based and 30% waste-based giving average emissions of 32 gCO_2/MJ. Emissions are assumed to fall by a further 10% by 2030 and then by 15% by 2050 for crop-based FAME and 10% for waste-based FAME.
HVO	As for FAME
Fuels from gasification	The value for 2020 and 2030 of 17 gCO_2/MJ is an average of the 'typical' values proposed in RED II for waste wood and farmed wood FT diesel. It is assumed that by 2030 this technology will be fully demonstrated and efficiencies in the process and general decarbonisation of the economy allow emissions to be reduced a further 25% by 2050.
eFuels	Emissions associated with production of fuel though electrolysis are assumed to be zero; emissions reflect those associated with ancillary operations and distribution and dispensing of fuels.

[10] Savings quoted compared to current fossil fuel comparator in RED of 83.8 g CO_2/MJ
[11] 80% saving on the new fossil fuel comparator proposed in RED II of 94 g CO_2/MJ; equivalent to a 78% saving compared to the current fossil fuel comparator of 83.8 g CO_2/MJ.

Figure 2.10: Well to Tank GHG emissions for biofuels

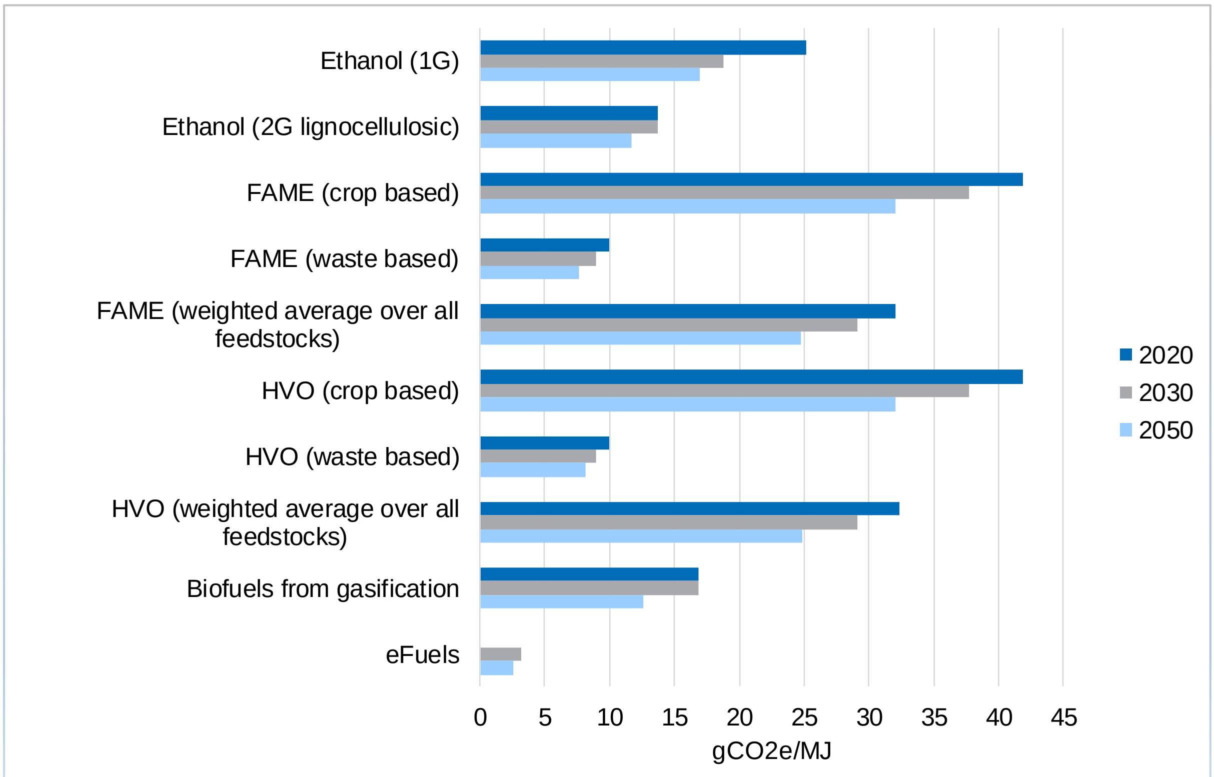
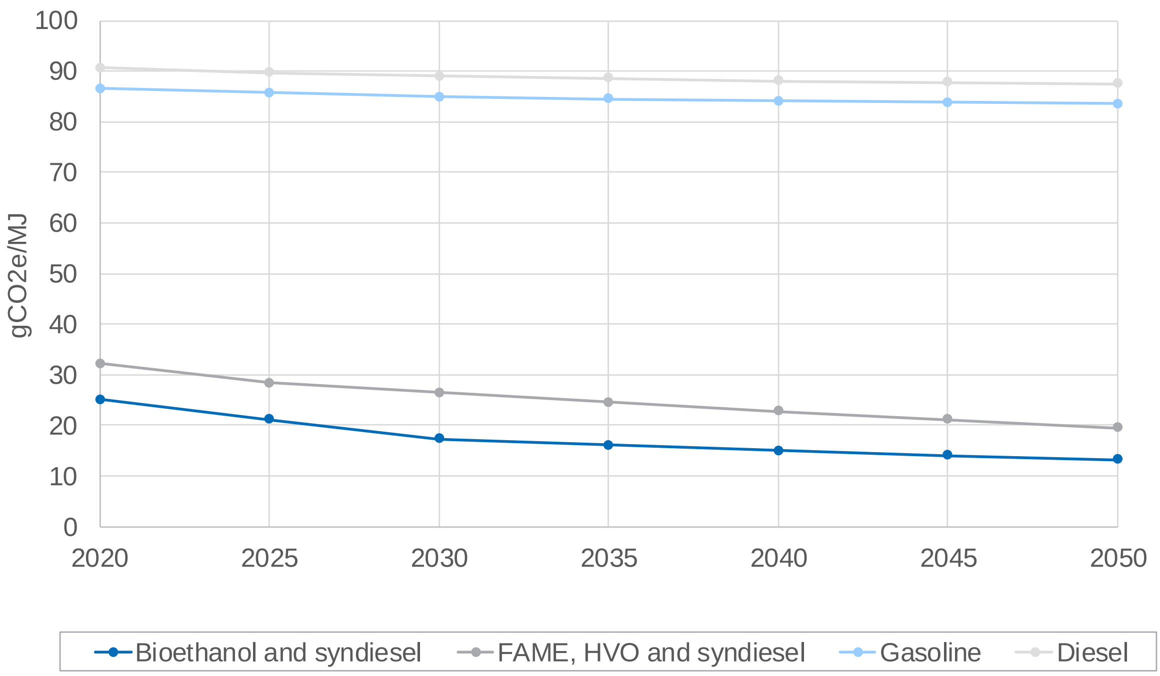


Figure 2.11: Weighted average Well to Wheel GHG emissions for conventional fuels and biofuels



2.3.2 Low carbon fuels sensitivity scenario

There has been considerable discussion in recent years over the Indirect Land Use Change (ILUC) impacts that production of some crop-based biofuels may cause, with considerable concern that the GHG emissions associated with ILUC may significantly erode the GHG emissions that biofuels may deliver. ILUC emissions are generally considered to be lower for bioethanol than FAME with the ILUC directive setting provisional values of 12 to 13 g CO_2/MJ for crop-based bioethanol and 55 g CO_2/MJ for oil crop-based FAME. More recent modelling work, (Ecofys/IIASA/E4tech, 2016) confirmed this trend giving much higher land use change emissions factors for FAME than bioethanol.

An alternative LCF scenario was therefore modelled, where these concerns over ILUC lead to more of the crop-based biofuels production permitted under the 7% cap being bioethanol production. Overall levels of crop-based biofuels production are kept the same, but over the period 2020 to 2050 there is a shift (of 1.5 Mtoe) from crop-based FAME production to 1G bioethanol production (see Figure 2.12 and Figure 2.13). This would mean that bioethanol production capacity would need to increase either through upgrading of existing plants or building new capacity; it is considered that the colocation of 2G bioethanol production on 1G bioethanol production sites could also offer opportunities to expand the production capacity of 1G bioethanol. Due to the lower WTT emissions from bioethanol compared to FAME, this shift in production increases the average savings delivered by biofuels to 75% by 2030 and 83% in 2050.

Figure 2.12: Availability of biofuels substituting for gasoline in the LCF sensitivity scenario (LCF2)

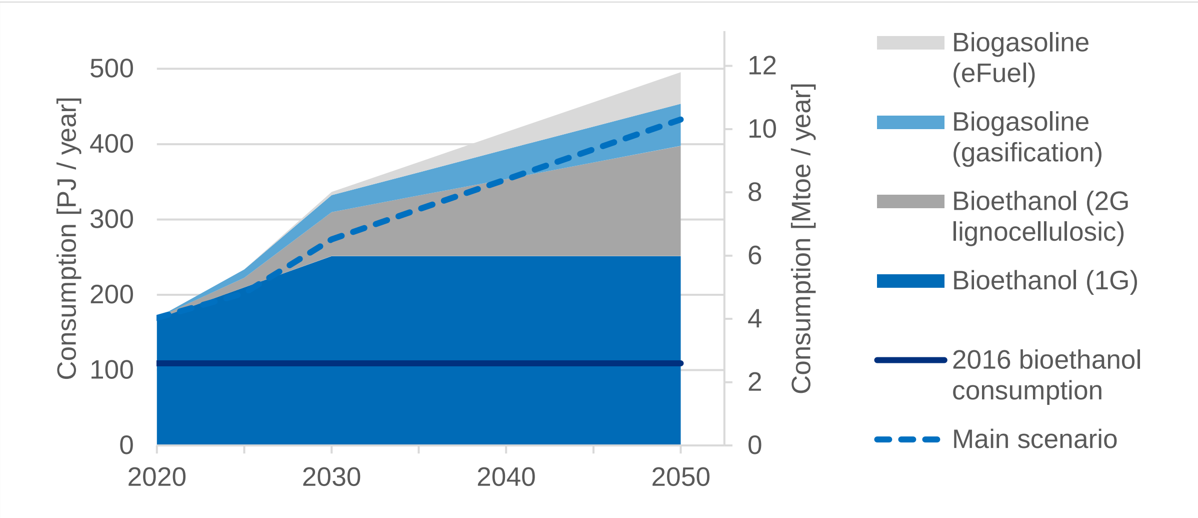
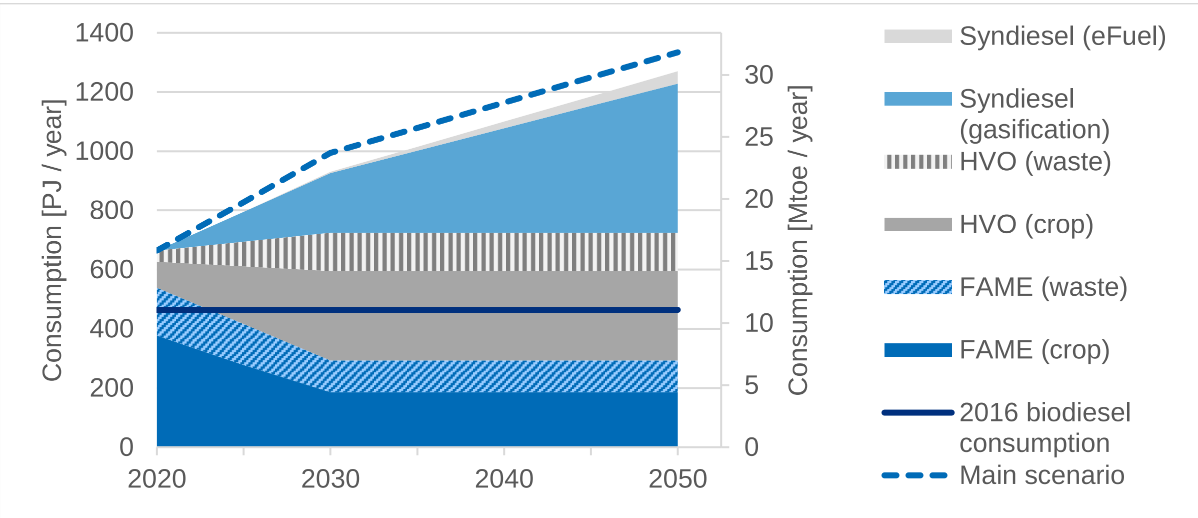


Figure 2.13: Availability of biofuels substituting for diesel in the LCF sensitivity scenario (LCF2)



2.3.3 Overall Low Carbon Fuel substitution rates for the different scenarios

Figure 2.14 illustrates the overall average low carbon fuel substitution rates in light duty vehicles resulting from the assumptions outlined above for the different variants for the medium xEV powertrain deployment scenario under the three low carbon fuel scenarios (i.e. MIDxEV, MIDxEV+LCF1 and MIDxEV+LCF2). These substitution rates also factor in the utilisation /energy consumption requirements for petrol and diesel in other transport modes (most significantly heavy duty vehicles for diesel) – i.e. that a similar substitution rate would be required across all modes with the same fuel.

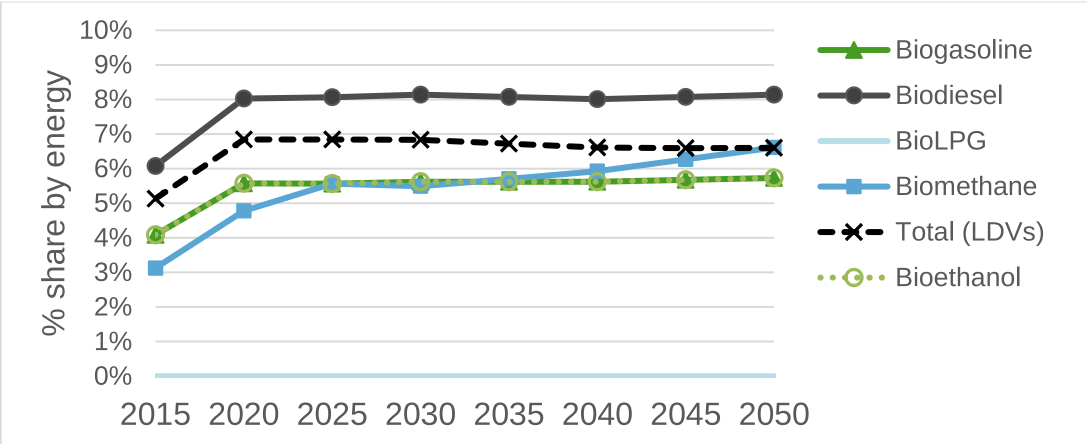
In the xEVs deployment scenarios, substitution of low carbon fuels is significant by 2050 for both diesel (~31%) and gasoline (~21%). For the MIDxEV scenario (and similarly for HIxEV and LOxEV), the share of biofuel in gasoline and diesel is assumed to remain ~constant as for the BAU scenario levels. However, for the low carbon fuels scenario variants, MIDxEV+LCF1/LCF2:

- Based on the biofuel availability (in Mtoe) for different fuel types, the substitution rate rises for bioethanol/syngasoline and biodiesel.
- Average bioethanol blend reaches the 25% by volume constraint by 2050 in the LCF2 scenario only (i.e. via higher ethanol blends in certain niche markets, for example. ED95, E85).

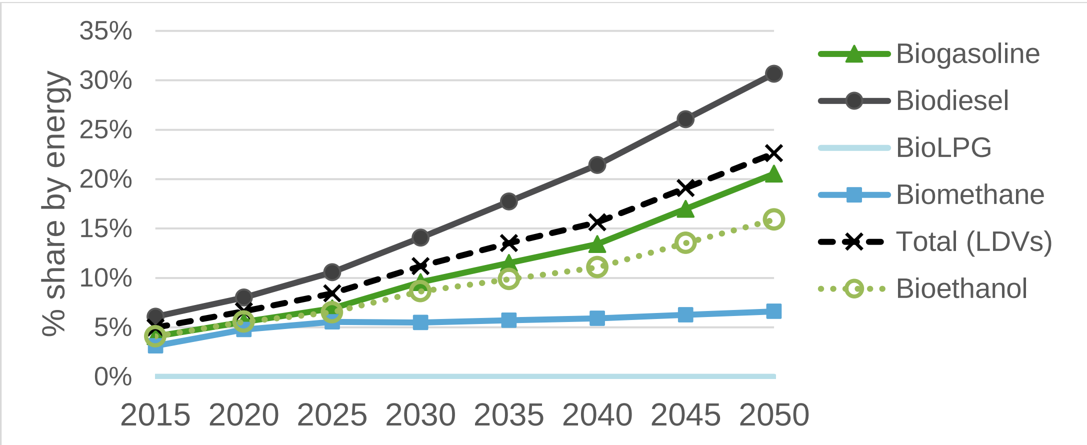
The overall percentage share for the MIDxEV+LCF1/LCF2 and LOxEV+LCF1/LCF2 scenarios are similar (only slightly lower) than for the HIxEV+LCF1/LCF2 scenarios. This is because the effect of increased share of xEVs is offset by less efficient conventional and hybrid petrol/diesel vehicles.

Figure 2.14: Low carbon fuel substitution rates by fuel for the high xEV deployment scenarios

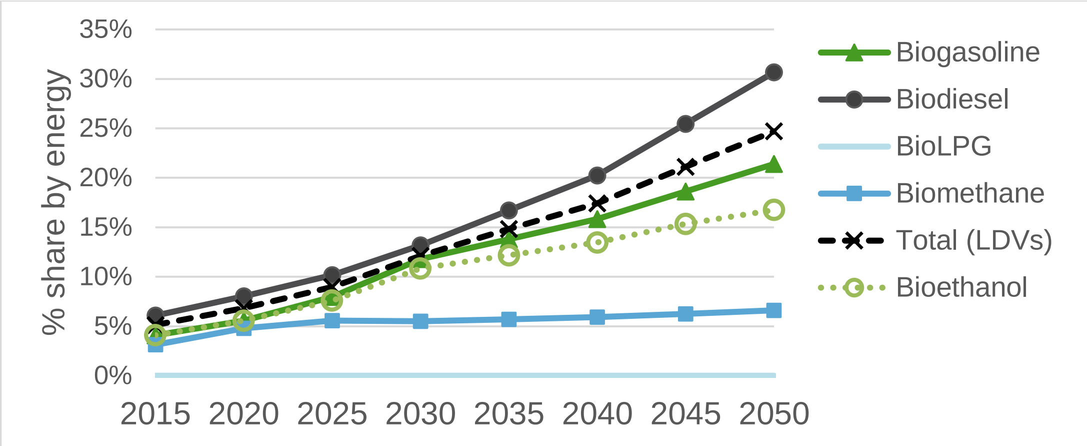
MIDxEV



MIDxEV +LCF1



MIDxEV +LCF2



2.4 Key considerations and limitations for the analysis

It is important to note a number of important considerations/limitations for the analysis:

- ***In terms of crop-based biofuels:***

Although the Commission's proposal for RED II suggested a reduction in the cap for crop-based biofuels from a maximum of 7% to 3.8% by 2030, the Council and European Parliament did not agree with this position, and it has been assumed that the 7% cap will be retained and not reduced. However, it is likely that Member States will be able to set lower limits so the aggregate limit in the EU could be lower[12].

- ***In terms of advanced biofuels:***
  - Although advanced biofuel technologies are close to being commercially available, they are currently progressing slowly and most of the large-scale demonstrations in Europe have encountered delays due to technology, policy and financial issues. Advanced bioethanol technologies have been demonstrated in the USA, but it is still difficult to make a commercial plant feasible financially, particularly for greenfield projects. Co-location of advanced biofuels technologies on existing biofuels sites, e.g. of 2G bioethanol process on 1G bioethanol sites could help to reduce costs and enhance financial viability. New approaches e.g. clear policy support for advanced biofuels, are therefore likely to be needed to give the market confidence to invest in these technologies.
  - Advanced technologies rely on the availability of agriculture or forestry residues, or energy crops. There is competition from other bioenergy sectors for the (usually fixed) amount of residues available. More ambitious production levels for advanced biofuels rely on the development of energy crops. Energy crops have also developed very slowly, particularly in Europe.

Such challenges would need to be overcome in order to enable the scenarios as modelled.

- ***In terms of achieving benefits from improved efficiency of E20-optimised vehicles:***
  - In the developed scenarios it is assumed that E20-compatible and optimised petrol engines are made widely available in new passenger cars from 2025 so that all new vehicles are optimised to run on E20 before 2030 (and potentially E25 by 2050). This is technically feasible, but in order for it to be achievable, a strong and early signal (and appropriate policy) would need to be given that E20 fuel would be made widely available in sufficient quantities to make this worthwhile. This could pose something of a challenge, particularly if there was not also support in other regions.
  - In prioritising measures for improving the CO_2 performance / efficiency of their vehicles, manufacturers are constantly evaluating the trade-offs in relative cost, performance and utility impacts (positive or negative) for different technical options. It is unclear exactly where this option would fit alongside other options. However, it is understood that the modifications necessary to enable optimised use of E20 are likely to be relatively inexpensive in comparison to other measures. Consultation with manufacturers on the potential for this option has previously indicated general support of this measure (DCL, 2013).

[12] For example, the UK Government is introducing a crop cap that will reduce plant-based renewable fuels down to 2% by 2032.

In order to achieve the full benefits of the E20-optimised scenario as defined, rapid, positive, EU-wide action would need to be taken: this would be extremely challenging in practice, and it is also unclear whether the cost or practical difficulties in achieving this end would be sufficiently beneficial in comparison to other options.

- ***In terms of the definition of the xEV powertrain deployment scenarios and impacts:***
  - The powertrain mixes assumed in the different scenarios, though informed by previous modelling analysis and the review of literature, are subject to significant uncertainty[13] and alternative mixes could also be envisaged involving a different balance of powertrain deployment and improvements to different vehicle types. However, we believe the range of xEV deployment explored in these three scenarios represents a reasonable view on the likely extremes of outcomes consistent with the overall gCO_2/km improvement trajectory.
  - The final post-2020 regulatory CO_2 targets/future trajectory could be higher or lower in ambition than that currently modelled. More ambitious reduction trajectories would further reduce the future volumes of liquid fuel consumption (either through higher xEV deployment or further/earlier improvement to the efficiency of conventional and hybrid vehicles). This could mean the blending constraints of non-drop-in fuels (i.e. FAME and bioethanol) are reached earlier than modelled, reducing the deployable levels of these fuels in LDVs.

[13] Notably due to infrastructure costs and load, vehicles (and batteries) production (including also a finite supply of mineral needing to be imported) and overall (vehicle and electricity lifecycle) green credentials.

3 Results from the scenario modelling

In this section, the results from the SULTAN scenario modelling exercise are presented together with a short summary of the key conclusions that might be drawn from the results.

3.1 Summary of key results

3.1.1 Powertrain mix in the LDV fleet

Figure 3.1 and Figure 3.2 provide an overview of the resulting fleet/vehicle parc mix of different powertrain types resulting from the assumptions for new vehicle deployment. The LOxEV to HIxEV scenarios, as illustrated, show that xEV powertrains (i.e. EV, PHEV and FCEV) will consist between 10% and 16% for passenger cars in 2030, and between 50% and 76% by 2050. The corresponding shares for LCVs are 7% and 14% for 2030 and 45% and 67% by 2030.

Further details on the vehicle parc mix are also provided in Appendix A1 of this report.

Figure 3.1: xEV powertrain scenarios – vehicle parc, passenger cars

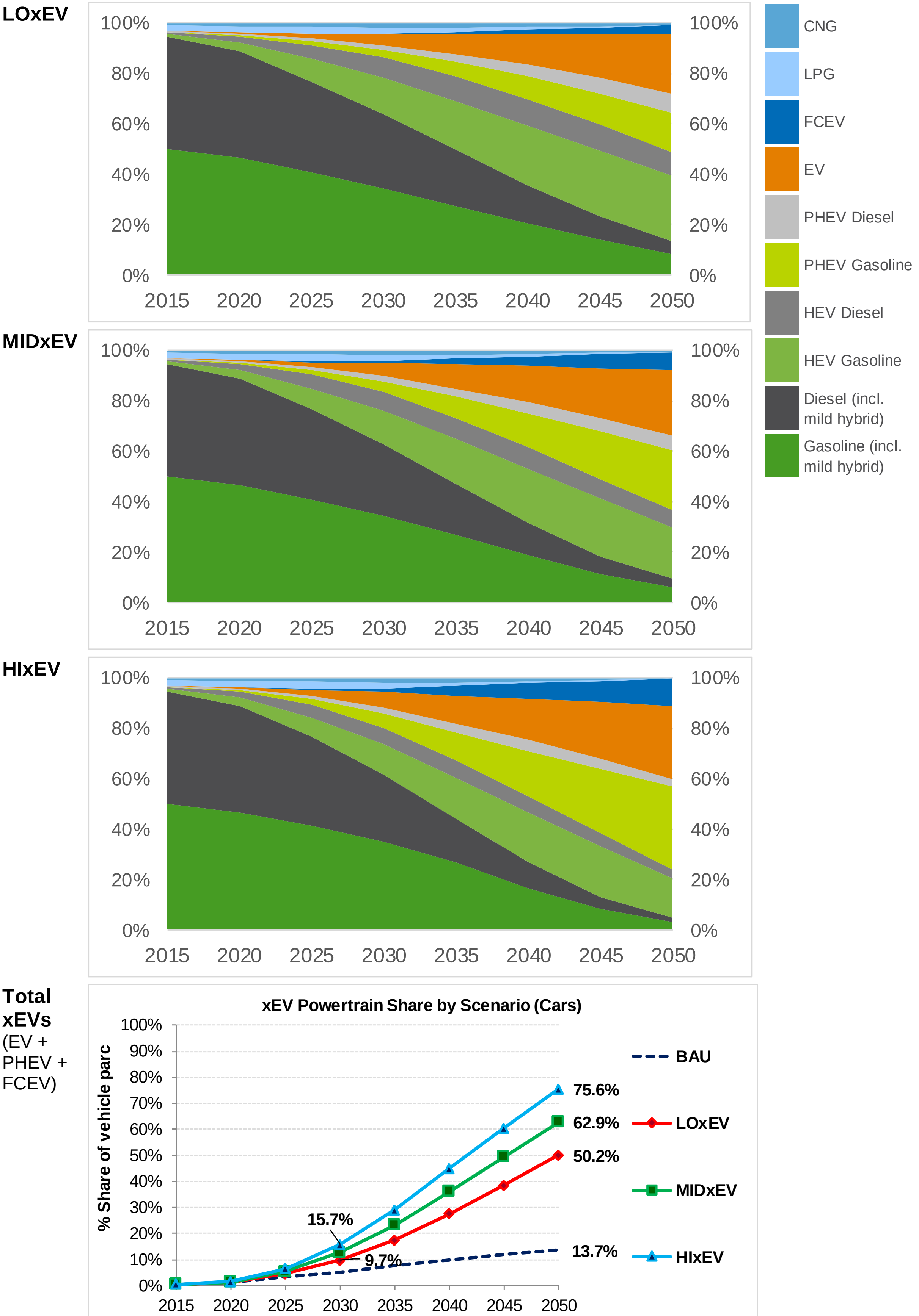
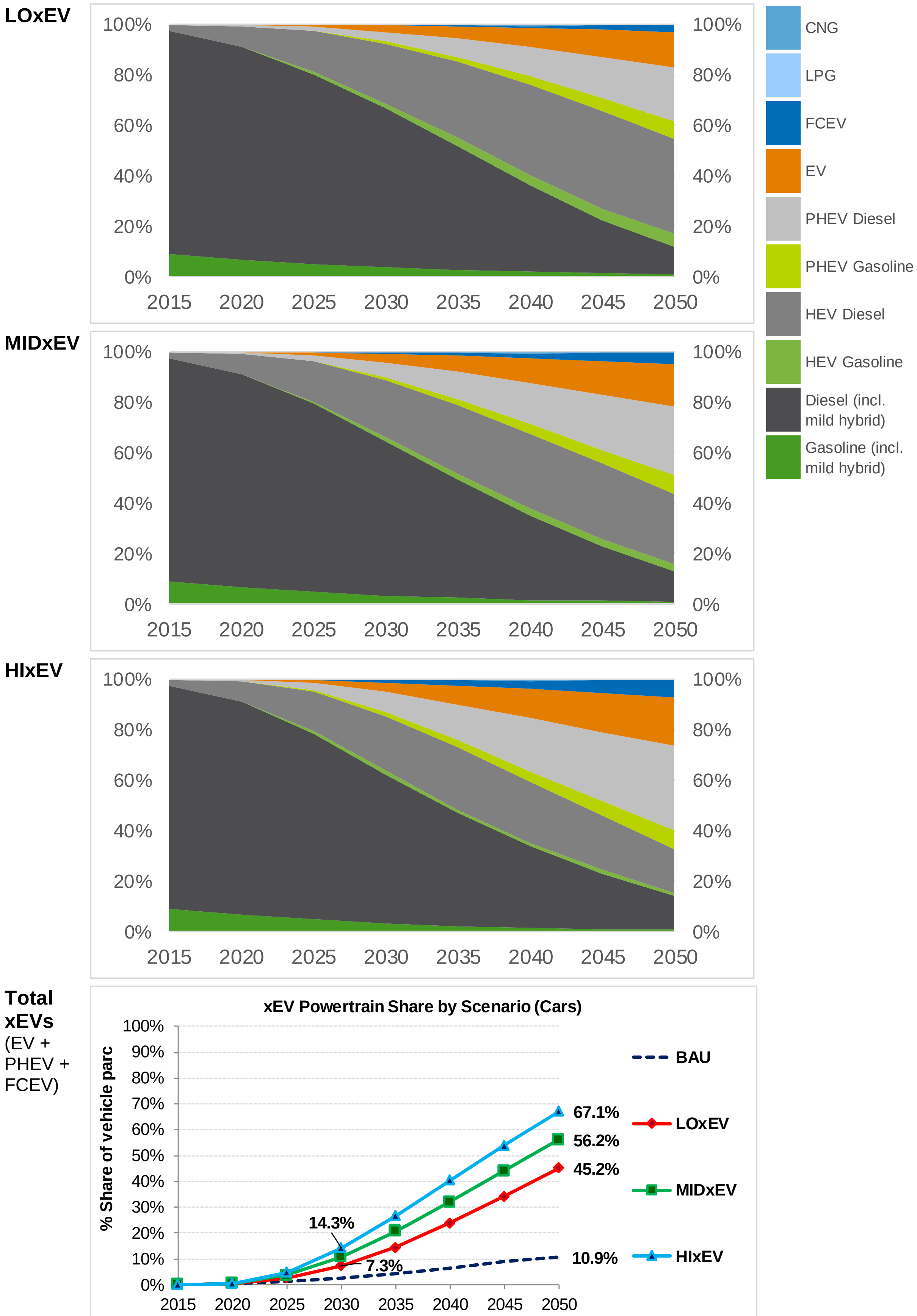


Figure 3.2: xEV powertrain scenarios – vehicle parc, light commercial vehicles



3.1.2 Energy consumption by LDVs

Figure 3.3 and Figure 3.4 provide an overview of the output energy consumption by fuel type for the different scenarios resulting from the input assumptions for new vehicle deployment and efficiency improvements consistent with the gCO_2/km trajectories. The overall EU objective for reduction in energy consumption from *all sectors* is 30% versus a 2007 baseline. In comparison, the LOxEV to HIxEV scenarios show a reduction in energy consumption of 27%-28% for 2030 compared to the 2007 baseline energy consumption for LDVs.

It is also useful to assess the reduction in energy consumption in the longer-term (for which there are as yet no specific objectives/benchmarks). By 2050 the overall energy consumption reduction is ~48% (for the all xEV scenarios) versus total energy consumption in 2015; the reduction in consumption of liquid fuels is between 61% (LOxEV scenario) and 69% (HIxEV scenario) versus 2015 levels by 2050.

The variation in total energy consumption, and the volume of liquid fuel consumption, between the different xEV deployment scenarios is relatively small due to the constraint of a similar regulatory average new vehicle gCO_2/km trajectory. This means that the reduction due to an increase in share in xEV uptake is offset by a reduced need to improve the efficiency of conventional and hybrid vehicles.

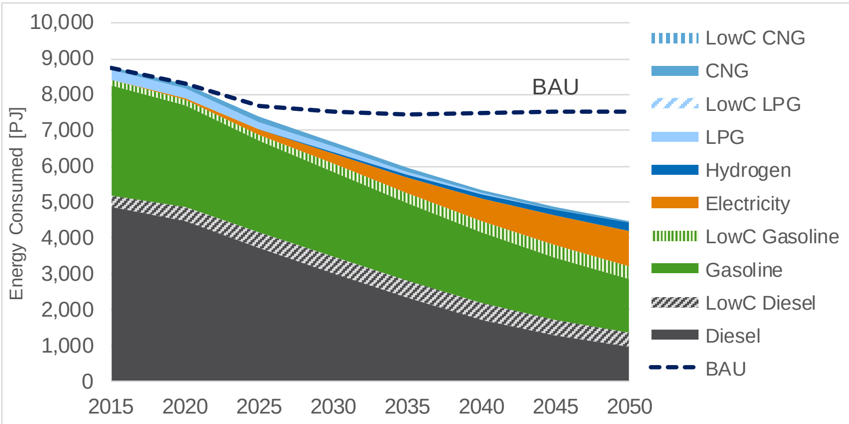
Changes in the overall energy consumption (and liquid fuel consumption) are more significantly impacted by the overall rate of improvement in new vehicle efficiency and CO_2 emissions that is assumed / set by future regulation.

The volume of low carbon diesel consumed reduces for light duty vehicles as the share of xEVs is increased in later periods, this is because the relative share of diesel consumption by heavy duty vehicles significantly increases in later periods (from around 50% in 2015). This means that the percentage substitution level in diesel for the whole of transport can only be increased by a relatively small amount to compensate for the reduced consumption of diesel fuel in light duty vehicles whilst respecting the overall total low carbon diesel availability (in PJ).

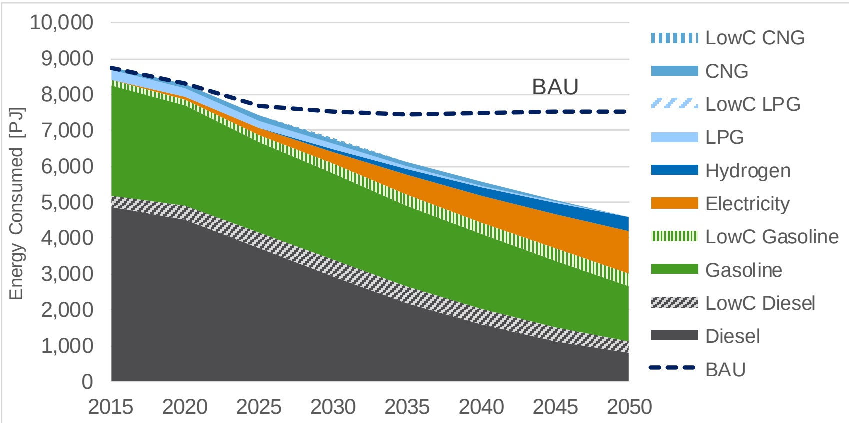
Since the vast majority of gasoline is used by light duty vehicles, the relative change in the low carbon fuel substitution level can vary to much more closely account for gasoline fuel consumption changes between the different xEV uptake scenarios. The main constraint here is the limit set for overall % substitution rate for bioethanol in gasoline.

Figure 3.3: Total energy consumption for different scenarios by fuel type (incl. low carbon fuels)*

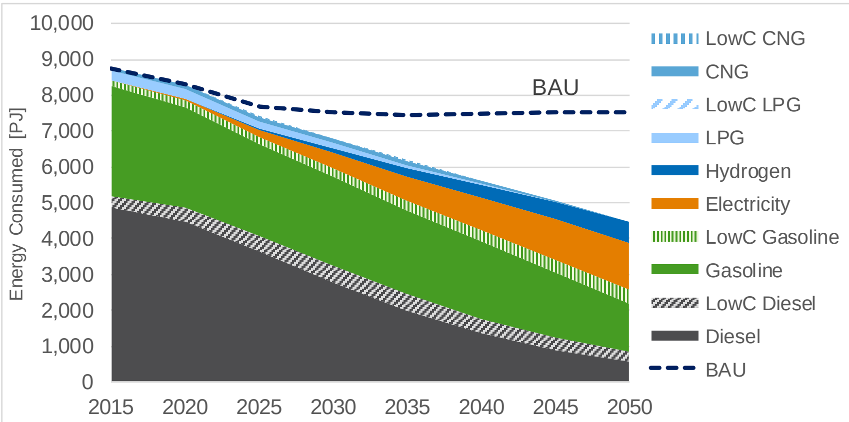
LOxEV +LCF1



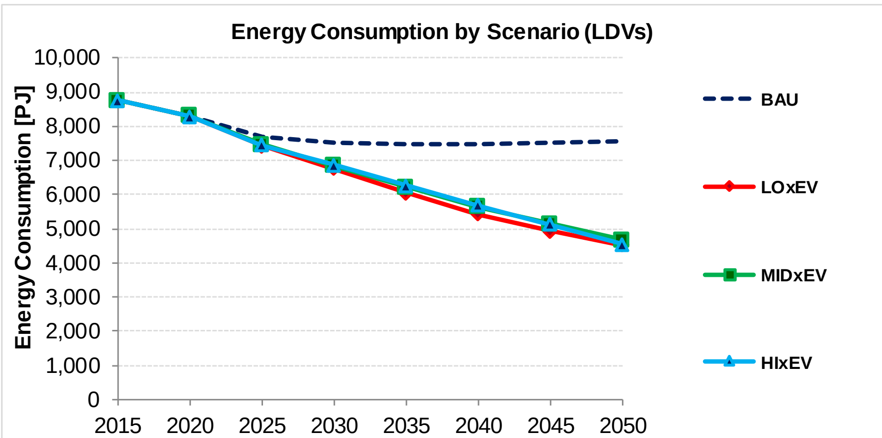
MIDxEV +LCF1



HIxEV +LCF1

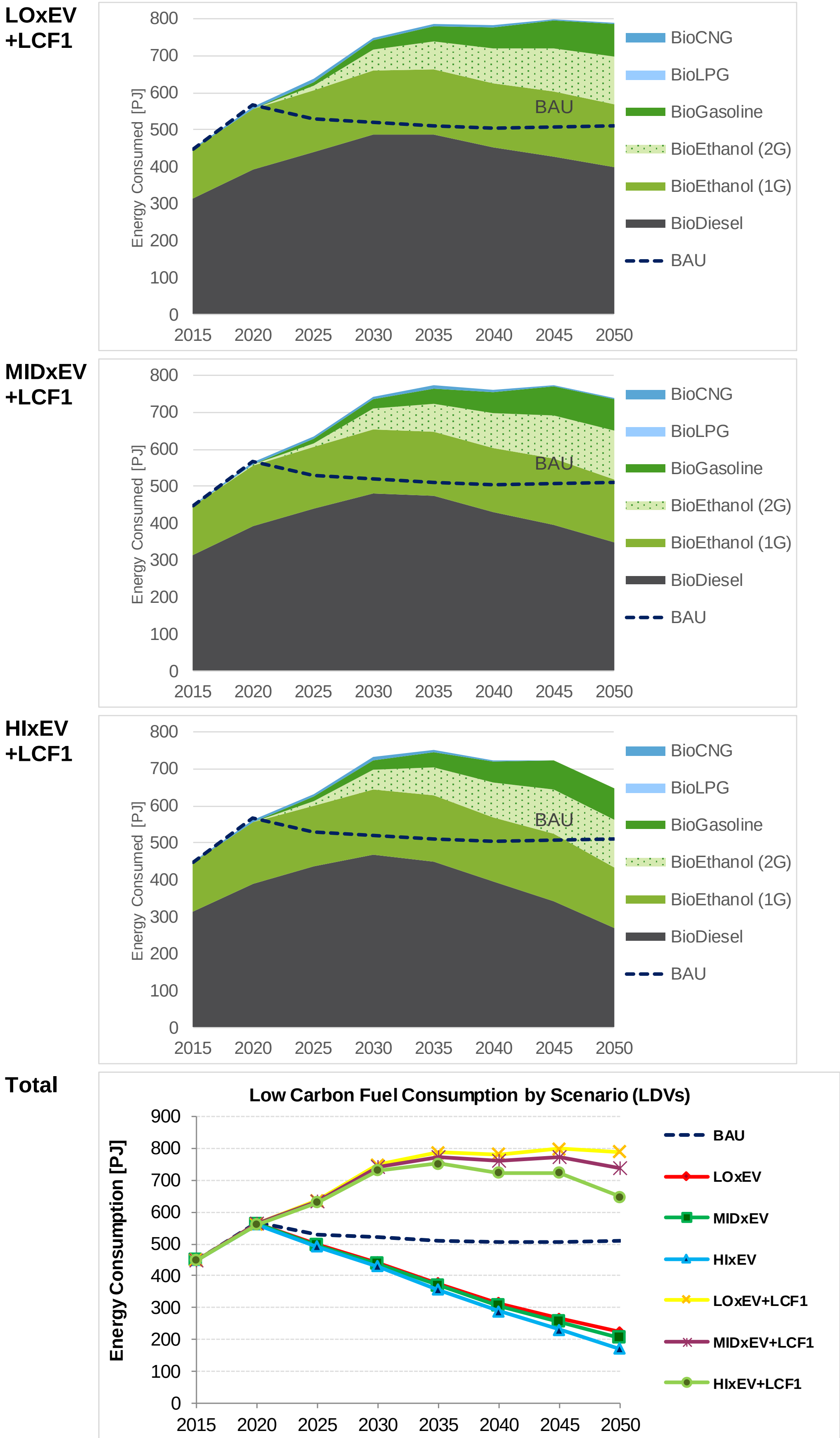


Total



Notes: * LowC = Low Carbon Fuels.

Figure 3.4: Total low carbon fuel consumption for different scenarios by fuel type



3.1.3 GHG emissions from LDVs

Figure 3.5, Figure 3.6 and Figure 3.7 provide a summary of the tailpipe (TTW) and WTW emissions impacts for the different scenarios, and an indication of their relative performance in relation to the baseline (BAU) scenario and various EU GHG reduction objectives, principally:

- The objective for 2030 to reduce EU non-ETS sector GHG emissions by 30%, relative to 2005 emission levels, as set out in the EU's 2030 climate and energy framework (European Commission, 2017c).
- The objective for 2050 to reduce overall EU transport sector (direct/TTW) GHG emissions by 60%, relative to 1990 emission levels, as set out in the 2011 Transport White Paper (European Commission, 2011a).
- The economy-wide objective for 2050 to reduce EU GHG emissions by at least 80%, relative to 1990 emission levels, as set out in the 2011 Roadmap for moving to a competitive Low Carbon Economy (European Commission, 2011b).

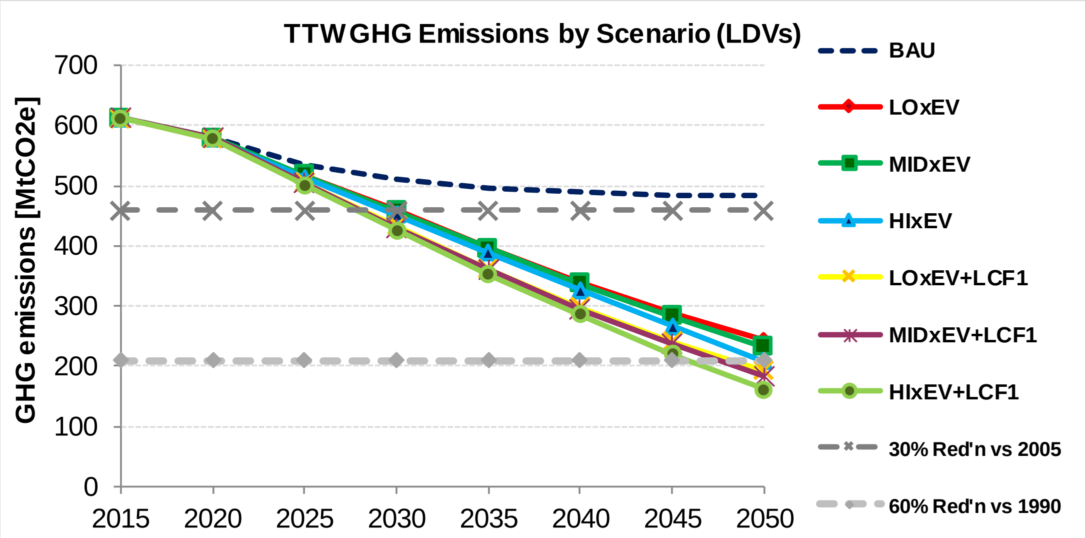
Whilst there are no transport-specific GHG reduction objectives for 2030 in the climate and energy framework, clearly it will be beneficial for transport to make a significant contribution to this, given its significance in terms of overall EU GHG emissions. Whilst it can be seen that in the default/base case biofuel scenarios TTW GHG emissions reductions are approximately in line with the economy-wide objectives, the full WTW GHG emission reductions fall somewhat short of reaching an equivalent contribution. The scenarios with increased utilisation of Low Carbon Fuels (i.e. +LCF1 variants) increase the reductions in LDV emissions by around four to five percentage points in all xEV deployment cases.

In the longer-term, only the HIxEV and all the xEVs + LCF1 scenarios achieve the 2050 GHG reduction objectives on a TTW basis. Given that longer-term GHG emissions reductions will be more difficult to achieve in other transport modes (notably aviation and maritime shipping, but also to a lesser extent heavy duty vehicles) this suggests that 2050 reductions in excess of 60% should be targeted for light duty vehicles (LDVs). Previous analysis has suggested that at least 70-80% improvements in GHG emissions could be necessary for LDVs. However, it should also be noted that there are a range of other (technical and non-technical) measures/policy options that could be (/are already being) deployed to also contribute to these medium- and long-term GHG reduction objectives.

For all the scenarios where additional sustainable low carbon fuels are deployed (i.e. +LCF1 variants) the overall 2050 GHG emissions reductions (versus 1990) are improved by around 10 percentage points for TTW emissions, and around 8 percentage points for WTW emissions. This demonstrates that low carbon fuels could also have important role in achieving long-term GHG reduction objectives across a wide range of possible xEV deployment scenarios.

Figure 3.5: Total TTW and WTW GHG emissions for different scenarios

TTW



WTW

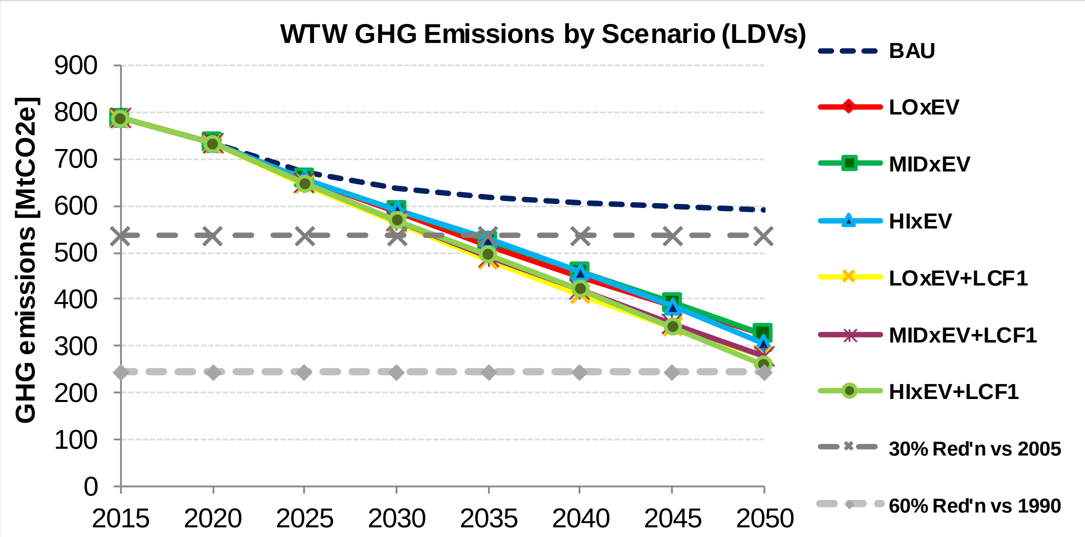
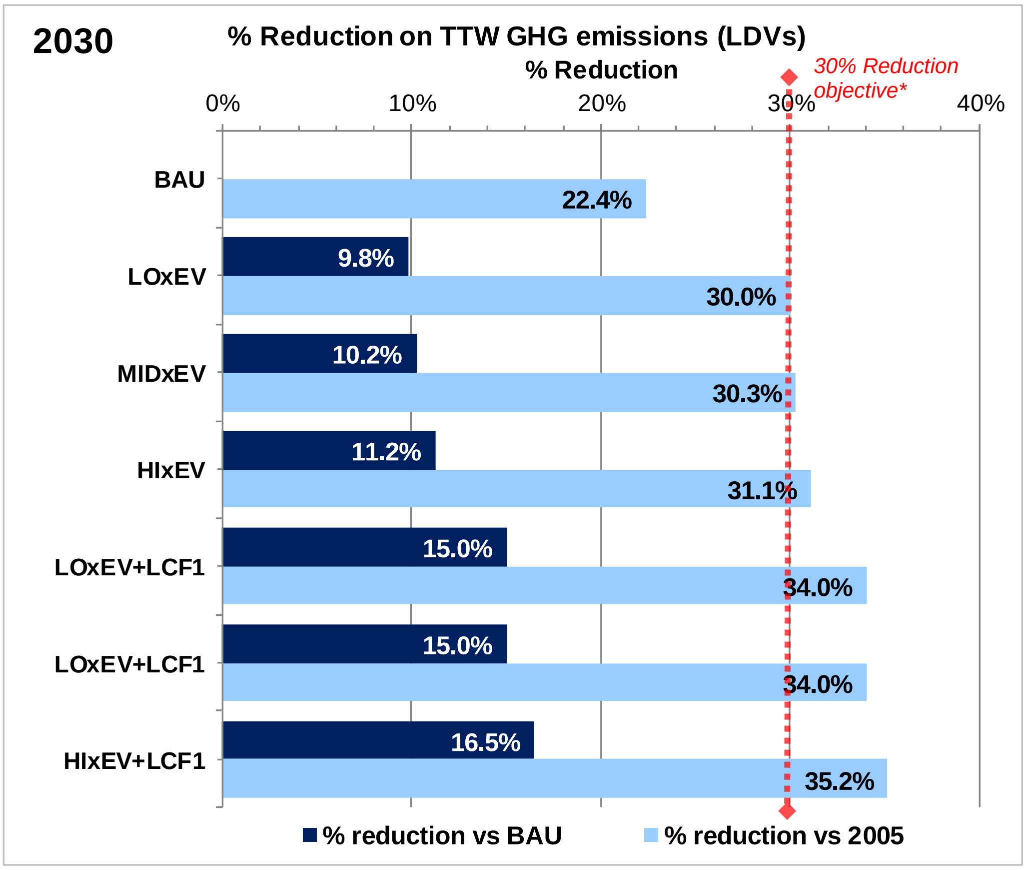
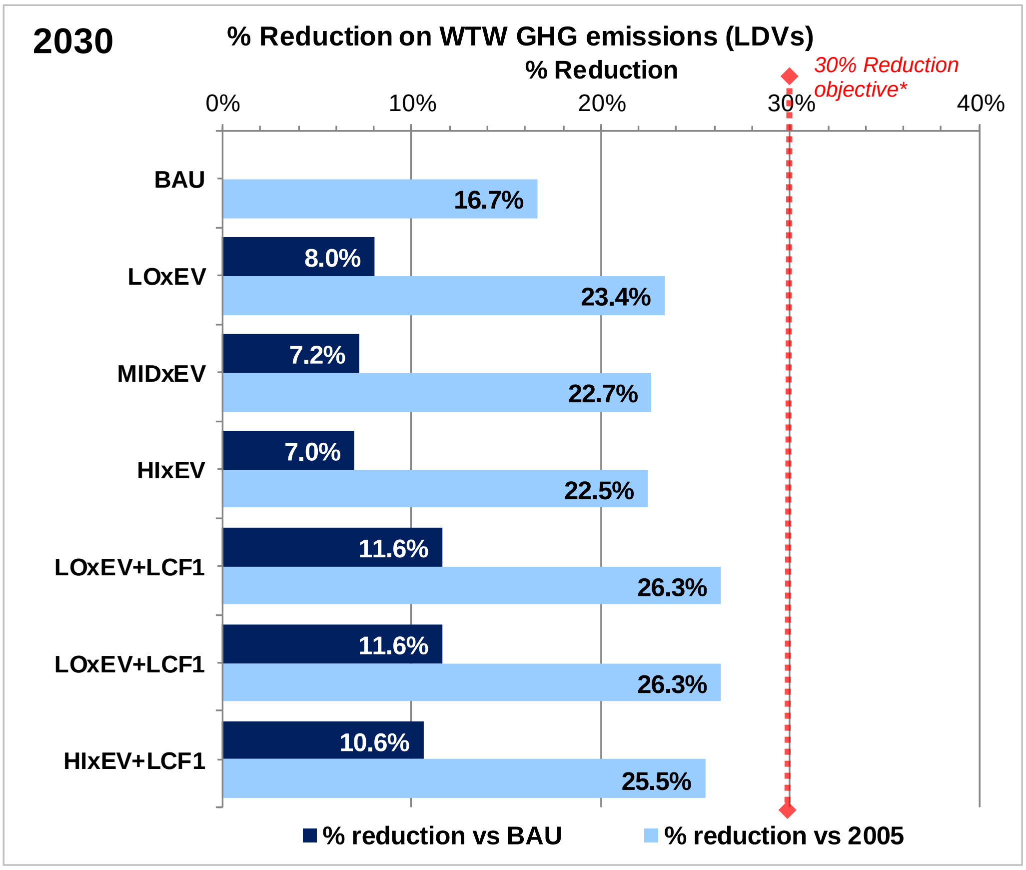


Figure 3.6: Total TTW and WTW GHG emissions for different scenarios – 2030 reduction vs 2005

TTW



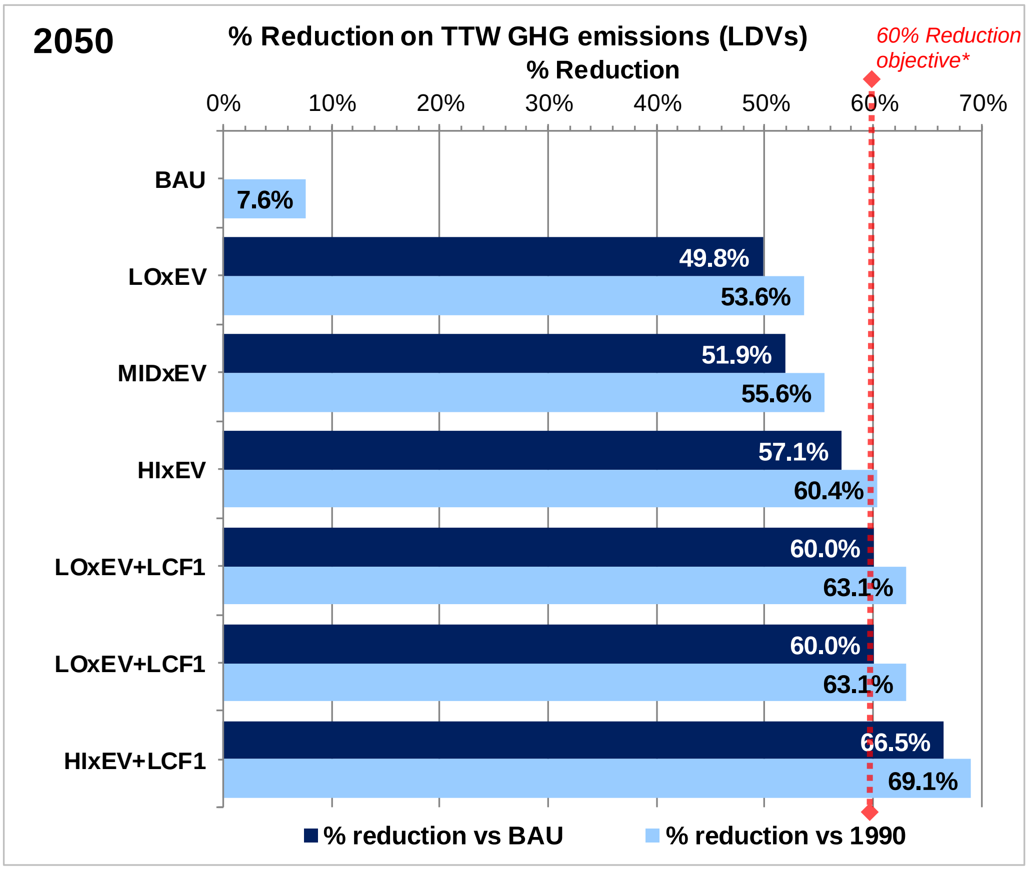
WTW



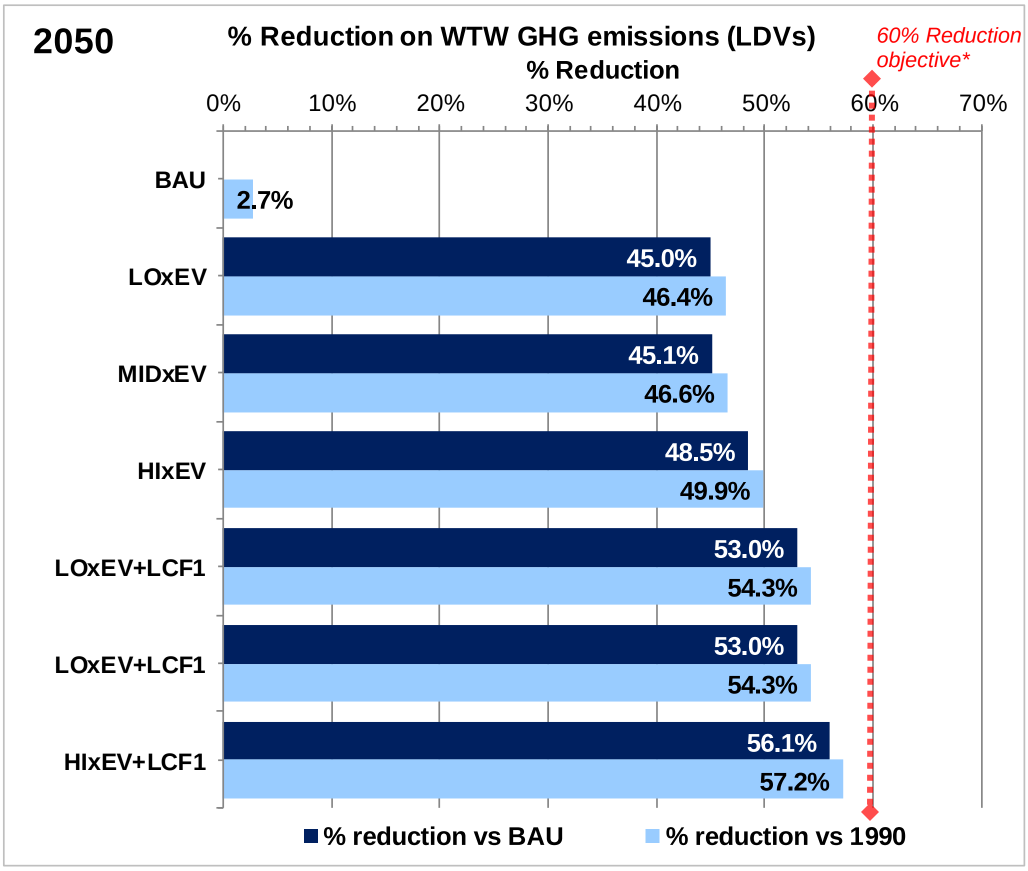
Notes: *The EU has an objective for 2030 to reduce EU non-ETS sector GHG emissions by 30%, relative to 2005.

Figure 3.7: Total TTW and WTW GHG emissions for different scenarios – 2050 reduction vs 1990

TTW



WTW



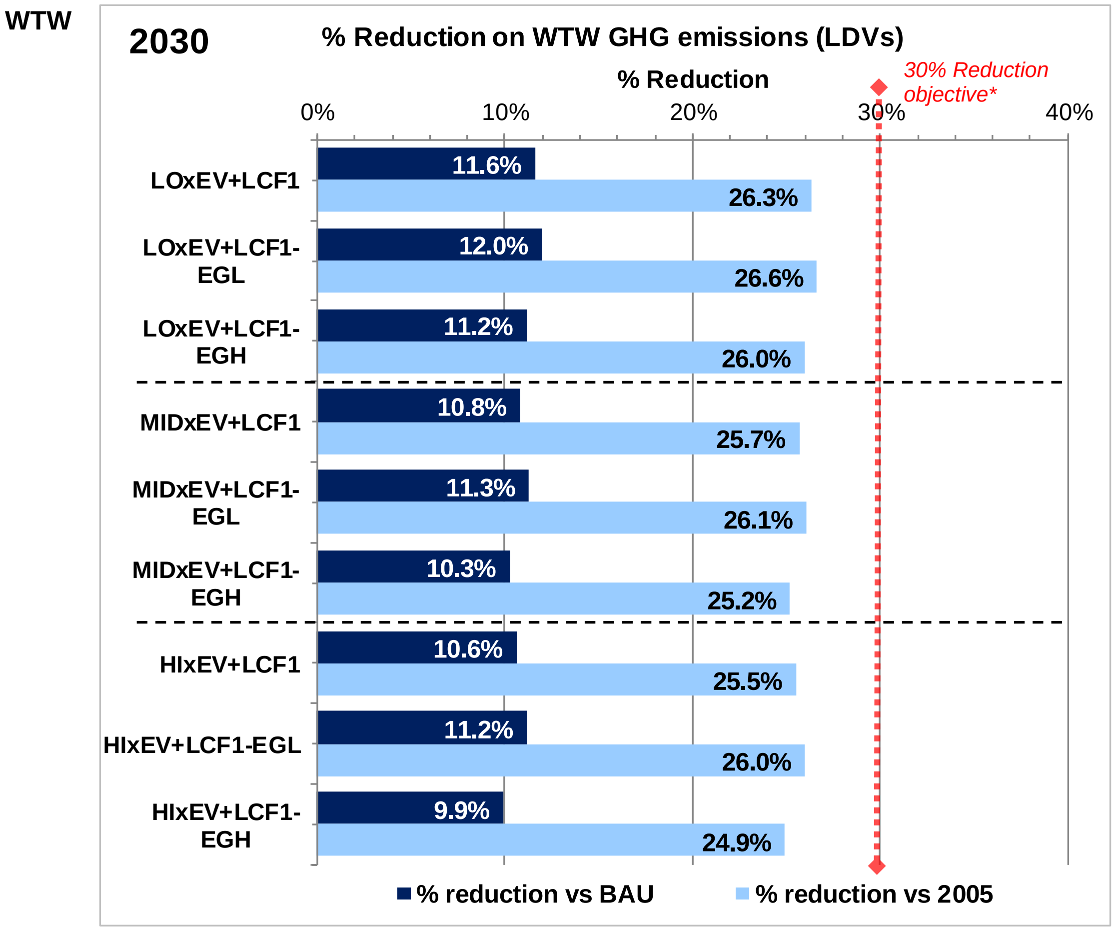
Notes: *The EU has an objective for 2050 to reduce transport sector TTW GHG emissions by 60%, relative to 1990.

3.2 Summary of results for sensitivities

3.2.1 Impact on net GHG of different assumptions about GHG intensity of electricity

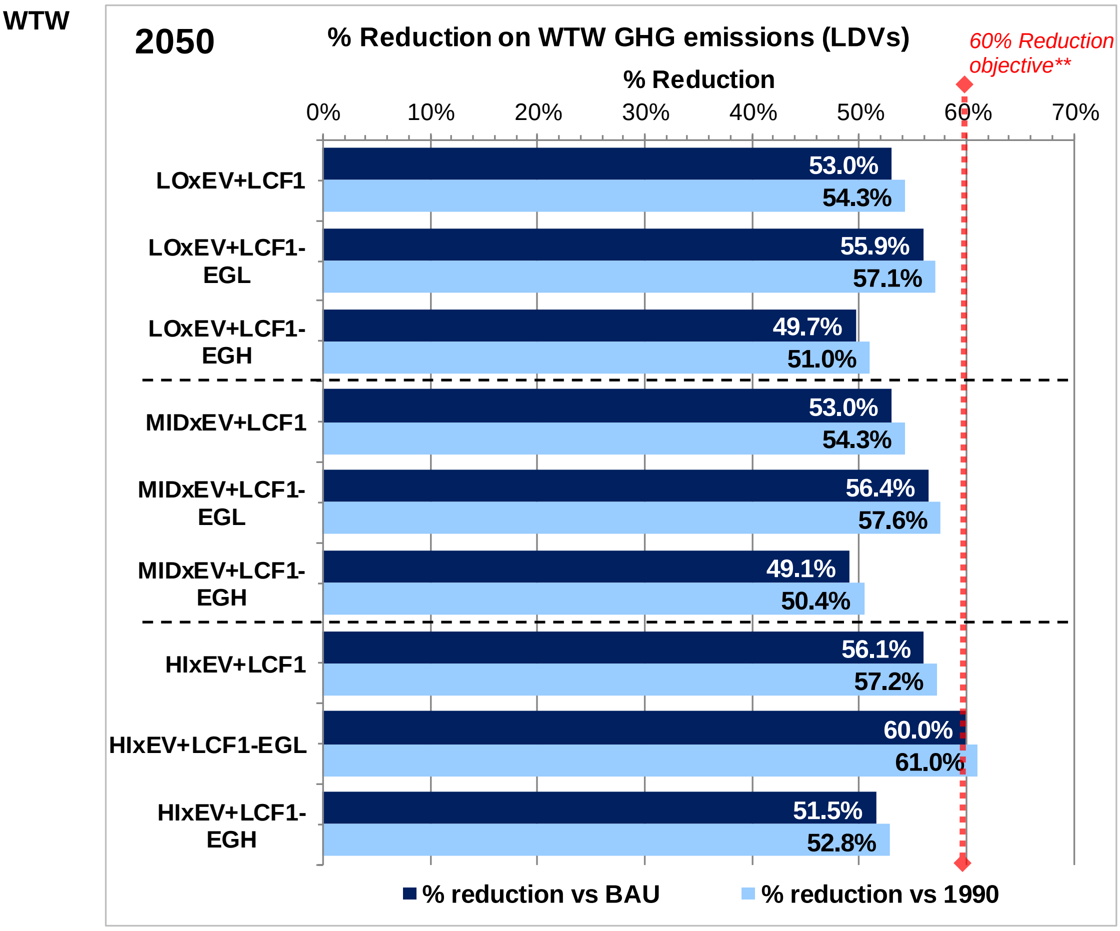
Figure 3.9 and Figure 3.9 provide a summary of the impacts of the sensitivity on the GHG intensity of electricity used by plug-in electric vehicles, in 2030 and 2050 respectively (see Appendix A3 for further details on the electricity GHG intensity and the renewable electricity share). The sensitivity shows a variation in 2050 of 6-8 percentage points between the high GHG intensity electricity (-EGH) and low GHG intensity electricity (-EGL) sensitivities, with the largest variation being for the high xEV deployment scenario. The variation in GHG emissions at the 2030 time-horizon is lower as the variation in the total fleet share of xEVs and the difference between low and high GHG intensity are both less significant. The variation in percentage points is also similar for the scenarios with the baseline biofuel shares.

Figure 3.8: Percentage reduction in total WTW GHG emissions for different scenarios in 2030 compared to (a) the business-as-usual scenario and (b) emissions in 2005*



Notes: *The EU has an objective for 2030 to reduce EU non-ETS sector GHG emissions by 30%, relative to 2005.

Figure 3.9: Percentage reduction in total WTW GHG emissions for different scenarios in 2050 compared to (a) the 2050 business-as-usual scenario and (b) emissions in 1990*



Notes: *The EU has an objective for 2050 to reduce transport sector TTW GHG emissions by 60%, relative to 1990. EGL = Electricity GHG intensity Low; EGH = Electricity GHG intensity High.

3.2.2 Impact of different assumptions regarding low carbon fuels on net GHG emissions (LCF2)

Figure 3.10 and Figure 3.12, respectively, provide a summary of the overall low carbon fuel consumption and the WTW emissions for the main low carbon fuels scenarios (LCF1) and the alternative low carbon fuels sensitivity (LCF2).

As illustrated in Figure 3.10, the overall low carbon fuel consumption is higher in the sensitivity scenario (LCF2) as almost all of the increase in the consumption of 1G bioethanol is added to light duty vehicles (mainly cars), whilst some of the substituted 1G biodiesel is taken also from other transport modes. For similar reasons, the volume of low carbon fuels used are greater in the LOxEV scenarios and least in the HIxEV scenarios (where also the available bioethanol exceeds the E25 maximum average blend set as a constraint for the scenarios by 2050).

Figure 3.10: Total low carbon fuel consumption for different scenarios by fuel type

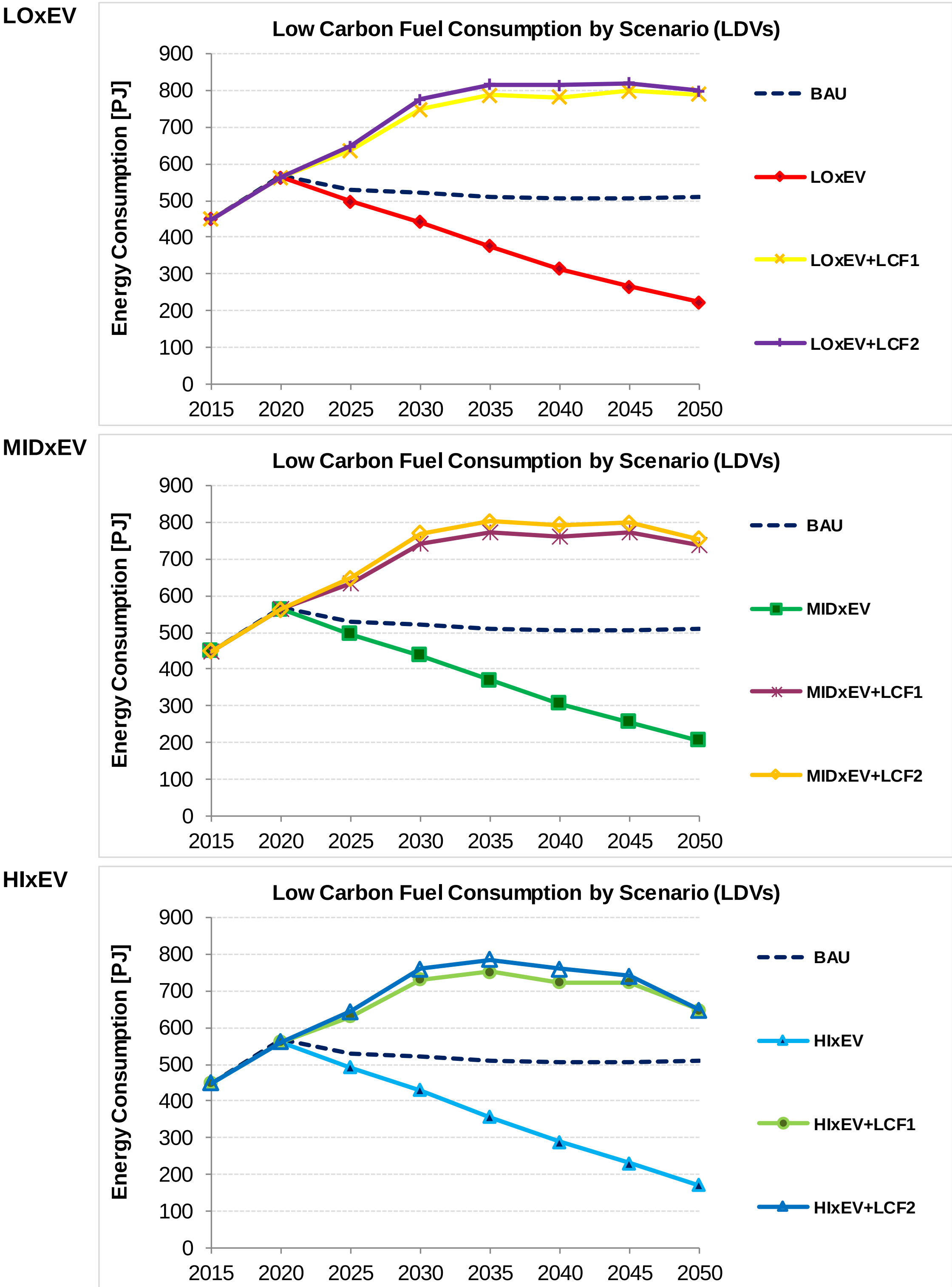
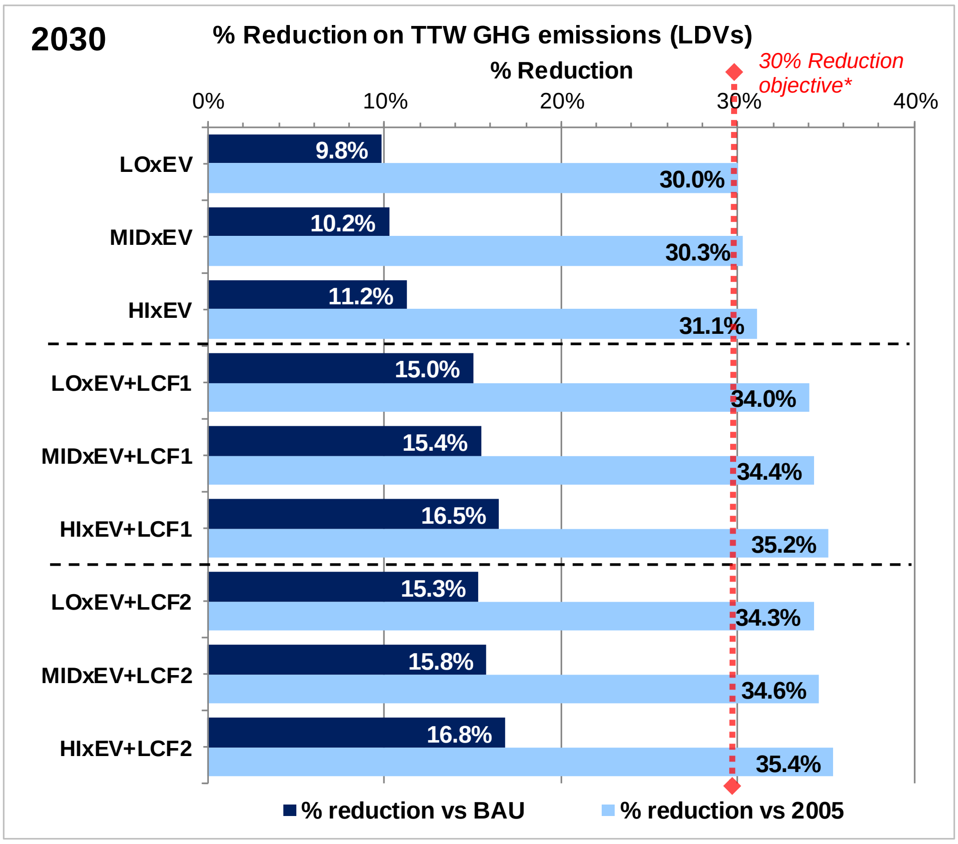


Figure 3.11 and Figure 3.12, below show that a combination of the improved average low carbon fuel WTW GHG emission factor, increased benefits from E20+ optimised cars, and higher average substitution rate of low carbon fuels in the sensitivity (LCF2) leads to increased emission reductions over the main (LCF1) scenario of around +0.3 percentage points in both 2030 and 2050 time-horizons.

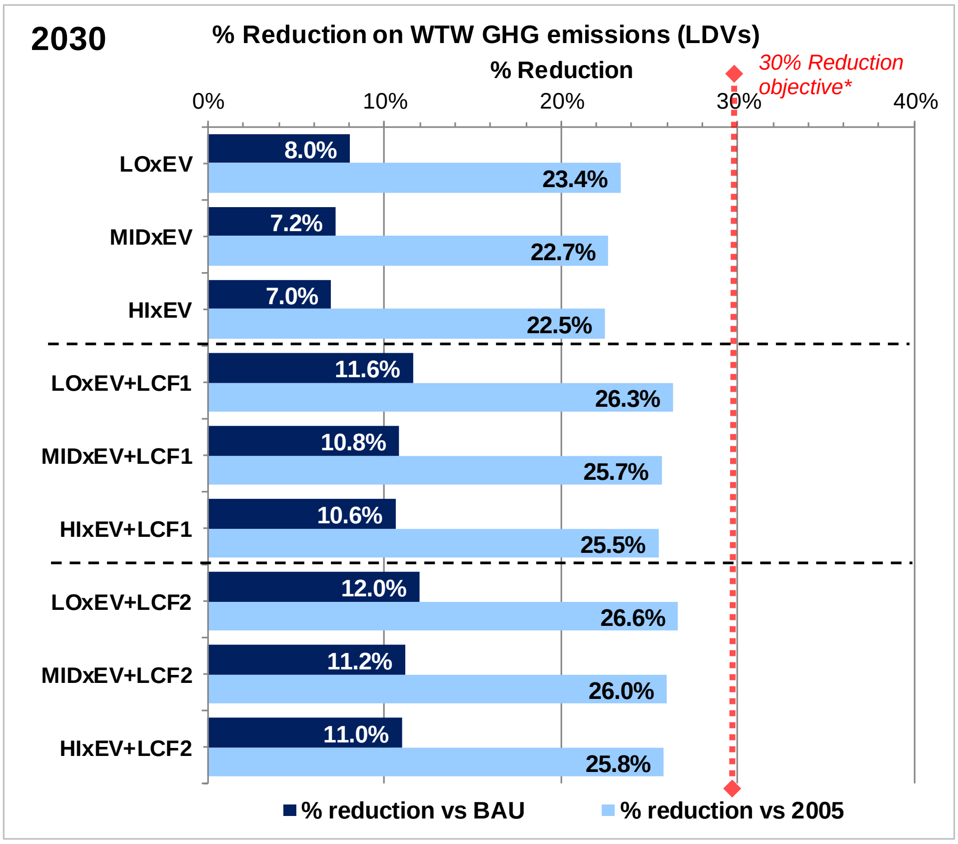
The figures also illustrate that there are additional TTW GHG savings of around +0.2 to +0.3 percentage points in 2030 for the low carbon fuels sensitivity (LCF2) compared to the main scenario (LCF1).

Figure 3.11: Percentage reduction in total TTW GHG emissions for different scenarios in 2030 and 2050 compared to (a) the baseline (BAU) scenario and (b) 2005 emissions (for 2030) / 1990 emissions (for 2050)

TTW



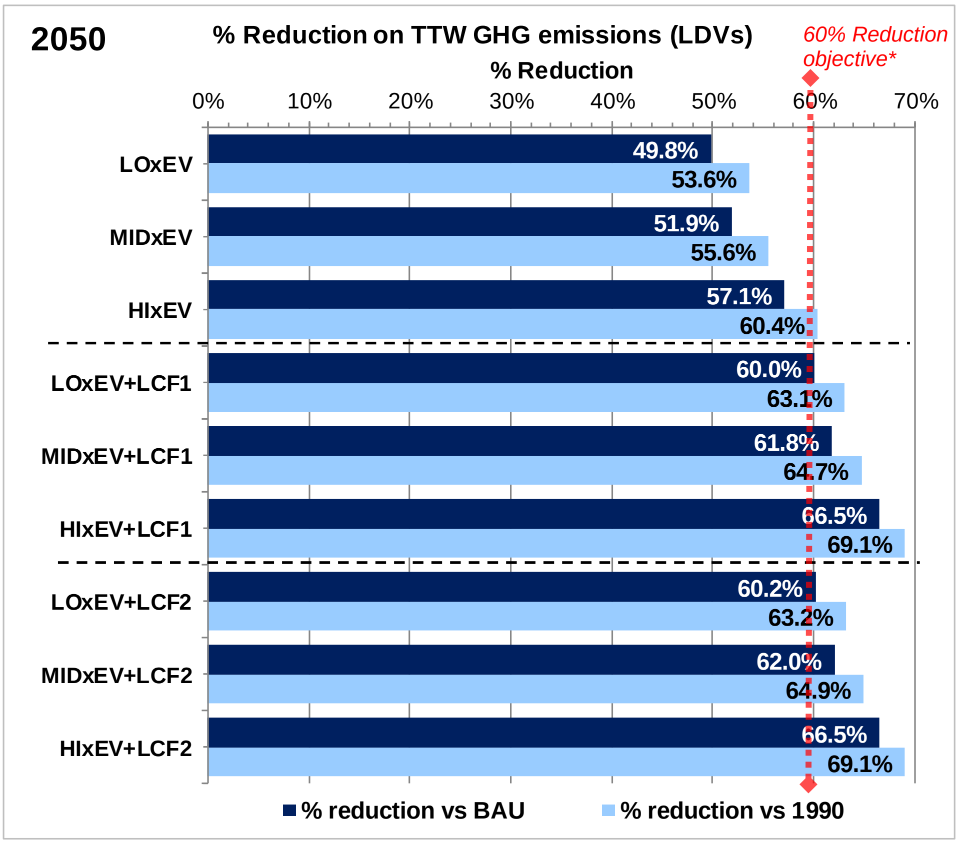
WTW



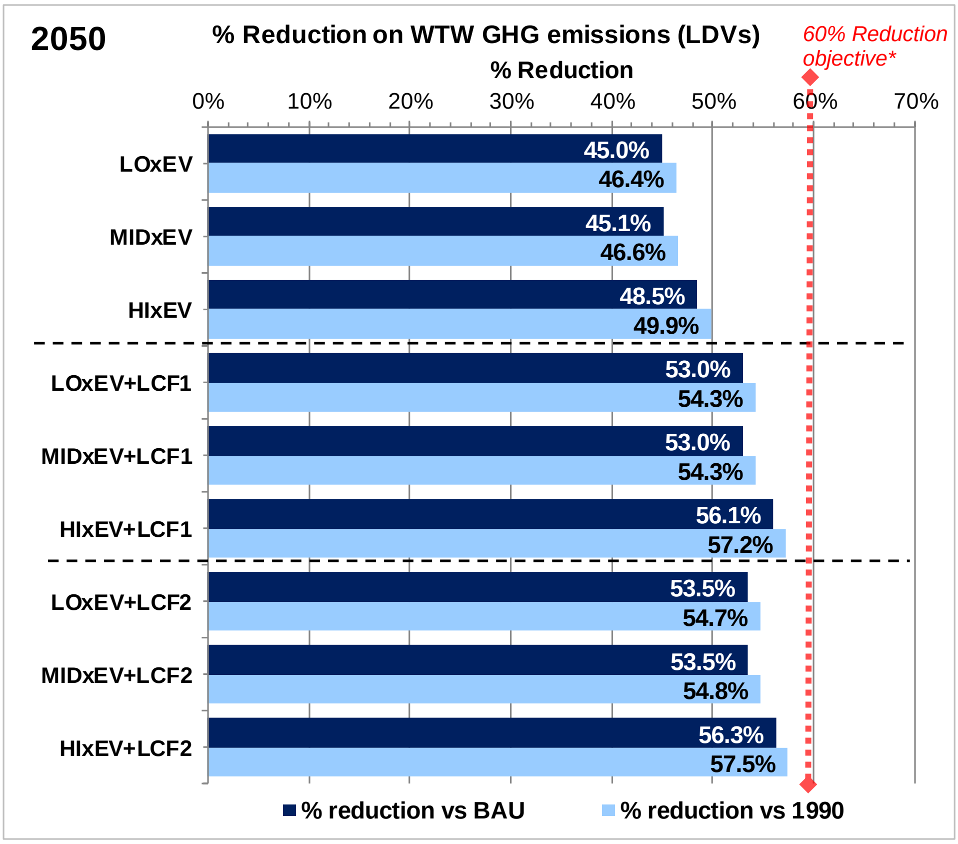
Notes: *The EU has an objective for 2030 to reduce EU non-ETS sector GHG emissions by 30%, relative to 2005.

Figure 3.12: Percentage reduction in total WTW GHG emissions for different scenarios in 2030 and 2050 compared to (a) the baseline (BAU) scenario and (b) 2005 emissions (for 2030) / 1990 emissions (for 2050)

TTW



WTW



Notes: *The EU has an objective for 2050 to reduce transport sector TTW GHG emissions by 60%, relative to 1990.

3.3 Summary of key findings

Overall the results of the scenario modelling analysis demonstrate that increased future deployment of sustainable low carbon fuels could make an important contribution to reducing the TTW and WTW GHG emissions from LDVs in the medium-term (i.e. 2030) and long-term perspectives (i.e. 2050) across a wide-range of potential xEV uptake rates.

Figure 3.13 clearly demonstrates the important contribution that increased use of low carbon fuels could make to reducing the GHG emissions from LDVs in 2030. For all potential xEV uptake rates, additional low carbon fuels reduce TTW GHG emissions further (compared to 2005[14]) by at least four percentage points. Impacts on WTW emissions from the introduction of more low carbon fuels are similar, with the increase in low carbon fuels further improving GHG savings by three percentage points. The additional savings generated by the increased use of low carbon fuels, mean that even with low electrification rates, reductions achieved under a low carbon fuels scenario are greater than a scenario with high electrification but no increased use of low carbon fuels. This is true even if electricity decarbonises more rapidly than in the reference scenario (scenario EGL in Figure 3.13).

Similar results are obtained for 2050, confirming that increased future deployment of sustainable low carbon fuels could make an important contribution to reducing the GHG emissions from LDVs in both the medium and long-term across a wide-range of potential xEV uptake rates. Importantly, the analysis showed that the EU's long-term transport GHG reduction objectives are unlikely to be achieved without additional measures beyond the rate of CO_2 reduction set in the post-2020 CO_2 regulation proposals.

Utilisation of such fuels could either support additional GHG emission reductions than would otherwise be achieved, and/or mitigate for potential uncertainty in the longer-term GHG intensity of electricity used by plug-in electric light duty vehicles (i.e. BEVs and PHEVs), as well as availability of key resources needed for xEVs, and/or their higher manufacturing emissions.

For a given trajectory of improvement in regulatory tailpipe gCO_2/km emissions, the GHG emissions reductions are relatively insensitive to different assumptions on xEV uptake when developing scenarios based on a specific amount (in PJ) of low carbon fuel availability.

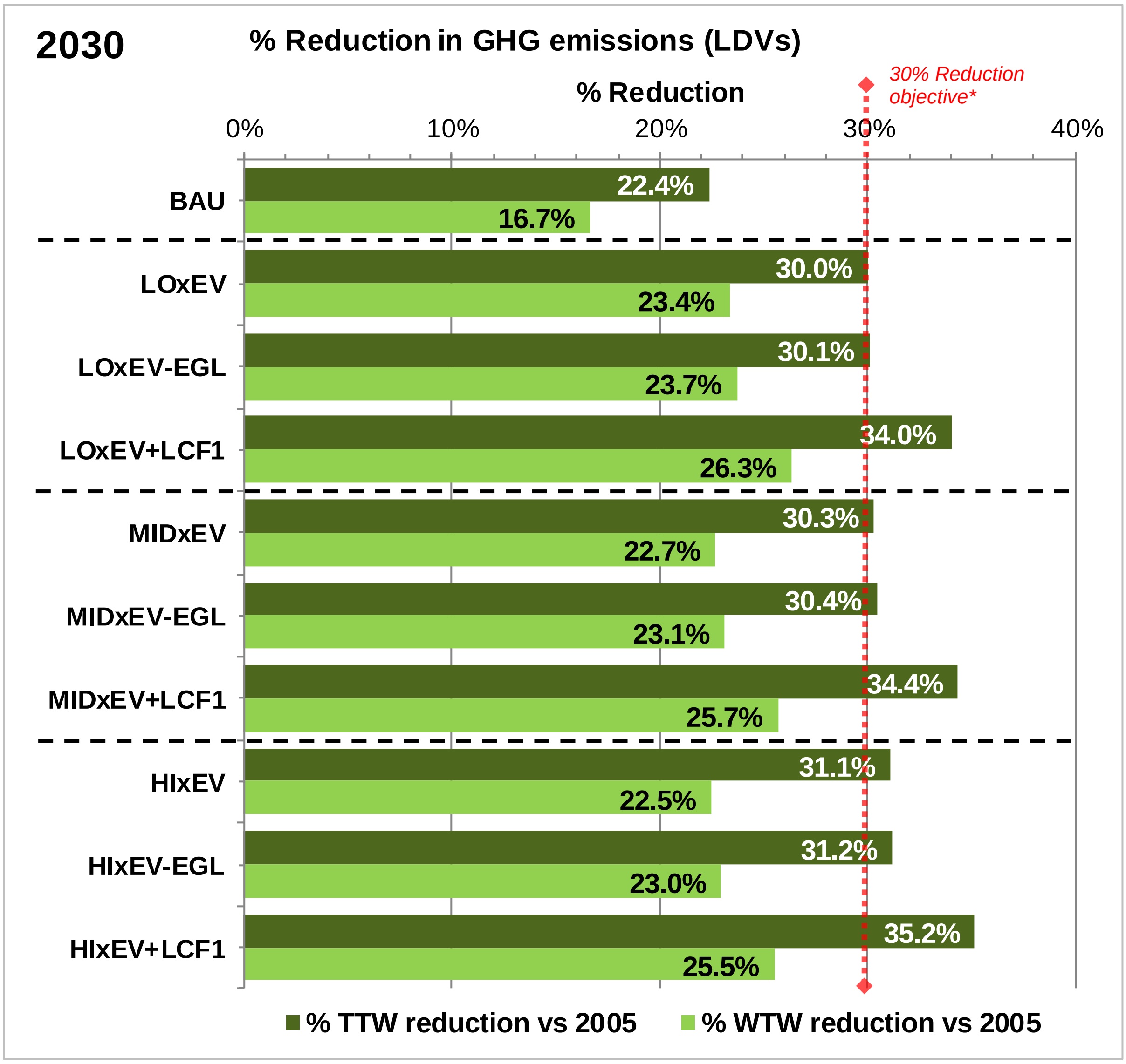
- The main reason for this is that with higher xEV shares, rates of improvement to conventional and regular hybrid powertrains can be lower, offsetting the reductions in conventional fuel use caused by a shift to xEVs.
- However, where a fixed % substitution rate is assumed/given as a constraint for low carbon fuels then the volumes of these fuels used will decline more significantly with higher xEV shares.
- Higher (or lower) targets for gCO_2/km improvement will have a more significant impact on overall energy consumption of liquid fuels, and consequently also the potential volumes / substitution levels of low carbon fuels.

In addition, the alternative low carbon fuel uptake sensitivity illustrated that additional direct (TTW) and WTW GHG emissions savings could be possible with an increased share of 1G bioethanol, offset by a reduction in FAME biodiesel from higher WTW emission sources. Furthermore, this sensitivity also delivered an additional +0.2 to +0.3 percentage point reduction in TTW GHG emissions in 2030.

It is worth noting that in this analysis we have utilised relatively conservative assumptions in terms of the deployment of low carbon fuels to 2030 and 2050; some recent analyses, e.g. (P Baker et al, 2017) have suggested that significantly higher volumes of low carbon fuels could be available to transport in this timeframe.

[14] The EU's 2030 climate and energy framework (European Commission, 2017c) sets an objective to reduce GHG emissions in non-ETS sectors by 30%, relative to 2005, by 2030.

Figure 3.13: Reduction in LDV GHG emissions in 2030 compared to 2005



Notes: * The EU has an objective for 2030 to reduce EU non-ETS sector GHG emissions by 30%, relative to 2005.

Key:

BAU	European Commission's 2016 Reference Scenario	**LOxEV**	Low xEV deployment
LCF1	Increase Low Carbon Fuels	**MIDxEV**	Intermediate xEV deployment
EGL	low GHG intensity electricity	**HIxEV**	High xEV deployment

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Appendices

A1: Appendix 1 – Powertrains

A2: Appendix 2 – Low Carbon Fuels

A3: Appendix 3 – Sensitivities

A1 Appendix 1 – Powertrains

A1.1 Summary of forecasts and projections for xEV uptake

Table A1: Summary of forecasts and projections for xEV uptake

Publication		% market share				
Source	Year	2020	2025	2030	2040	2050
SULTAN HIxEV Scenario (this study)	2018	5.5%	19.0%	40.0%	70.0%	100.0%
SULTAN LOxEV Scenario (this study)	2018	5.0%	11.5%	22.5%	45.0%	70.0%
SULTAN MIDxEV Scenario (this study)	2018	5.0%	15.3%	31.3%	57.5%	85.0%
ECF "Tech" 2018	2018	2.5%	10.0%	25.0%	100.0%	100.0%
ECF "Tech OEM" 2018	2018	2.5%	15.0%	75.0%	100.0%	100.0%
Ricardo Post-2020 HIGH xEV 2018	2018	5.4%	17.3%	34.1%	65.2%	81.3%
Ricardo Post-2020 LOW xEV 2018	2018	4.5%	13.7%	24.3%	47.1%	64.0%
EAFO Sc 1: LOW ZEV forecast 2017	2017	5.8%	20.2%	28.8%	56.9%	65.3%
EAFO Sc 2: Average EV uptake 2017	2017	9.0%	25.2%	37.9%	61.6%	76.0%
EAFO Sc 3: HIGH ZEV forecast 2017	2017	14.0%	33.5%	46.7%	66.1%	83.1%
ACEA LOW 2017	2017	2.0%	2.0%			
ACEA HIGH 2017	2017	8.0%	8.0%			
IEA B2DS 2017	2017	4.0%	13.0%	30.0%		
IEA 2DS 2017	2017	3.0%	11.0%	23.0%		
Paris Declaration 2017	2017	3.0%	8.0%	17.0%		
IEA RTS 2017	2017	2.0%	4.0%	8.0%		
FEV "Base scenario" 2016	2016			32.0%		
FEV "Accelerated scenario" 2016	2016			45.0%		
Roland Berger Scenario A 2016	2016	4.0%	5.0%	6.0%		
Roland Berger Scenario B 2016	2016	4.0%	7.0%	10.0%		
SCelecTRA 2016	2016					
Oliver Wyman "slight change" 2015	2015		6.6%			
Oliver Wyman "Awareness" 2015	2015		19.0%			
Oliver Wyman "Green world" 2015	2015		35.0%			
McKinsey below 10 2014	2014	16.0%		51.0%		
McKinsey below 40 2014	2014	17.0%		39.0%		
McKinsey below 100 2014	2014	3.0%		13.0%		
Camecon/Ricardo, Tech 2 2013	2013	4.0%	13.0%	30.0%		
Camecon/Ricardo, Tech 3 2013	2013	10.0%	38.0%	65.0%		
AT Kearney 2012	2012	23.0%	40.0%			
CE Delft "most realistic" 2011	2011	2.0%	6.0%	18.0%		
CE Delft "ICE breakthrough" 2011	2011	2.0%	3.0%	7.0%		
CE Delft "EV breakthrough" 2011	2011	2.0%	12.0%	33.0%		
JRC EU15 low 2011	2011	4.0%		8.0%		

Publication		% market share				
Source	**Year**	**2020**	**2025**	**2030**	**2040**	**2050**
JRC EU15 medium 2011	2011	10.0%		20.0%		
JRC EU15 high 2011	2011	17.0%		30.0%		
JRC EU12 low 2011	2011	2.0%		4.0%		
JRC EU12 medium 2011	2011	4.0%		8.0%		
JRC EU12 high 2011	2011	10.0%		20.0%		

A1.2 Scenario input assumptions for new vehicle shares

Table A2: Low xEV Scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	40.4%	38.0%	32.0%	22.0%	16.0%	10.0%	5.0%	0.0%
Diesel	43.2%	33.1%	25.7%	17.5%	10.8%	4.0%	2.0%	0.0%
HEV gasoline	5.6%	10.8%	18.0%	23.0%	26.5%	30.0%	26.0%	22.0%
HEV diesel	3.7%	8.2%	9.0%	12.0%	11.0%	10.0%	9.0%	8.0%
PHEV gasoline	0.8%	1.6%	4.0%	7.0%	11.0%	15.0%	17.5%	20.0%
PHEV diesel	0.7%	1.4%	2.0%	4.0%	5.5%	7.0%	8.5%	10.0%
EV	0.5%	2.0%	5.0%	10.0%	15.0%	20.0%	27.5%	35.0%
FCEV	0.0%	0.0%	0.5%	1.5%	2.3%	3.0%	4.0%	5.0%
LPG	3.3%	2.8%	1.9%	1.0%	0.5%	0.0%	0.0%	0.0%
CNG	1.7%	2.1%	1.9%	2.0%	1.5%	1.0%	0.5%	0.0%
xEVs	**2.0%**	**4.9%**	**11.5%**	**22.5%**	**33.8%**	**45.0%**	**57.5%**	**70.0%**

Table A3: Medium xEV Scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	40.4%	38.0%	33.5%	21.0%	13.0%	5.0%	2.5%	0.0%
Diesel	43.2%	33.1%	23.4%	13.8%	7.9%	2.0%	1.0%	0.0%
HEV gasoline	5.6%	10.8%	15.5%	21.5%	24.5%	27.5%	19.3%	11.0%
HEV diesel	3.7%	8.2%	8.5%	9.5%	8.5%	7.5%	5.8%	4.0%
PHEV gasoline	0.8%	1.6%	5.0%	11.0%	16.8%	22.5%	27.5%	32.5%
PHEV diesel	0.7%	1.4%	2.5%	4.5%	5.3%	6.0%	5.5%	5.0%
EV	0.5%	2.0%	6.5%	12.5%	17.5%	22.5%	30.0%	37.5%
FCEV	0.0%	0.0%	1.3%	3.3%	4.9%	6.5%	8.3%	10.0%
LPG	3.3%	2.8%	1.9%	1.0%	0.5%	0.0%	0.0%	0.0%
CNG	1.7%	2.1%	1.9%	2.0%	1.3%	0.5%	0.3%	0.0%
xEVs	**2.0%**	**4.9%**	**15.3%**	**31.3%**	**44.4%**	**57.5%**	**71.3%**	**85.0%**

Table A4: High xEV Scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	40.4%	38.0%	35.0%	20.0%	10.0%	0.0%	0.0%	0.0%
Diesel	43.2%	32.6%	21.2%	10.0%	5.0%	0.0%	0.0%	0.0%
HEV gasoline	5.6%	10.8%	13.0%	20.0%	22.5%	25.0%	12.5%	0.0%
HEV diesel	3.7%	8.2%	8.0%	7.0%	6.0%	5.0%	2.5%	0.0%
PHEV gasoline	0.8%	2.0%	6.0%	15.0%	22.5%	30.0%	37.5%	45.0%
PHEV diesel	0.7%	1.5%	3.0%	5.0%	5.0%	5.0%	2.5%	0.0%
EV	0.5%	2.0%	8.0%	15.0%	20.0%	25.0%	32.5%	40.0%
FCEV	0.0%	0.1%	2.0%	5.0%	7.5%	10.0%	12.5%	15.0%
LPG	3.3%	2.8%	1.9%	1.0%	0.5%	0.0%	0.0%	0.0%
CNG	1.7%	2.1%	1.9%	2.0%	1.0%	0.0%	0.0%	0.0%
xEVs	**2.0%**	**5.5%**	**19.0%**	**40.0%**	**55.0%**	**70.0%**	**85.0%**	**100.0%**

A1.3 Scenario outputs for vehicle parc (whole fleet) shares

Table A5: Low xEV Scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	49.8%	46.3%	40.4%	34.3%	27.5%	20.5%	14.1%	8.5%
Diesel	44.7%	42.4%	36.5%	29.8%	22.6%	15.2%	9.2%	4.8%
HEV gasoline	1.2%	3.6%	8.8%	14.1%	19.2%	23.7%	26.2%	26.0%
HEV diesel	0.7%	2.5%	5.5%	8.0%	9.8%	10.4%	10.3%	9.5%
PHEV gasoline	0.1%	0.5%	1.6%	3.2%	5.7%	9.0%	12.4%	15.5%
PHEV diesel	0.1%	0.4%	1.0%	1.9%	3.1%	4.6%	6.1%	7.6%
EV	0.1%	0.5%	1.8%	4.2%	7.7%	12.2%	17.5%	23.7%
FCEV	0.0%	0.0%	0.1%	0.5%	1.0%	1.8%	2.6%	3.5%
LPG	2.4%	2.7%	2.6%	2.2%	1.6%	0.9%	0.4%	0.2%
CNG	0.8%	1.2%	1.6%	1.9%	1.8%	1.6%	1.2%	0.8%
xEVs	**0.3%**	**1.4%**	**4.6%**	**9.7%**	**17.5%**	**27.5%**	**38.5%**	**50.2%**

Table A6: Medium xEV Scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	49.8%	46.3%	40.8%	34.6%	27.1%	18.5%	11.2%	5.9%
Diesel	44.7%	42.4%	36.0%	28.4%	20.3%	12.6%	6.9%	3.3%
HEV gasoline	1.2%	3.6%	8.2%	13.0%	17.6%	21.8%	23.2%	20.7%
HEV diesel	0.7%	2.5%	5.4%	7.4%	8.4%	8.4%	7.8%	6.5%
PHEV gasoline	0.1%	0.5%	1.8%	4.3%	8.3%	13.5%	18.9%	24.2%
PHEV diesel	0.1%	0.4%	1.1%	2.2%	3.3%	4.5%	5.2%	5.4%
EV	0.1%	0.5%	2.2%	5.1%	9.4%	14.4%	19.9%	26.1%
FCEV	0.0%	0.0%	0.3%	1.0%	2.3%	3.9%	5.5%	7.2%
LPG	2.4%	2.7%	2.6%	2.2%	1.6%	0.9%	0.4%	0.2%
CNG	0.8%	1.2%	1.6%	1.9%	1.8%	1.4%	1.0%	0.5%
xEVs	**0.3%**	**1.4%**	**5.4%**	**12.6%**	**23.3%**	**36.2%**	**49.5%**	**62.9%**

Table A7: High xEV Scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Gasoline	49.8%	46.3%	41.1%	34.9%	26.6%	16.5%	8.2%	3.3%
Diesel	44.7%	42.3%	35.3%	26.7%	17.9%	10.0%	4.6%	1.8%
HEV gasoline	1.2%	3.6%	7.7%	11.9%	16.1%	19.9%	20.2%	15.4%
HEV diesel	0.7%	2.5%	5.2%	6.7%	7.0%	6.4%	5.3%	3.6%
PHEV gasoline	0.1%	0.6%	2.1%	5.5%	11.0%	18.0%	25.4%	32.8%
PHEV diesel	0.1%	0.5%	1.3%	2.5%	3.6%	4.4%	4.3%	3.2%
EV	0.1%	0.5%	2.5%	6.1%	11.0%	16.5%	22.3%	28.6%
FCEV	0.0%	0.0%	0.5%	1.6%	3.5%	6.0%	8.5%	10.9%
LPG	2.4%	2.7%	2.6%	2.2%	1.6%	0.9%	0.4%	0.2%
CNG	0.8%	1.2%	1.6%	1.9%	1.8%	1.3%	0.7%	0.3%
xEVs	**0.3%**	**1.5%**	**6.4%**	**15.7%**	**29.1%**	**44.9%**	**60.5%**	**75.6%**

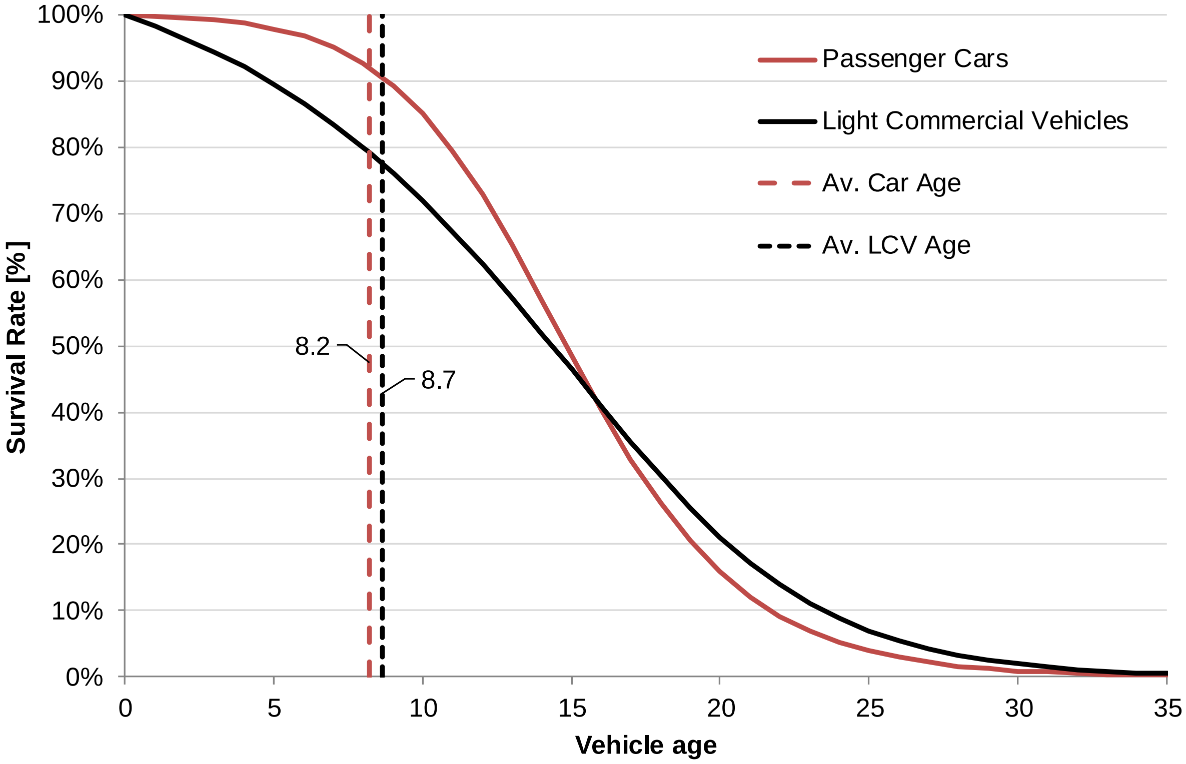
A1.4 Vehicle survival rate curves used in the SULTAN model

The SULTAN model uses vehicle survival curves in its fleet/stock model, which determine the share of the (new) vehicles added to the fleet in year 20XX that are remaining after Y years (i.e. in year 20XX+Y).

The survival functions are based upon the average EU vehicle age profiles from the TRACCs project database (Emisia, 2013), further calibrated/adjusted to the 2016 Reference Scenario (European Commission, 2016a).

An illustration of these survival functions for cars and vans (light commercial vehicles) is presented in the following Figure A1, together with the implied average vehicle age for the fleet.

Figure A1: Survival functions for passenger cars and light commercial vehicles used by the SULTAN stock model



A2 Appendix 2 – Low Carbon Fuels

A2.1 Main Scenario (LCF1)

A2.1.1 Overview

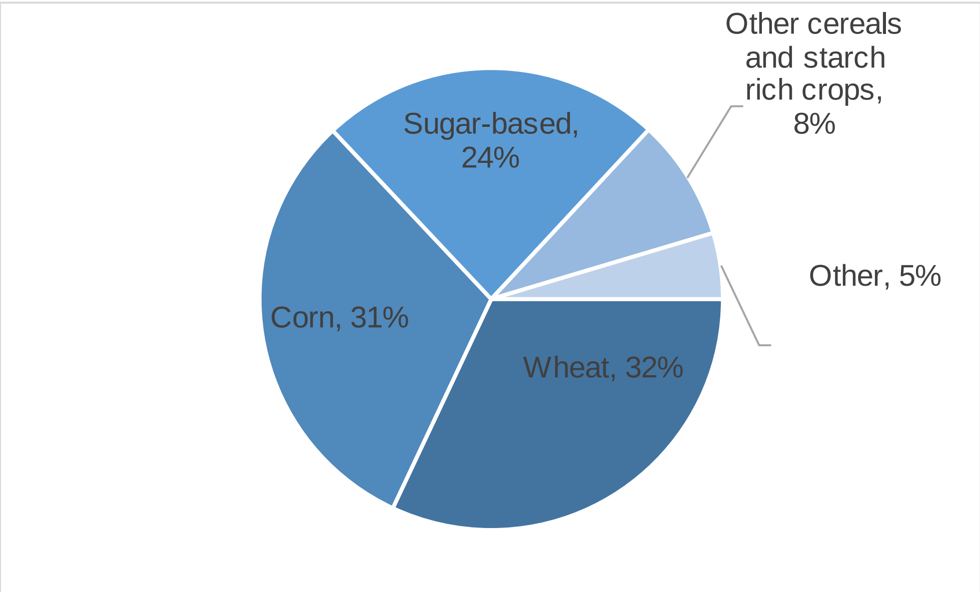
A scenario for the future availability of biofuels was constructed based on a number of sources which have looked at the potential for biofuels in the EU in the short (2020) medium (2030) and long term (2040 to 2050). Starting from current consumption of biofuels, the scenario is intended to provide an optimistic yet realistic picture of biofuels development, which also takes account of proposed policy developments. These are still uncertain at the moment as the proposal for a successor to the Renewable Energy Directive (RED), RED II is currently the subject of trilogue negotiations between the European Commission, European Council and European Parliament. One of the main changes proposed in RED II, a decline in the cap for crop-based biofuels from 7% to 3.8% was opposed by both the Council and Parliament and in the scenario here is assumed to remain at 7%. The contribution of crop-based biofuels is however kept at slightly below this 7% given the possibility that Member States may impose lower limits. Indeed, the UK has already introduced legislation to set a maximum cap of 4% in 2018 reducing to 2% in 2032[15]. While production of 1G biofuels increases to 2030, post 2030 the only growth is in advanced biofuels, reflecting policy ambitions to increase production of these biofuels which generally have less potential for ILUC and higher greenhouse gas savings.

The key assumptions made in estimating the availability of biofuels are given below and quantities of each fuel in Table A9.

A2.1.2 Bioethanol

Current (2016) consumption of biogasoline in road transport is 2.6 Mtoe[16]. Data on feedstocks used for bioethanol production (for all uses) are available from ePURE Members; this indicates that for all bioethanol produced by ePURE's members (of which fuel bioethanol accounts for 78%), the predominant feedstocks are crop based – cereals and other starch rich crops and sugar based – accounting for 95% percent of production. As ePURE member's bioethanol production accounts for the vast majority of fuel bioethanol production, in Europe, it is assumed that almost all bioethanol production currently is 1G crop-based bioethanol.

Figure A2: Bioethanol production (for all uses) by feedstock (ePURE Members 2016)



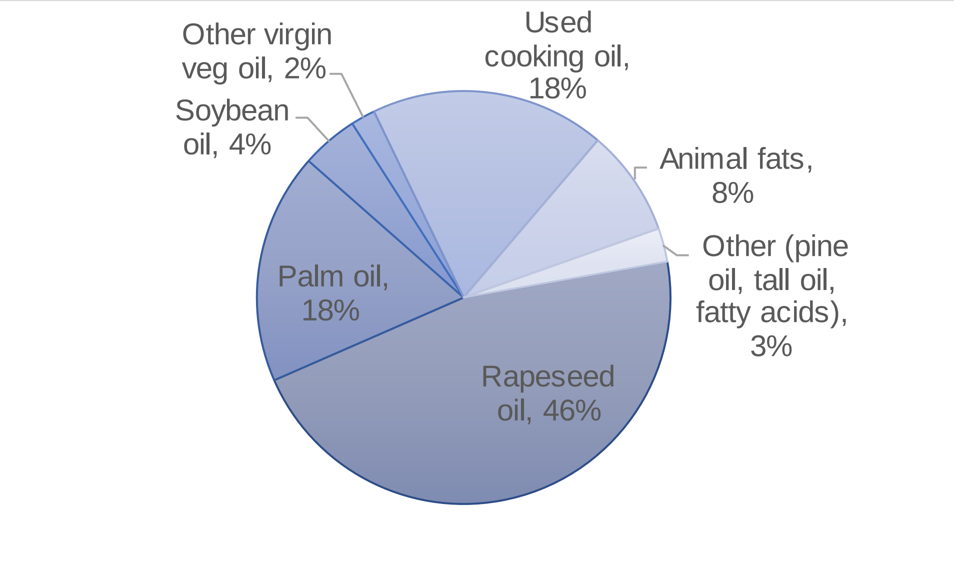
[15] https://www.gov.uk/government/news/new-regulations-to-double-the-use-of-sustainable-renewable-fuels-by-2020
[16] Eurostat

In the baseline bioethanol production increases to 4 Mtoe by 2020, and in the low carbon scenario a further increase to 4.5 Mtoe is assumed by 2030. This expansion of production is based on the understanding that there is some production capacity which is currently under-utilised. Production then remains constant between 2030 and 2050. Production of lignocellulosic bioethanol is based on a recent study (E4Tech, 2017) which suggested under a central scenario that production in the EU could rise from 0.02 Mtoe in 2020 to 1.4 Mtoe by 2030. Production is then assumed to double by 2050.

A2.1.3 FAME and HVO

Biodiesel consumption in road transport in 2016 was 11.1 Mtoe. Of this about 10 Mtoe was produced in the EU, although production capacity is almost double this at 55%[17]. In 2016 an estimated 71% of biodiesel consumption used oils from crops and 29% from wastes. was crop based.

Figure A3: Biodiesel production by feedstock



11.4 Mtoe of FAME and 4.5 Mtoe of HVO are assumed to be available in 2020 in the BAU scenario. SGAB (Sub Group on Advanced Biofuels (Sustainable Transport Forum), 2017) forecast in their base case than by 2030 about 10 additional HVO plant could be installed, taking total production up to 10.3 Mtoe. Assuming that the proportion of crop based to 'waste' oil-based feedstocks for FAME and biodiesel remains as at present i.e. a 70:30 ratio, then this expansion of HVO capacity and the 7% crop-based cap, together with the assumed bioethanol production, limit FAME production to 8.5 Mtoe in 2030. Production is then assumed to remain constant to 2050.

A2.1.4 Advanced biofuels from gasification technologies

Advanced biofuels production using gasification followed by a Fischer-Tropsch process have been under development for several years and moving from the demonstration to commercialisation phase. However, progress has generally been slower than historically forecast and therefore a relatively cautious approach has been used to estimate availability in the medium term to 2030. SGAB estimated in their base case that there could be 9 Mtoe of advanced biofuels (which includes lignocellulosic bioethanol) by 2030. In the LCF scenario, it is assumed that 75% of this i.e. 6.75 Mtoe is actually achieved; after deducting the 2030 estimate for lignocellulosic bioethanol production, this gives production from gasification technologies of 5.3 Mtoe. Post 2030, it is assumed that he technology is fully commercialised, and production grows by 250% by 2050 to 13.4 Mtoe 90% of production is assumed to be syndiesel and the remainder syngasoline, due to the higher economic value of syndiesel.

[17] Biodiesel Production, European Biodiesel Board http://www.ebb-eu.org/stats.php#.

Table A8: Availability of biofuels in main scenario

Biofuel	2020 Mtoe/y	2030 Mtoe/y	2050 Mtoe/y
1G bioethanol	4.0	4.5	4.5
2G lignocellulosic bioethanol	0.0	1.4	3.5
FAME	12.9	8.5	8.5
of which crop based	*9.0*	*6.8*	*6.8*
HVO	3.0	10.3	10.3
of which crop based	*2.1*	*7.2*	*7.2*
Gasification to syngasoline	0.0	0.5	1.3
Gasification to syndiesel	0.0	4.8	12.0
eFuel from EU renewables	0.0	0.1	1.0
eFuel from EU renewables	0.0	0.1	1.0
Gasoline substitutes	**4.0**	**6.5**	**10.3**
Diesel substitutes	**15.9**	**23.7**	**31.9**
Total	**19.9**	**30.3**	**42.2**

A3 Appendix 3 – Sensitivities

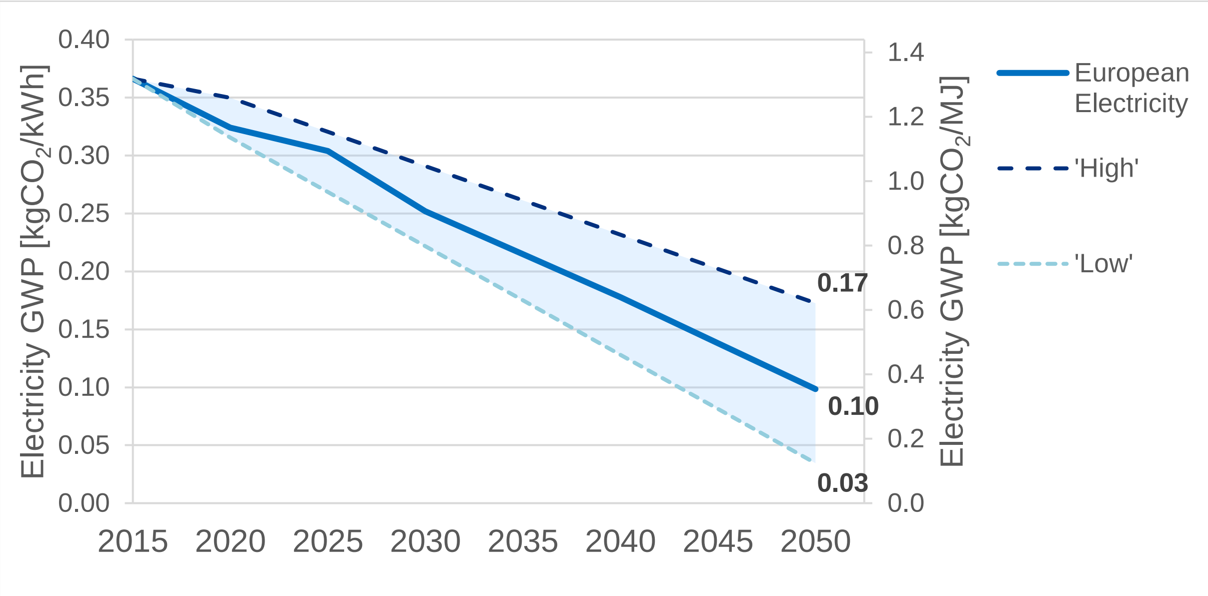
A3.1 Electricity GHG Intensity

The following figure provides an illustration of the GHG intensity trajectories used in the analysis.

The baseline trajectory for electricity GHG intensity is taken from the European Commission's 2016 Reference scenario dataset (with ~55% Renewable Energy Share (RES) by 2050) (European Commission, 2016a). The alternative 'High' and 'Low' scenarios for GHG intensity are based on previous analysis for the EC from the EU Transport GHG: Routes to 2050 (R2050) projects (AEA et al., 2010), (AEA et al., 2012):

- Low GHG intensity (93% reduction on 1990) is consistent with the high decarbonisation scenario from the Commission's *"Roadmap for moving to a competitive low carbon economy in 2050".*
- High GHG intensity (65% reduction on 1990) is a sensitivity from R2050.

Figure A4: Comparison of electricity GHG intensity scenarios



Note: Renewables share of electricity generation in 2050 ranges from 60%-86% in the decarbonisation scenarios from the Commissions Energy Roadmap (2011), average of all scenarios is ~67%. The baseline scenario trajectory above has ~55% RES.

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