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Greenhouse Gas Emissions Reduction Potential in the Scottish Transport Sector From Recent Advances in Transport Fuels and Fuel Technologies

January 2017

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Final report

for

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Element Energy Limited
Terrington House
13-15 Hills Road
Cambridge CB2 1NL

Tel: 01223 852499

elementenergy

Contents

Authors

For comments or queries please contact:

Alex Stewart, Director, alex.stewart@element-energy.co.uk, 01223 852495

Jonathan Stokeld, Consultant, jonathan.stokeld@element-energy.co.uk, 01223 855249

Reviewers

Celine Cluzel, Associate Director, Element Energy

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Acronyms

APD	Air Passenger Duty
B4	Diesel with up to 4% (volume) biodiesel
B7	Diesel with up to 7% (volume) biodiesel
BA	British Airways
BEUC	European Consumer Association
BEV	Battery Electric Vehicle
CCC	Committee on Climate Change
CMAL	Caledonian Maritime Assets Ltd
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
CSRF	Centre for Sustainable Road Freight
DECC	Department of Energy and Climate Change
DfT	Department for Transport
DoD	Depth of Discharge
EC	European Commission
ECCo	Element Energy's Electric Car Consumer model
EEDI	Energy Efficiency Design Index
ETS	Emissions Trading Scheme
EV	Electric Vehicle
FAME	Fatty Acid Methyl Ester
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicle
FHV	Flywheel Hybrid Vehicle
gCO_2e	Grams of Carbon Dioxide equivalent
GHG	Greenhouse Gas
HDV	Heavy-Duty Vehicle
HEV	Hybrid Electric Vehicle (standard hybrid)
HHV	Hydraulic Hybrid Vehicle
HRS	Hydrogen Refuelling Station
ICAO	International Civil Aviation Organisation
ICE	Internal Combustion Engine
IMO	International Maritime Organisation
$ktCO_2e$	Kilotonnes of Carbon Dioxide equivalent
kWh	Kilowatt-hour
LA	Local Authority
LEZ	Low Emissions Zone
LowCVP	Low Carbon Vehicle Partnership
LNG	Liquefied Natural Gas
MARPOL	International Convention on the Prevention of Pollution from Ships
MBM	Market-Based Measure

MDO	Marine Diesel Oil
MGO	Marine Gas Oil
$MtCO_2e$	Megatonnes of Carbon Dioxide equivalent
NEDC	New European Driving Cycle
NEXBTL	Neste Renewable Diesel
NO_x	Oxides of Nitrogen
OEM	Original Equipment Manufacturer
OLEV	Office for Low Emission Vehicles
PHEV	Plug-In Hybrid Electric Vehicle
PM	Particulate Matter
R&D	Research & Development
RE-EV	Range-Extended Electric Vehicle
SMMT	Society of Motor Manufacturers and Traders
SO_2	Sulphur Dioxide
TCO	Total Cost of Ownership
tCO_2e	Tonnes of Carbon Dioxide Equivalent
UCC	Urban Consolidation Centre
UCO	Used Cooking Oil
ULEV	Ultra-Low Emission Vehicle
ULEZ	Ultra-Low Emissions Zone
VAT	Value-Added Tax
VED	Vehicle Excise Duty
vkm	Vehicle kilometres
WLTP	World harmonized Lightweight vehicles Test Procedure
WTW	Well To Wheel
ZEV	Zero Emission Vehicle

1 Introduction

Scotland has set ambitious legally binding targets for its future greenhouse gas emissions to 2050, as part of a worldwide effort to tackle global warming. The Climate Change (Scotland) Act, 2009, sets out targets for Scottish GHG emissions reductions of 42% by 2020 and 80% by 2050, relative to a 1990/1995 baseline. Intermediate emissions targets have also been set in the Climate Change (Annual Targets) (Scotland) Orders 2010, 2011, and 2016, covering each year from 2010 to 2032, following the trajectory to 2050. Further targets from 2033 onwards will be set at a later date. The Act also requires that the carbon debt from missing intermediate targets must be "repaid" in future years. This means that the trajectory of emissions reductions is of similar importance to the final CO_2e target in a single year. Scotland's targets include emissions from international aviation and shipping, which is a stronger commitment than similar UK targets which do not include these emissions.

Figure 1 shows current progress against these targets, along with the trajectory required by the first sets of intermediate targets to 2032, and a characteristic trajectory towards the 2050 target of an 80% reduction against the 1990/1995 baseline. No sector-specific targets are set, and so for the purposes of this report we also present a trajectory for transport emissions to 2030, in which transport contributes a proportional or "fair share" of emissions reductions; 47% from 2013 to 2030. This proportional pathway is used as a comparison for evaluating the scale of the CO_2e reductions achieved in each of the scenarios that we present.

For this study, Element Energy was commissioned by Transport Scotland to assess the potential emissions reductions from the Scottish transport sector, in the light of recent technology progress. We determined the latest cost and efficiency trends for a comprehensive range of vehicle powertrains, including battery electric and fuel cell electric power, from a review of literature and discussions with technology suppliers and vehicle manufacturers. These technology trends were combined with detailed modelling of Scotland's vehicle fleet to create projections of the emissions from Scottish transport to 2032. Using this modelling framework, a range of policy options were explored, and their CO_2e reduction potential and cost effectiveness determined.

In Section 2 of this summary report, we provide an overview of the cost and performance trends of surface transport (cars, vans, trucks, and buses), marine transport, and aviation. Latest figures on the costs of battery and fuel cell technologies are also presented. Section 3 then shows the results of our modelling of the Scottish transport fleet, and resulting emissions. A baseline case is presented, followed by sector-specific scenarios describing different levels of policy intervention. Our conclusions are then presented in Section 4. A technical annex also accompanies this summary report. This describes the outcomes of our analysis of emerging technology trends in greater detail, and gives more detail of the outcomes of our policy modelling, including outputs extending to 2035.

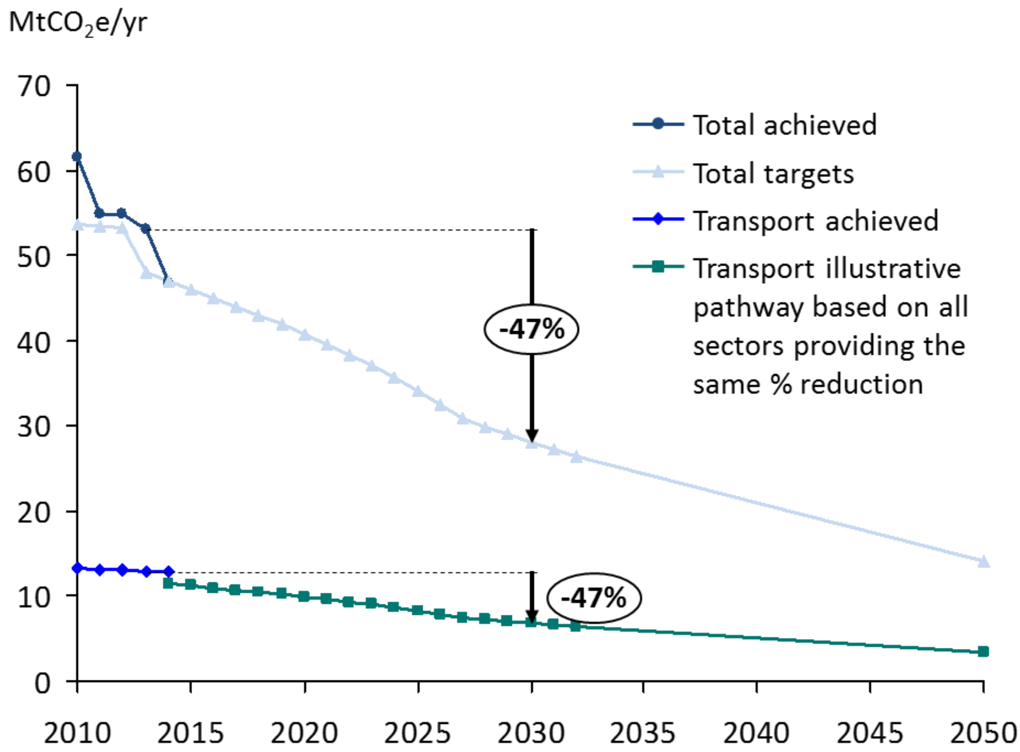

Figure 1: Historical Scottish GHG emissions[1], targets to 2032, and the 2050 target. Transport's emissions are also shown, with the required trajectory in order for transport to contribute its "fair share".

[1] Emissions from 2010 to 2013 were published in 2015. An updated emissions inventory containing 2014 emissions and revised emissions to 2013 was published in 2016. We present these 2014 emissions, but do not present the revised 2010-2013 emissions, since the analysis in this study was based on the data published in 2015.

2 Overview of emissions reduction potential

2.1 Cars and vans

2.1.1 Potential efficiency improvements to 2030

Carbon dioxide emissions from cars and vans can be reduced through increasing the use of alternative powertrains such as hybrids, PHEVs and BEVs, and through the adoption of efficiency improvement technologies, such as improved aerodynamics, weight reduction and internal combustion efficiency improvements. The efficiency impact and costs of individual technologies are detailed in the accompanying technical annex. Here we present the expected efficiency improvement trends from adoption of these technologies for each powertrain to 2035, as shown for cars in Figure 2, with similar trends also produced for vans[2]. Our modelling uses nine size categories for cars in line with the SMMT classification[3], and here we show a segment D vehicle (equivalent to a Ford Mondeo-size car) to illustrate the trends relative to 2015.

New car efficiency is expected to improve strongly, with a 31-41% reduction in energy consumption per kilometre by 2035 for incumbent ICE powertrains, with improvements of 25-38% by 2035 for BEVs and FCEVs (on an energy use per kilometre basis, since tailpipe CO_2e emissions are always zero) which also benefit from improvements in aerodynamics and weight reduction. Recent reductions in fuel consumption from the adoption of efficiency improvement technologies are primarily driven by EU level regulatory targets. These specify that the average emissions of new cars in 2021 must be 95 gCO_2/km. The annual rate of emissions reduction in passenger cars increased from 1% per year in the year before the CO_2 regulation was introduced to 4% per year in the years afterwards[4]. It is expected that efficiency improvements in conventional petrol or diesel cars will play a large role in reaching the 2021 target, along with the introduction of alternative powertrains. In addition, recent evidence suggests an increasing gap between the CO_2 emissions or fuel consumption given by the official New European Driving Cycle (NEDC) and their performance in the real world[5]. This increasing gap is primarily driven by increasing use of

[2] Full details are presented in the accompanying technical annex.
[3] For an example use of these size segments, see SMMT 2016, New Car CO_2 Report.
[4] See for example:
http://www.theicct.org/sites/default/files/publications/ICCTbriefing_EU-CO2_201507.pdf
[5] Element Energy & ICCT 2015, Quantifying the impact of real-world driving on total CO_2 emissions from UK cars and vans

test ‘flexibilities’ by vehicle manufacturers, for example testing vehicles at the highest temperature permitted in the test protocol to minimise powertrain friction. The result of this gap is that new vehicles are likely to meet the 2021 target relatively easily and at lower cost than predicted before the target was set, since fewer additional technologies are needed to meet a given CO_2 value.

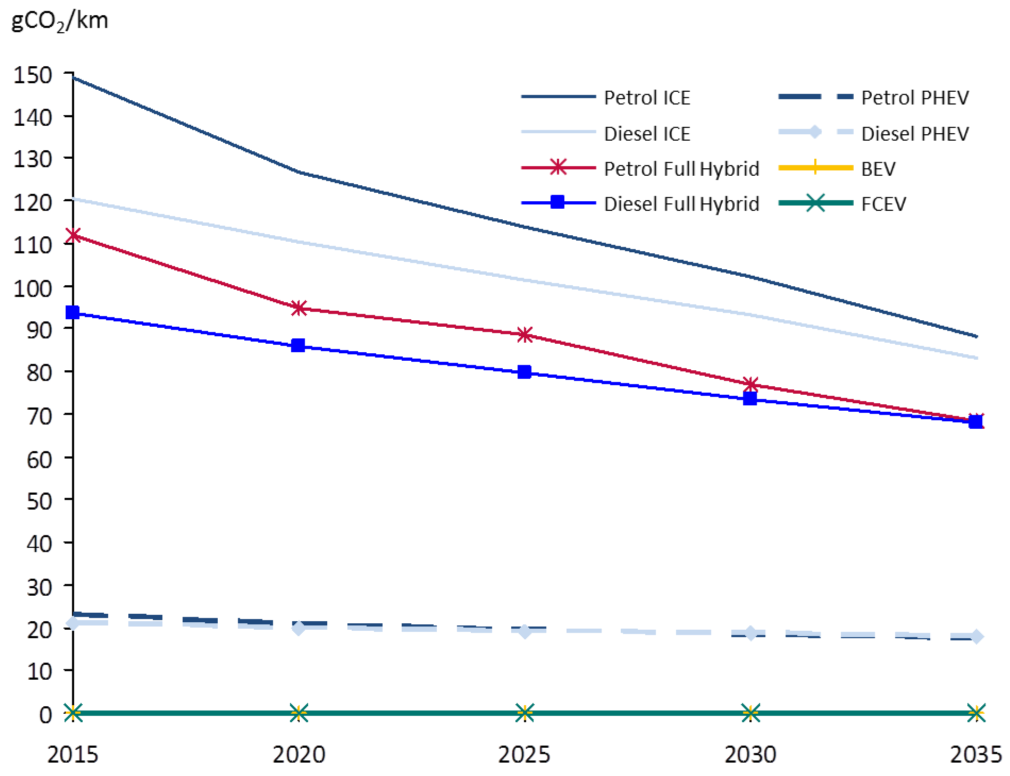

Figure 2: Baseline efficiency trends to 2035 for a range of car powertrains. A representative SMMT segment (D, upper medium car) is used.

This has strong implications for Scottish light vehicle emissions, as real-world emissions are likely to be significantly higher in the 2020-2030 period than predicted based on the EU fleet-average target. This gap may be addressed in part by the transition to the World harmonized Lightweight vehicles Test Procedure (WLTP) expected by 2020, and is accounted for in the fleet emissions modelling in this project[6]. These developments highlight the importance of strong EU-level policies to bring fleet-level emissions down and address current limitations with test cycles, as this has a strong influence on the availability and pricing of low and ultra-low emission vehicles offered on the Scottish market.

[6] Further information is set out in the technical annex accompanying this report

In the van sector, new diesel and petrol vans are expected to see efficiency improvements of 12-22% by 2035, which are significant, but less strong than for cars, as the EU 2020 new van average emissions target of 147 gCO_2/km is in proportion slightly less aggressive than for cars. This small efficiency improvement is due to several factors, for example the fact that the shape of a van and the need for it to carry a certain load mass and shape reduces the opportunities for aerodynamic improvements and weight reduction. In addition to improvements in diesel vans, a range of ultra-low emissions models is likely to be available in the 2020s, including battery electric, fuel cell and potentially plug-in hybrid options. These offer low CO_2e emissions due to improved drivetrain efficiencies, as well as partial or full zero tailpipe emissions transport with particular benefits for urban air quality.

2.1.2 Battery and fuel cell cost trends

Between 2010 and 2015, battery pack energy density for current technology (intercalated Li-ion) has improved incrementally by 15%. Other improvements include higher-density cathode chemistries, reduced weight and increased depth of discharge (DoD) capabilities. In the next 10-15 years, given the length of the process to implement new breakthroughs in final applications and the stringent demands (life, power, size, safety) of the automotive industry, it is expected that lithium-ion chemistry will still be prevalent, with progressive and substantial improvements (in energy density, DoD, thermal management, etc.). It is thereby expected that although no ‘step change’ technology will be fully introduced in the automotive market before 2030, improvements in current chemistries will allow lower cost, longer range electric vehicles in the 2020s.

Figure 3 shows battery cost scenarios for the 2015-2030 period, based on Element Energy’s component-level battery cost model and validated with cell suppliers and battery pack integrators. Since greater sales lead to more quickly decreasing costs, these scenarios are related to projections of new plug-in vehicle sales. The baseline battery cost and energy density scenario is based on the assumption that policy support in developed countries brings the uptake of plug-in and BEV vehicles to follow the same trajectory as that of hybrid electric vehicles (~1% PH/BEV global uptake by 2020). It should be noted that several car manufacturers have recently disclosed battery costs significantly lower than our central scenario, with GM disclosing cell costs of $145/kWh (£100/kWh) in 2016 falling to $100/kWh (£69/kWh) by 2022, and Tesla executives suggesting that their pack costs are approximately $190/kWh in 2016 during investor teleconferences. These costs may not be representative of current costs for all car manufacturers, but they highlight the significant upside for plug-in vehicles should packs at these costs become available for a wide range of vehicle models.

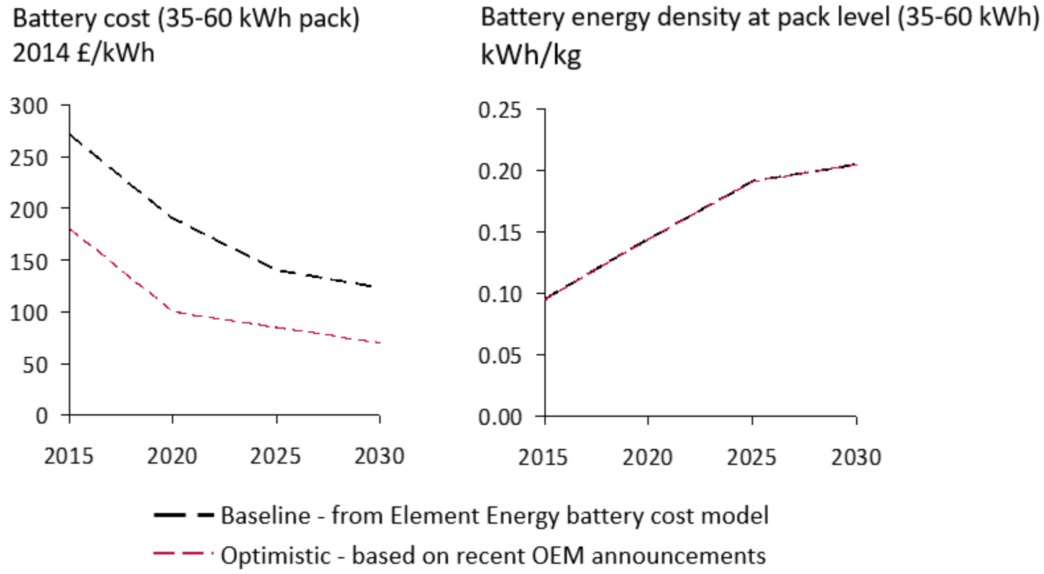

Figure 3: Projected battery cost and energy density scenarios.

In the automotive fuel cell sector, significant R&D investments and publicly funded demonstrations have delivered substantial improvements over the past 10 years in terms of power density and fuel cell stack lifetime and efficiency. Future improvements are expected to be available from better membranes, better cell designs, higher working temperatures, and streamlined fuel cell system packaging. Figure 4 shows scenarios for fuel cell system and hydrogen tank costs, with corresponding differences in system sales, as in the case of battery costs. In all scenarios, we assume that the next generation of fuel cell stacks, systems and related balance of plant components enters the market on achieving the 200,000 units per annum milestone. Further technology progress is assumed for higher volumes (consistent with the OEMs' statements and international R&D publications). Most of these technology solutions are aimed at simplifying and reducing the costs of the fuel cell system, as well as improving life and reducing weight.

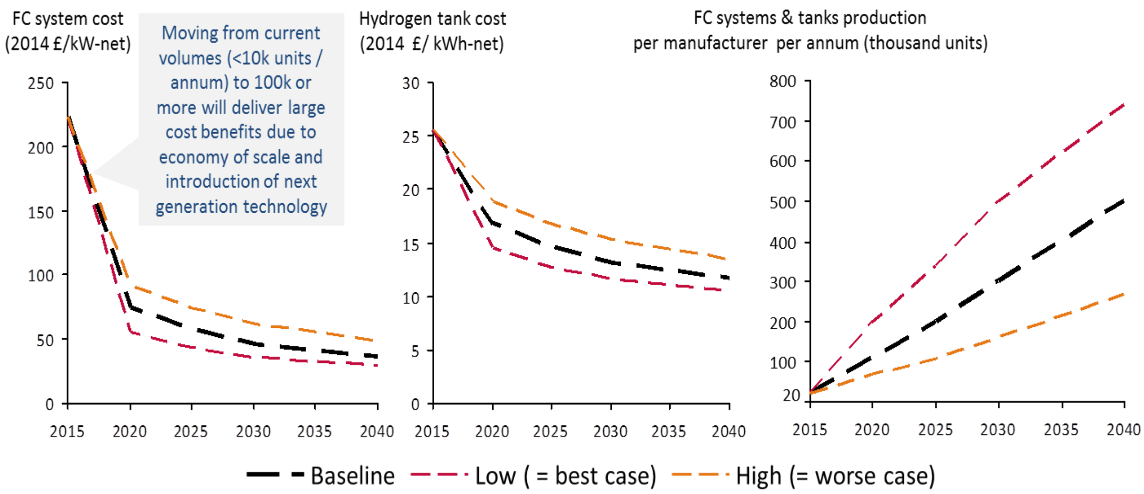

Figure 4: Projected fuel cell system and hydrogen tank cost scenarios, with corresponding sales volumes.

In the baseline scenario, we assume that the main manufacturers succeed in achieving sufficient scale economies via cooperative agreements and international market demand capable to attract around 200 thousand units per annum by 2025. In the worst case scenario, this is modelled to happen 10 years after (in 2035) while in the best case scenario this happens in 2020.

The car and van cost premiums between conventional ICE vehicles and alternatives such as hybrids and BEVs are expected to shrink substantially between 2015 and 2030, as shown for cars in Figure 5 (SMMT segment D, corresponding to Ford Mondeo-sized car, is shown for representativeness as above; trends in the cost premium between powertrains are similar in other size segments). The reductions in costs for alternative powertrains will largely be driven by greater manufacturing volumes, as well as some reductions in the costs of batteries, fuel cells, and ancillary equipment. Conventional ICE vehicles are expected to increase in cost due to the introduction of more efficiency improvement and other technologies, and this base cost increase will hinder the reduction in cost of other ICE-derived powertrains such as hybrids and PHEVs.

For cars, the PHEV/RE-EV cost premium over baseline ICE is expected to decrease to around 10% by 2030, while the cost premium for BEVs and FCEVs over ICE is expected to be 10-20% by this time. The cost difference between BEVs and FCEVs is expected to be marginal (~£1,000 by 2030). For vans, the PHEV/RE-EV cost premium over baseline ICE is expected to reduce to below 20% by 2030, while the cost premium for BEVs and FC RE-EVs over ICE is expected to be 20-25% by this time. The cost savings in fuel and maintenance for low emission vehicles are expected to offset much of this capital cost premium, leading to near parity with conventional cars on a total ownership cost basis by 2025[7].

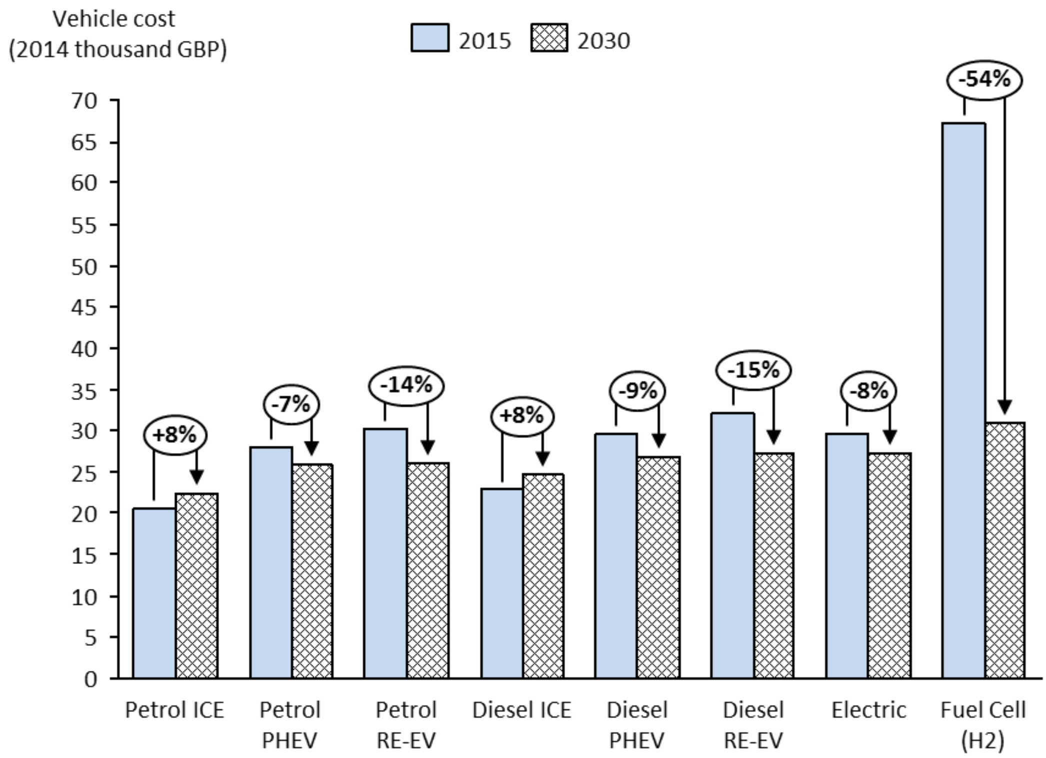

Figure 5: Costs in 2015 and 2030 for a D segment (upper medium) car, including retailer margins, excluding VAT.

2.2 Trucks and Buses

Similarly to light vehicles, there is a range of technical improvements that can be applied to diesel trucks and buses to reduce their emissions per kilometre. These include aerodynamic improvements, low rolling resistance tires, and powertrain improvements such as waste heat recovery. In addition, zero emission powertrains are already available in the bus sector, with ongoing demonstrations and early commercial deployments of hydrogen and battery electric buses in the UK. Battery electric solutions are also available in low volumes for small trucks, although no current solution exists for zero emission long haul trucks, with the exception of the 'e-

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[7] Element Energy for BEUC 2016, Low carbon cars in the 2020s: Consumer impacts and EU policy implications.
This is also consistent with other recent studies, such as by Bloomberg New Energy Finance which expects ownership cost parity to be reached between 2020 and 2025. See http://about.bnef.com/press-releases/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/

Highway' solution using a pantograph and overhead wires being trialled by Siemens[8].

In the US, there are already binding truck efficiency targets expressed on a grams of CO_2e per tonne-mile basis, and a large amount of technical analysis was conducted during the regulatory process to assess the costs and emissions reduction potential of a wide range of truck technologies. We used efficiency improvement trends in our modelling which are based on the results of this analysis, and these are presented in Figure 6 for articulated trucks[9]. The trends show a reduction in CO_2e/km of 31% by 2035, and are very similar across powertrains as many of the technologies available are applicable to all powertrains. The improvements shown can be achieved using a range of cost-effective efficiency improvement technologies, the individual efficiency impact and costs of which are detailed in the accompanying technical annex.

It should be noted that the EU currently does not have a binding target for the fuel efficiency of trucks, and so these improvements are not guaranteed without EU-level legislation similar to that in place in the USA. The European Commission is currently developing an HDV strategy, which will at first include mandatory 'CO_2 labelling' for trucks. Hence, a fleet CO_2 target (similar to existing regulations for cars and vans), could be introduced in the future.

Efficiency trends for various bus powertrains are shown alongside those for trucks in Figure 6, with improvements of 9-18% expected for a standard bus. Future improvements are likely to be driven both by fuel cost considerations for operators, and investment from public bodies and initiatives such as the Green Bus Fund, which seek to accelerate the adoption of low carbon technologies such as hybrids and zero emission powertrains. The efficiency trends are more modest for buses than articulated trucks (and similar to those for small rigid trucks) as there is much less scope for improvements from improved aerodynamics and low rolling resistance tires, since buses operate mostly on stop-start duty cycles (small rigid trucks experience similar reductions to buses in this regard). Conversely, buses experience a much greater improvement from hybridisation and stop-start technology.

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[8] w3.siemens.com/topics/global/en/electromobility/pages/ehighway.aspx

[9] Articulated trucks are tractor-trailer trucks, where the trailer is separate from the tractor, and can articulate about the tractor-trailer joint. Conversely, rigid trucks are those where the cab and cargo area are part of the same chassis.

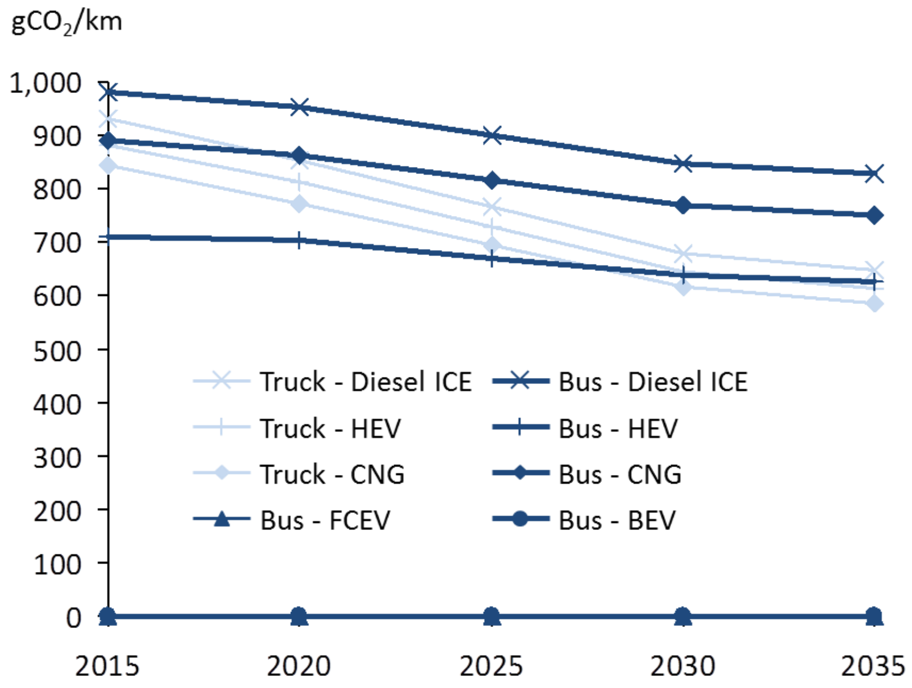

Figure 6: Baseline efficiency trends by powertrain for articulated trucks and standard buses.

2.3 Marine and aviation

Marine vessels can be considered as two distinct groups. The first is large international freight ships, contributing the majority (~85%) of marine emissions from Scotland. Their efficiency and demand trends are driven by global economics, fuel prices, and international regulation. As a result, the types of vessels visiting Scottish ports will be influenced more heavily by EU and international regulations than Scotland-specific policies. Efficiency improvement trends are hence taken from the expected impact of global regulation, in particular the Energy Efficiency Design Index (EEDI) which governs the design efficiency of new ships built in 2010 or later. The International Maritime Organisation is also working on developing a Market Based Measure to incentivise CO_2e emissions reductions. MARPOL Annex VI[10] regulates emissions of air pollutants, driving the use of sulphur scrubbers and fuel switching from fuel oil to marine distillate oil (MDO/MGO) or liquefied natural gas (LNG). This is expected to be brought about through the adoption of a range of efficiency improvement technologies and fuel switching to LNG, as detailed in the technical annex, but does not include reductions in fuel consumption due to operational

[10] MARPOL is the International Convention on the Prevention of Pollution from Ships, and the annexes regulate a range of airborne and waterborne pollution.

measures such as reduced sailing speeds. In this study, it is assumed that the EEDI and subsequent efficiency regulation in the medium term deliver on average a 34% reduction in a new ship's emissions by 2035 relative to 2010.

The second group of marine vessels is shorter range ferries and fishing vessels. For these vessels, there is greater scope for national measures such as franchise conditions for ferries or emissions standards for fishing boats. As a result, alternative powertrains such as hybrid ferries, which reduce fuel consumption by 20-30%, could make up a significant proportion of new vessels to 2032, with associated reductions in emissions. There is also greater technical viability of zero emission options such as electric or hydrogen ferries. However, despite the benefits of zero emission vessels (including air quality benefits), it should be noted that only 15% of marine emissions come from these smaller vessels, and hence it will be critical to reduce emissions from international shipping in parallel.

In the aviation sector, new aircraft fuel consumption has historically fallen strongly, by 45% (1.3% per annum average) since the start of the jet age in the late 1960s, and driven by interest in reducing fuel costs. These reductions were strongest in the 1960s and 1970s, but are smaller now, with a 9% improvement since 2000 (0.7% per annum average). Future fleet efficiency improvements are likely to come from a combination of incremental improvements, step-change technologies such as electric taxiing, operational improvements, and modernisation of the fleet. We use fleet efficiency trend assumptions from DfT 2013's central scenario, corresponding to a 0.8% per annum improvement. This is consistent with the CCC 2009 “likely” scenario and below voluntary industry targets of a 1.5% per annum improvement, which we assume to be a best case scenario. The 0.8% annual reduction yields a 15% reduction in aviation sector emissions by 2030 before changes in demand are taken into account (see Section 3.1).

3 Results of emissions modelling of the Scottish transport sector

3.1 Overview of emissions modelling methodology

The surface transport fleet was modelled using projections of new vehicle sales, efficiency improvements, fuel switching, and adoption of new powertrains, combined with vehicle scrappage and annual driving distance data. The model was then calibrated against Scottish transport statistics. Uptake of alternative powertrains for light vehicles under different policy environments was modelled using Element Energy's Electric Car Consumer model (ECCo)[11], adapted to reflect the Scottish car and van parc. This allowed the impacts of real consumer behaviour to be accounted for in the generation of uptake scenarios. For uptake of alternative powertrains in heavy duty vehicles, a scenario-based approach was used, wherein different levels of market penetration of alternative powertrains are achieved, with descriptions of the type of policy landscape that would be needed for these scenarios to occur.

Demand growth projections for surface transport were produced by combining the expected growth in the vehicle parc with annual driving distance data, and ensuring consistency with data in the Transport Model for Scotland. Marine demand projections were taken from the UK Committee on Climate Change's 2009 Review of Shipping Emissions, and aviation demand projections by airport (based on growth in air traffic movements) were taken from the Department for Transport's 2013 UK Aviation Forecasts. These growth trends are summarised in Figure 7, with all sectors apart from buses growing by 16-29% by 2035, and are based on current growth trends, taking into account anticipated changes in Scotland's GDP and population. The most quickly growing sector is aviation and buses show minimal growth in demand, in line with current trends. These demand projections have a strong effect on the emissions of the Scottish transport sector, since Scotland's CO_2e targets are defined on an absolute basis relative to a 1990/95 base year rather than on a grams per km basis. A c.25% increase in demand relative to 2015 increases emissions by the same proportion, all other things being equal, and means that deeper cuts in emissions and deployment of low or zero emission

[11] ECCo is a consumer uptake model, which takes input assumptions on vehicle attributes, wider economic considerations such as energy and fuel prices, and policies/incentives, and combines them with Element Energy's research into consumer purchasing behaviour, to generate UK market uptake projections by powertrain for cars and vans. The model was last revised in 2015 for DfT and is widely used to produce vehicle uptake scenarios. For more detail, refer to the accompanying technical annex.

technologies are required to meet the target. The impact of changing these demand projections is shown in Section 3.7.

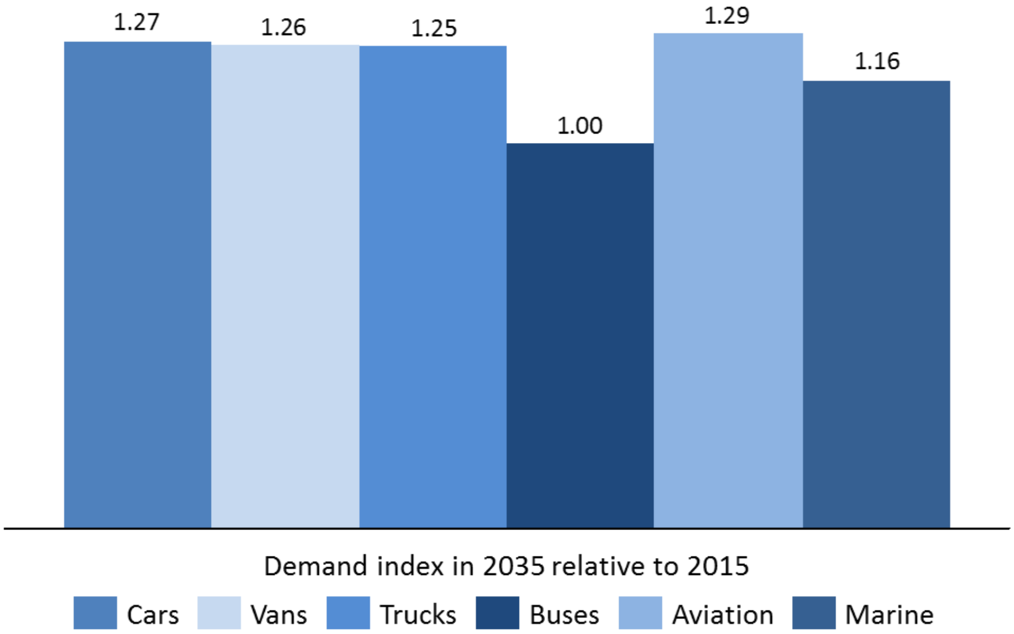

Figure 7: Demand growth projections for each sector in 2035 relative to 2015.

In the following sections, a base case for emissions reductions is presented based on expected vehicle efficiency improvements and changes in travel demand. This is followed by sector-specific scenarios with varying degrees of policy support and additional technology deployment. This will be used to produce an overall ambitious scenario for what could be achieved from national and local level policy measures.

The results presented below show tailpipe emissions from land vehicles, ships and aircraft. Zero tailpipe emissions such as battery electric and fuel cell electric vehicles are counted as zero for the purpose of carbon budgets in the transport sector. Emissions from fuel production (i.e. electricity generation for BEVs) are allocated to the power generation sector. This is consistent with the approach for petrol and diesel, where tailpipe emissions are recorded in the transport sector but upstream refining emissions are recorded as industrial emissions. A different approach is used for biofuels and biomethane, where the transport sector receives the credit for emissions savings even though the tailpipe emissions are often similar or identical to petrol or diesel, as otherwise the analysis would not reflect the GHG emissions benefit of biofuel use.

In the biofuels scenarios below, it is assumed that use of drop in biofuels is prioritised for heavy vehicles rather than cars and vans, since there is a wider range of viable low and ultra-low emissions technologies for cars and vans. In reality drop-in fuels made available at public refuelling stations would be used by all vehicles, but it remains a useful illustration of the volumes of biofuels required to reduce emissions from the heavy vehicle sector.

For each vehicle type, we also undertook a cost effectiveness analysis to determine the abatement cost in £/tCO_2e of introducing alternative powertrains. In each case, the difference in emissions over the lifetime of the vehicle between the alternative powertrain vehicle and an ICE incumbent was calculated, and divided by the total cost of ownership. The TCO calculation was performed on a social basis, with fuel duty and VAT not included, reflecting the cost to society, and on a private basis, with fuel duty and VAT included, reflecting the cost to an individual buyer. For the social case, the HM Treasury Green Book social discount rate of 3.5% was used, and for the private case, a discount rate of 7.5% was used. These are consistent with the discount rates used in the CCC Fifth Carbon Budget Sectoral Scenarios. Fuel prices were determined from the DECC 2015 fossil fuel price projections, and for electricity, a representative 43% price reduction was applied to reflect the reduced price of electricity that is likely to be available to EVs charging at night. This figure was calculated by comparing the standard rate (12.461p/kWh exc. VAT) and “White Meter” night rate (7.054 p/kWh exc. VAT) for electricity from Scottish Power[12]. These prices were checked against DECC energy price statistics to confirm their representativeness. The results of the cost effectiveness analysis are presented with the emissions reduction scenarios in Sections 3.3 to 3.5.

3.2 Emissions modelling results – baseline

Baseline emissions scenarios were first calculated for each sector. For light vehicles, a baseline uptake scenario was generated using ECCo, describing a case with continued EU-level regulations on car and van CO_2 emissions, but no specific support for ultra-low emission vehicles except for exemption of zero emission vehicles from UK Vehicle Excise Duty. New car and van emissions are reduced through a combination of efficiency improvements and some penetration of alternative powertrains (car market shares of c.10% plug-in vehicles, 33% hybrids by 2030), as shown in Figure 9. Uptake of low emission powertrains is driven by falling costs that significantly reduce the total cost of ownership premium in the 2020s, even in the absence of additional financial incentives.

The base case for trucks, buses, aviation, and marine assumes minimal uptake of alternative powertrains or fuel switching, due to higher ownership

[12] Scottish Power 2015, Prices: Your domestic gas and electricity pricing information

costs than conventional powertrains and without targeted policy support. As a result, a general trend emerges of efficiency improvements counterbalanced against increasing demand. It should be noted that while this is a baseline scenario, the efficiency improvements used here are not guaranteed, particularly in the case of trucks, where potential efficiency improvements may not be realised without future EU-level efficiency standards, as explained in Section 2.2. In a study for the Committee on Climate Change, the Centre for Sustainable Road Freight (CSRF) determined that there is potential for emissions reductions of 22% from 2015 to 2030 through the introduction of retrofit technologies such as aerodynamic fairings and low rolling resistance tires, and logistics measures such as relaxed delivery time windows, backhaul (carrying goods on return journeys to reduce empty running), urban consolidation centres and larger capacity vehicles[13]. We assume that half of these reductions are achieved in the baseline, as consultation with the industry suggests that the full potential these measures will not be realised without significant policy support.

In addition, the base case assumes an increase in biodiesel blend from B4 in 2015 to B7 in 2020[14], in order to reach the EU Renewable Energy Directive targets. UK biodiesel currently provides an 86% WTW reduction in emissions including indirect land use change effects[15,16]. Using this value gives an overall emissions reduction of 2.7% from biodiesel blends by 2020 relative to remaining at B4.

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[13] Centre for Sustainable Road Freight (CSRF) 2015, An assessment of the potential for demand-side fuel savings in the Heavy Goods Vehicle (HGV) sector

[14] Element Energy for Low CVP 2014, A Fuel Roadmap for the UK

[15] DfT 2015, https://www.gov.uk/government/statistics/biofuel-statistics-year-8-2015-to-2016-report-1

[16] The process of producing biofuels generally results in some CO_2 emissions, through mechanisms including the production of fertilisers, transportation of the fuel, and changes in the CO_2 stored in the land. These emissions lessen the effectiveness of the biofuels at reducing CO_2 emissions, and so a well to wheel (WTW) percentage reduction is used to represent what the net reduction in CO_2 emissions from producing and using biofuel instead of petrol/diesel.

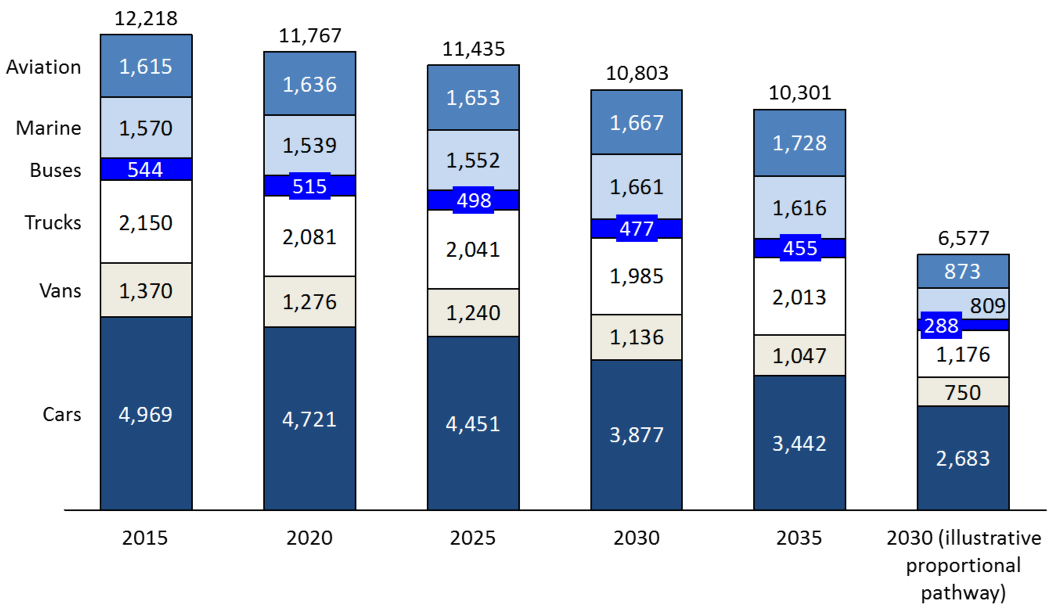

Figure 8: Transport emissions in ktCO$_2$e/year by sector in the baseline scenario, compared against the 2030 proportional pathway.

Figure 8 shows the projected emissions by sector for the baseline scenario. Annual emissions in 2030 are 1.4 MtCO$_2$e/year lower than in 2015, and 4.2 MtCO$_2$e/year away from the 2030 emissions in the illustrative pathway in which the transport sector reduces its emissions by the same proportion as the overall target for Scotland. The baseline scenario highlights the variation in emissions savings across each vehicle type. Cars and vans in combination deliver a 21% saving by 2030 despite a 25% increase in overall vehicle kilometres travelled. Buses also experience a 12% saving by 2030 due to efficiency improvements and minimal demand growth. In contrast, trucks and the marine sector show minimal change as efficiency improvements are almost entirely offset by demand growth, while aviation emissions are expected to grow by 16% in the base case as demand growth exceeds the annual efficiency improvement.

3.3 Emissions reduction scenarios – cars and vans

In addition to the baseline shown above, a more ambitious scenario for cars and vans was developed that included specific support for ultra-low emissions vehicles throughout the 2020s. Current OLEV grants for low emissions vehicles are set to end in 2018. In order to incentivise continued uptake of BEVs and FCEVs, incentives in the order of ~£1,000 per vehicle are expected to be required through the 2020s, since these vehicles will continue to have a total cost of ownership premium relative to conventional vehicles during that time[17]. This £1,000 could be provided through a combination of ongoing monetary benefits such as free city parking, free use of ferries, exemption from VED (which is already included in the baseline in line with announced UK policy), convenience benefits such as access to bus lanes, improved charging infrastructure, and other measures such as exemption from urban access restrictions.

Here we consider an uptake scenario in which ongoing benefits as described above are worth £2000 over the lifetime of the vehicle to city dwellers (owning 23% of cars and who derive more benefit from free city parking etc.), and benefits worth £400 are available for those living elsewhere (77% of cars). We also consider the impact of significant investment in charging infrastructure, such that 100% of consumers have access to overnight charging[18] (in practice, giving access to those without off street will be challenging, as on street solutions such as the dedicated residents' bays with charging are still in early stages of development), and 50% have access to local public charging and workplace charging by 2025[19]. Total investment needs for widespread public charging points are expected to be in the order of £50 million for Scotland, based on spending about 10% of the estimated infrastructure need for the UK for rapid charging points by 2030[20]. It should be noted that a substantial proportion of this investment could be privately funded, providing that the business case is sufficiently attractive based on the risk of underutilisation, the prices that EV drivers are willing to pay for electricity at rapid charge points etc. This high infrastructure scenario represents a significant increase on current levels, but demonstrates the potential uptake of ULEVs if the current infrastructure limitation is fully addressed i.e. nationwide electric mobility is enabled. Under these incentives, a 15% car market penetration and a 9% van market penetration of zero emissions vehicles is expected by 2030, as shown in Figure 9, resulting in 155,000 ZEV cars (6% of the total fleet) and 27,000 ZEV vans (9% of the total fleet) in the parc in 2030. This is in addition to large numbers of plug-in hybrids (offering partial zero emissions driving), making up 25% of new vehicle sales in 2030. In

[17] https://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-EV-pathways_FINAL-REPORT_17-12-13-Final.pdf
[18] This is used in our modelling to determine what proportion of customers include EVs as one of their options when purchasing a new car.
[19] This implies that 50% of customers are able to charge locally/at work, but does not imply that each of these customers has a dedicated charging point for each of these purposes.
[20] Element Energy's infrastructure roadmap for the LowCVP suggests cumulative spending of £450m - £800m on rapid charging points by 2030. Roadmap available at: http://www.lowcvp.org.uk/projects/fuels-working-group/infrastructure-roadmap.htm

addition, we assume that there is an EU level shift from laboratory emissions testing to real-world testing from 2025 to 2030, reducing the real-world emissions gap from ~30% in 2025 to 10% in 2030, driving significant emissions reductions as new cars are required to meet the more stringent efficiency requirements. Overall, these policies would produce savings of 1 $MtCO_2e$/year in cars and vans by 2030 compared to the baseline, as shown in Figure 10, with combined emissions of the car and van sectors falling to 3.9 $MtCO_2e$ per year in 2030, compared with 3.4 $MtCO_2e$ per year in 2030 in the proportional pathway.

It should be noted that consumer attitudes to ULEVs will have a strong influence on their uptake in the 2020s. For example, if next-generation BEVs are perceived as attractive and convenient to prospective buyers (for example if buyers begin to place a high value on the low noise and smooth performance of these vehicles or on the time saving of not visiting refuelling stations), then uptake of BEVs could be significantly higher than shown in this scenario. If on the other hand buyers still perceive BEVs as not suitable for their driving patterns even with higher driving ranges and widespread infrastructure availability, the market may favour PHEVs over BEVs. In this case, provision of widespread electric charging infrastructure is still highly important, to maximise the proportion of driving in electric mode rather than using the internal combustion engine.

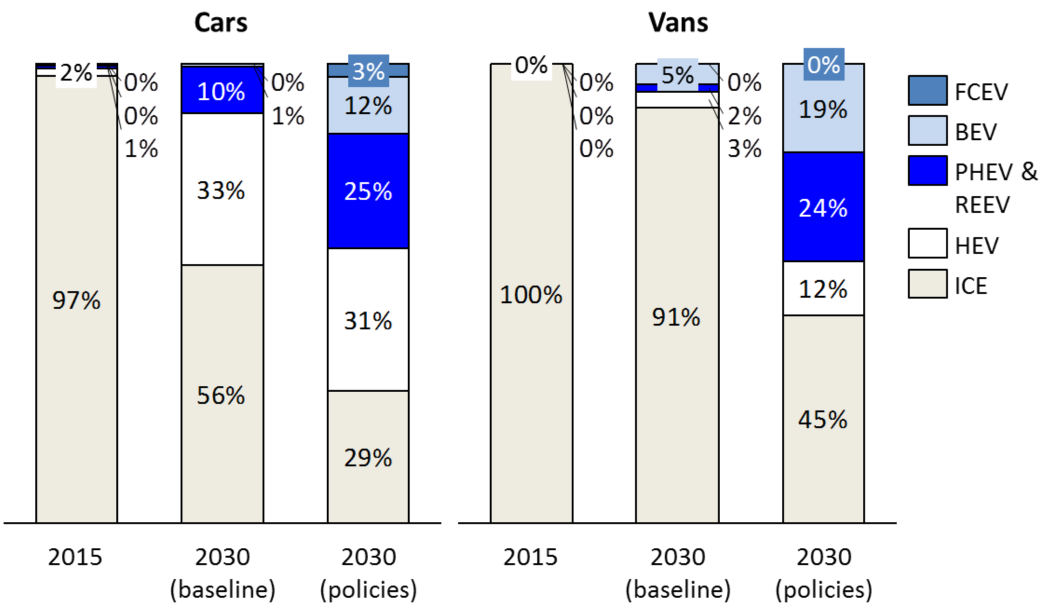

Figure 9: Car and van market shares (new sales) in 2015 and in 2030 for the baseline and strong policies scenarios

Table 1 shows the abatement costs in 2030 of substituting a baseline diesel ICE vehicle for an alternative powertrain vehicle (for cars, SMMT segment D is used for reference, see Section 2.1.1). Costs are represented on both a social and private basis, as defined in Section 3.1. Hybrid cars and vans show negative abatement costs on both a social and private basis, and so offer the best value reductions, although the overall level of CO_2e abatement they can achieve is significantly lower than for ZEVs. Battery electric cars and vans offer the next lowest abatement costs, with BEV cars offering abatement costs of £37 and -£102 /tCO_2e respectively on a social basis.

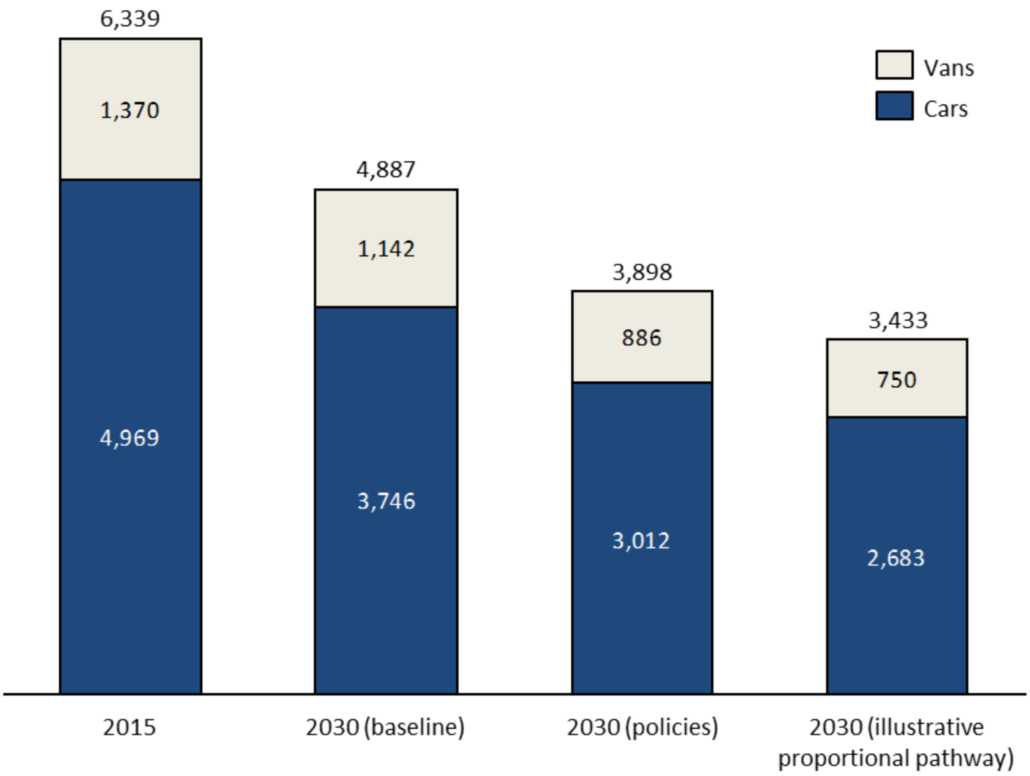

Figure 10: Emissions from cars and vans in ktCO_2e/year for each scenario, compared against the present day and the 2030 proportional pathway.

Table 1: Cost Effectiveness of CO_2e abatement from different car and van powertrains in 2030, relative to a diesel ICE baseline. For cars, a representative SMMT segment (D, upper medium car) is shown. For vans, a standard panel van is shown.

		Capital Cost Premium (£) exc. Margin & VAT	Lifetime Fuel Cost Premium (£)		Lifetime Abatement Cost (£/tCO_2e)	
			Social	Private	Social	Private
Cars	Hybrid	600	-980	-1,600	-80	-143
	PHEV	2,600	-650	-3,600	170	-88
	BEV	2,900	-2,000	-5,500	37	-102
	FCEV	4,800	1,900	-1,500	274	252
Vans	Hybrid	800	-2,200	-3,700	-123	-211
	PHEV	3,500	-3,300	-12,900	4	-217
	BEV	5,900	-5,600	-17,100	3	-121
	FC RE-EV	5,100	-2,800	-14,000	29	-75

3.4 Emissions reduction scenarios – trucks and buses

The baseline results in Section 3.2 show that projected increases in heavy vehicle efficiency are strongly offset by anticipated increases in demand. To deliver further emissions reductions, a combination of the following will be required:

- Reductions in vehicle-kilometres or tonne-kilometres travelled, through more efficient logistics,
- Deployment of zero emissions powertrains for buses and trucks,
- Fuel switching away from fossil diesel towards liquid biofuels, CNG, and/or biomethane.

The impact of each of these factors is considered using a scenario approach below.

A scenario-based approach was used to derive uptake scenarios for ultra-low emission trucks and buses, based on the number of vehicles potentially affected by policy interventions such as access restrictions in cities. An indicative strong policy scenario was developed corresponding to urban access restrictions for trucks and zero emissions procurement policies for urban buses, in Edinburgh, Glasgow, Aberdeen, and Dundee. Data from Scottish Transport Statistics on the split of trucks and public transport vehicles in these cities and the rest of the country was used to find the share of new vehicles whose new sales could be switched to zero emissions powertrains. 50% of the remaining trucks and buses were then also assumed to switch to hybrid powertrains by 2030. Market shares for 2030 that were used in this scenario are presented in Figure 11, with the assumption that 40% of rigid trucks and 30% of buses can be switched to zero emissions powertrains under this scenario based on the proportion of vehicles based in cities. This results in 5400 ZEV trucks and 5500 hybrid trucks (26% of the fleet), and 1700 ZEV buses and 1500 hybrid buses (20% of the fleet) in 2030. In addition, we assume that the remaining potential for emissions reductions through improved logistics and application of retrofit technologies as described in Section 3.2 is realised through a favourable policy landscape, including policy support for urban consolidation centres (further detail in Section 4), permitting the use of larger capacity vehicles on trunk roads, and incentivising reduced empty running.

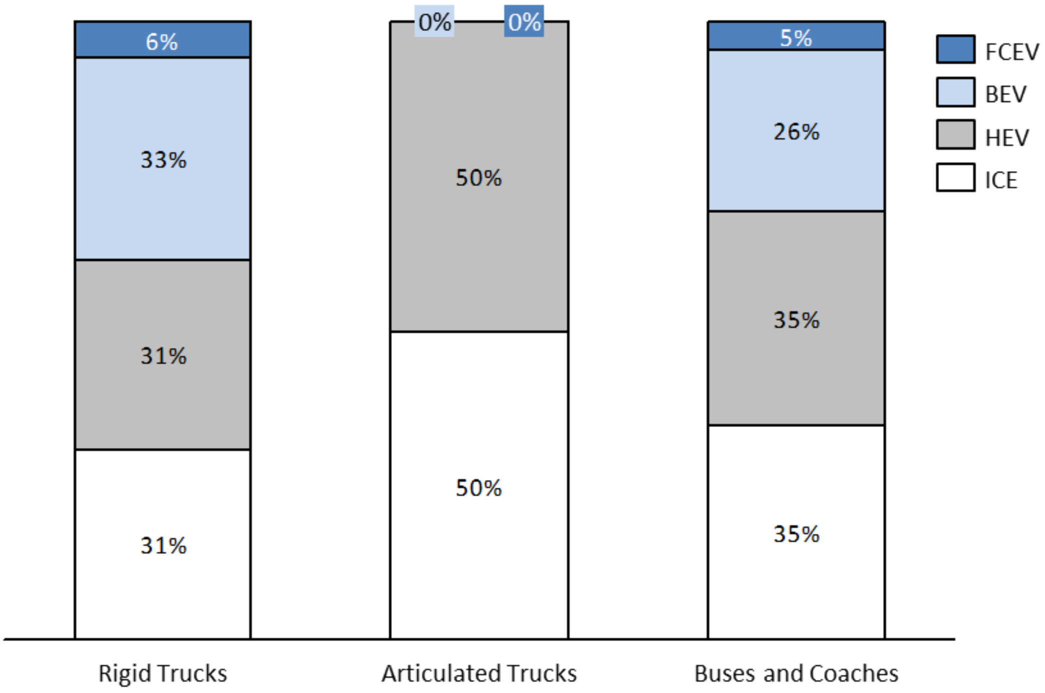

Figure 11: 2030 market shares (new sales) for each of rigid trucks, articulated trucks, and buses and coaches, under a strong policy environment.

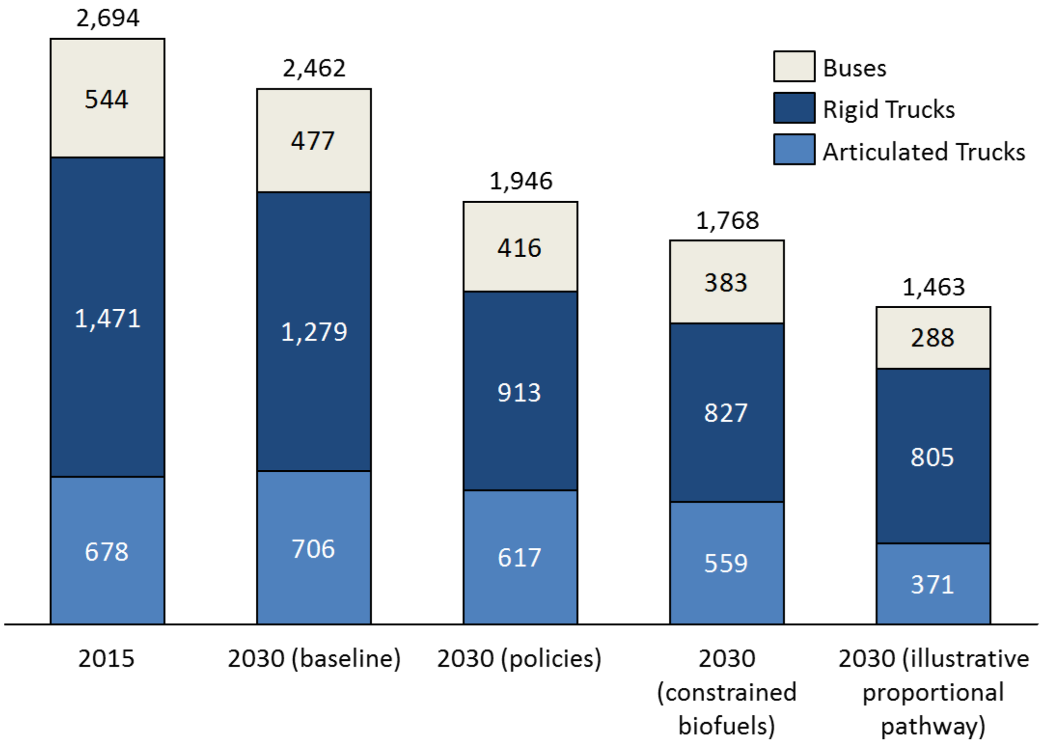

Figure 12: Emissions from trucks and buses in ktCO₂e/year for each scenario, compared against the present day and 2030 proportional pathway.

These measures reduce emissions in 2030 by 23% for trucks and by 13% for buses, as shown in Figure 12. For trucks, 13% of the emissions reductions come from the introduction of zero emissions powertrains for rigid trucks. HEV trucks provide 5-15% efficiency improvements over diesel ICE (with the smallest reduction for large articulated trucks), and so combined with time taken for new vehicles to spread through the existing vehicle fleet, they provide an emissions reduction of ~1%. The remaining 11% reduction is provided by logistics improvements and retrofit technologies.

We next considered a scenario in which the strong policies of the previous scenario were implemented, but the impact of introducing alternative fuels was also included. We first determined the impact of introducing drop-in biofuels for trucks and buses (see Box 1 for an overview of the drop-in vs. non-drop-in fuels), based on quantities consistent with upper limit estimates of domestic production available to Scotland. These were calculated by taking the upper limit domestic UK biofuels production of 800 million litres per year by 2030[21], and allocating 9% of this to Scotland, in proportion with its share of the UK's greenhouse gas emissions. Similarly, drop-in biofuels were allocated to the truck, bus, aviation, and marine sectors according to

[21] Sustainable Aviation 2015, Sustainable Fuels Roadmap

the total volume of liquid fuels that they each consume. This results in 3.4% of fuel being drop-in biofuel for each sector in 2030. In reality, a strategic decision may be taken as to which sectors most need biofuels due to a lack of alternative zero emissions options. This may result in greater proportions of the biofuel being allocated to aviation, marine, and long haul trucks. We assume that drop-in biofuels would provide a 60% net reduction in carbon intensity over diesel, and so this scenario provides modest further emissions reductions of 2% in each sector in 2030 compared to the Policies scenario, as shown in Table 2.

The potential impact of introducing natural gas trucks and buses running on either dedicated fossil CNG or biomethane was also assessed. Although these vehicles offer fuel cost savings to users, they offer relatively modest GHG savings when powered by fossil CNG or LNG. Biomethane for CNG vehicles is currently available in the UK, but there is no current UK production of bioLNG, limiting the current GHG savings from LNG vehicles. Element Energy analysis for the LowCVP[22] suggests that 50,000 trucks and 9,700 buses in the UK may be running on natural gas by 2030. We assumed that 7.3% of these trucks and 9% of these buses would be in Scotland in line with current proportions[23]. WTW emissions reductions of 23% for CNG from the UK continental shelf and 80% for biomethane from municipal waste were used, based on analysis by the European Commission Joint Research Centre[24]. The results are summarised in Table 3, and show that modest reductions of up to 48 ktCO_2e/year (2.4% relative to the policies scenario) are achievable using CNG, whereas using biomethane can provide emissions reductions of up to 169 ktCO_2e/year (8.5% relative to the policies scenario).

22 Element Energy for the LowCVP 2015, Methane Infrastructure Roadmap (scenarios for gas truck uptake are policy-led)
23 DfT Vehicle licensing statistics 2015, veh0504 & veh0604
24 European Commission Joint Research Centre 2013, Well to Tank Report v4.0

Box 1: Current and future biofuels vary both by types of molecules and the feedstocks from which they are made.

- Non-drop-in fuels include the bioethanol and biodiesel blends used today, and are made of different molecules compared to standard fuels such as petrol and diesel. Examples include ethanol as a petrol substitute and fatty acid methyl esters (FAME, or biodiesel) as a diesel substitute. As a result, they require engine modifications or blending in order to be used.
- Drop-in fuels are biofuels comprised of exactly the same molecules as the fuel they replace (petrol, diesel, marine oil, aviation turbine fuel). As a result, they can be "dropped" straight into present engines and distribution infrastructure without the need for modification. Vegetable oil-derived drop-in fuels (petrol, diesel and jet fuel) are already available on the market through hydrotreating processes such as Neste's NEXBTL or Honeywell's Green Diesel.

- 1st and 2nd generation processes usually refer to the feedstock used to produce the biofuel.
- 1st generation fuels use food/crop feedstocks such as sugar and virgin (first use) or used cooking oil (UCO). As a result, they are often in competition for land with food production (either directly or indirectly), with associated concerns for sustainability and well-to-wheel emissions once indirect land use change is taken into account.
- 2nd generation fuels use waste or crop residue feedstocks, and so are not in competition with food production.

	Non Drop-In (non-identical molecules)	Drop-In (identical molecules)
Food/ Crop/ UCO Feedstock (1st generation processes)	Current biofuels e.g. ethanol, FAME	Hydrotreated vegetable oils
Plant waste/ Residue Feedstock (2nd generation processes)	"Cellulosic" biofuels	Best case for sustainability and engine compatibility Chemical/thermal conversion of wastes/residues

Table 2: Quantities of drop-in biofuels used by trucks and buses in the constrained biofuels scenario.

	Trucks	Buses
2030 proportion of drop-in biofuel (relative to Policies)	3.4%	3.4%
2030 million litres of drop-in biofuel	26	6.4
Emissions reduction in 2030 relative to “Policies”	2% (32 $ktCO_2e$/year)	2% (7 $ktCO_2e$/year)

Table 3: Summary of the modelled emissions reductions from gas powered trucks and buses.

	Number of gas vehicles in UK in 2030	Number of gas vehicles in Scotland in 2030	Proportion of Scottish vehicles running on gas in 2030	Emissions reduction ($ktCO_2e$/year in 2030) using CNG	Emissions reduction ($ktCO_2e$/year in 2030) using biomethane
Trucks	50,000	3,650	8.8%	41	144
Buses	9,700	873	5.6%	7	25

Hence, we assumed an overall fuel switching scenario in which the maximum reductions achievable using domestic production were achieved, using both drop-in biofuels and biomethane. Resulting emissions reductions compared to the policies scenario were 0.2$MtCO_2e$/year in 2030, as shown in Figure 12. This left the overall emissions from trucks and buses in 2030 at 1.8 $MtCO_2e$/year, 0.3 $MtCO_2e$/year above the emissions in the illustrative proportional pathway. For reference, the measures included in each scenario are shown in Table 4.

It should be noted that the availability of biomethane for transport as opposed to decarbonising the Scottish gas grid for all consumers is uncertain, since the majority of biomethane sold for transport is done through natural gas from the grid accompanied by Green Gas Certificates, rather than transporting biomethane by road to the refuelling station. Biomethane is potentially of particular interest in refuse collection vehicles, where there are relatively large collections of depot-based vehicles with high fuel consumption (and hence gas demand), and the option of producing biomethane from the food waste collected.

Table 5 shows the abatement costs in 2030 of substituting a baseline diesel ICE vehicle for an alternative powertrain vehicle. Since there are fewer solutions available for long range trucks and buses, we present figures for small rigid trucks and city buses only. Costs are represented on both a social and private basis, as defined in Section 3.1. All hybrid trucks show negative abatement costs, and the abatement costs of FHV buses are also low (£77 /tCO_2e on a social basis), whereas HEV buses have very high abatement costs due to their large cost premiums. Of the zero emission bus options, BEVs have the lowest abatement costs, of £224 /tCO_2e on a social basis. For FCEV buses, we present high and low cost premium scenarios, reflecting different levels of technology readiness and sizes of the fuel cell market in 2030. We considered capital cost premiums (exc. margin and VAT) of £80,000 (roughly £100,000 including margin) to £245,000 for fuel cell buses, which led to abatement costs of £438 and £911 /tCO_2e respectively on a social basis.

Table 4: Summary of the measures included in each scenario for trucks and buses.

Scenario	New Diesel ICE Efficiency improvements by 2030	Alternative powertrains market share by 2030	Level of biofuels penetration in 2030	Reduction from logistics and retrofit by 2030
Baseline	Trucks: 10-27% Buses: 14-16%	None	Biodiesel blend B7	11%
Policies	As above	Rigid Trucks: 39% ZEVs All remaining non-ZEV trucks: 50% hybrids Buses: 31% ZEVs, 35% hybrids	As above	22%
Constrained biofuels	As above	As in "Policies"	Drop-in biofuels: 3.4% penetration of fuel relative to "Policies" 8.8% of trucks and 5.6% of buses running on biomethane	22%

The truck and bus scenarios highlight the challenge of reducing emissions in heavy vehicles, given the time needed for low emission vehicles to spread through the parc. For trucks in particular, there is a lack of viable zero emissions powertrains for larger, long-haul vehicles. Since incremental efficiency improvements and logistics optimisation are partially offset by demand growth, further reductions can only be met by widespread fuel switching or switching to zero emissions heavy trucks. Additional research and development of such vehicles would be highly valuable in ensuring that a wide range of low emissions solutions is available on the market in the 2020s when they are needed. The Scottish Government could play a valuable role here, which could include providing funding for advanced powertrain research, funding on-road demonstrations or providing procurement commitments for zero emission vehicles meeting a defined specification to stimulate private sector competition.

Table 5: Cost Effectiveness of CO_2e abatement from different small rigid truck and standard city bus (31-40 seats) powertrains in 2030, relative to a diesel ICE baseline.

		Capital Cost Premium (£) exc. Margin & VAT	Lifetime Fuel Cost Premium (£)		Lifetime Abatement Cost (£/tCO_2e)	
			Social	Private	Social	Private
Small Rigid Trucks	HEV	2,100	-16,000	-22,000	-163	-222
	FHV	3,800	-10,000	-14,000	-117	-166
	HHV	2,600	-4,900	-6,600	-87	-129
City Buses	HEV	93,000	-17,000	-25,000	880	1,055
	FHV	16,000	-11,000	-16,000	77	57
	BEV	101,000	-22,000	-66,000	224	168
	FCEV (high premium)	245,000	73,000	0	911	922
	FCEV (low premium)	80,000	73,000	0	438	335

3.5 Emissions reduction scenarios – aviation and marine

The baseline scenario for aviation and marine shows a slight increase in emissions, as increasing efficiency only partially offsets demand growth. In order to reduce emissions further, as in the case of trucks and buses, a combination of efficiency improvements, demand reduction, and introduction of alternative powertrains is required. However, no alternative powertrains (apart from LNG for shipping, which is included in the baseline) are currently feasible for aircraft or international shipping, and so the role of alternative powertrains will be limited to shorter distance vessels such as island ferries.

There are relatively few Scottish-level policy options available for the marine and aviation sectors, since progress in fuel efficiency is primarily driven by demand from customers operating in multiple countries or through international regulatory agreements (e.g. the Energy Efficiency Design Index for ships). There are, however, some measures that can be effected at a national level, such as the obligatory use of shore-based power for ships, or ground power and single engine taxi for aircraft (already implemented to an extent at Scottish airports). Although these can have significant air quality benefits, the CO_2e reductions available are relatively small. We use an estimate of a 1.5% reduction from ground power and single engine taxi, based on 5%[25] of CO_2e emissions occurring on the ground, and 30%[26] of these emissions being eliminated using these measures. A more significant reduction in domestic marine emissions can be achieved by moving to alternative powertrains for ferries, such as the three hybrid ferries already in operation in Scotland. Here, we model the impact of introducing a 50% hybrid ferries procurement policy from 2015 onwards, which takes into account the fact that it is unlikely to be cost effective to switch the largest ships serving the longest crossings. Overall, these measures result in an emissions reduction of 25 $ktCO_2e$/year from aviation and 18 $ktCO_2e$/year from the marine sector by 2030, as shown in Figure 13.

The proportional impact of these measures is small, and so these sectors remain far away from their 2030 fair share targets, with aviation requiring an additional 47% reduction and marine requiring an additional 51% reduction. We finally consider a scenario in which the policies of the above scenario are implemented, but with levels of biofuels penetration of 3.4% for each of the aviation and marine sectors. This is consistent with the upper limit estimate of production available to Scotland in 2030, as detailed in Section 3.4. We assume that drop-in biofuels provide a net emissions reduction of 60% as above, which results in emissions reductions of 34 and 33 $ktCO_2e$/year, as shown in Table 6. Final emissions in this scenario are presented in Figure 13, and show that a total reduction of 0.1 $MtCO_2e$/year is achievable by 2030 relative to the baseline, missing the fair share target by 1.5 $MtCO_2e$/year. For reference, the measures included in each scenario are shown in Table 7.

[25] ATAG 2010, A Beginner's Guide to Aviation Efficiency
[26] Sustainable Aviation 2012, Reducing the Environmental Impacts of Ground Operations and Departing Aircraft: An Industry Code of Practice

Estimated cost effectiveness figures[27] for hybrid ferries are shown in Table 8. Two cost premium scenarios are presented, with premiums of £2m and £4m. These were determined by considering the capital costs of the hybrid ferries, the MV Hallaig (£10m) and the MV Lochinvar (£12m). These costs were compared to the cost of replacing the small ferry, the Isle of Cumbrae (£8m), which in 2013 was replaced on the Tarbert to Portavadie route by the MV Lochinvar. Present day figures for the annual fuel consumption, CO_2e emissions per year and capital cost premiums were combined to produce cost effectiveness values (we use the lower bound estimate of a 20% reduction in fuel consumption). We see that in both cases the capital cost premium contributes the majority of the difference in lifetime costs. As a result, the abatement costs on both a social and private basis are high, at £617 – £1314 /tCO_2e on a social basis.

While these are high costs, it should be noted that the Scottish hybrid ferry programme is still at early stages, and so the costs will come down with time. Hence, the abatement cost is expected to have decreased by 2030. In addition, this analysis does not include the value of air quality improvements, which are significant for ferries due to the high emissions of SO_2, NO_x and PM from marine fuels. Such air quality benefits would otherwise require equipment such as sulphur scrubbers, which have their own associated costs. In addition, in order to make an authoritative statement on the cost effectiveness of hybrid ferries, improved data on the real-world fuel savings and cost premium relative to a like-for-like replacement, from a full review of the hybrid ferry programme, would be required.

Table 6: Quantities of drop-in biofuels used in the aviation and marine sectors in each scenario.

	Aviation	Marine
2030 proportion of drop-in biofuel	3.4%	3.4%
2030 million litres of drop-in biofuel	22	18
Emissions reduction in 2030 relative to “Policies”	2% (34 $ktCO_2e$/year)	2% (33 $ktCO_2e$/year)

[27] Data from CMAL 2010, Scottish Government Ferry Review Work Package 6 – Vessels

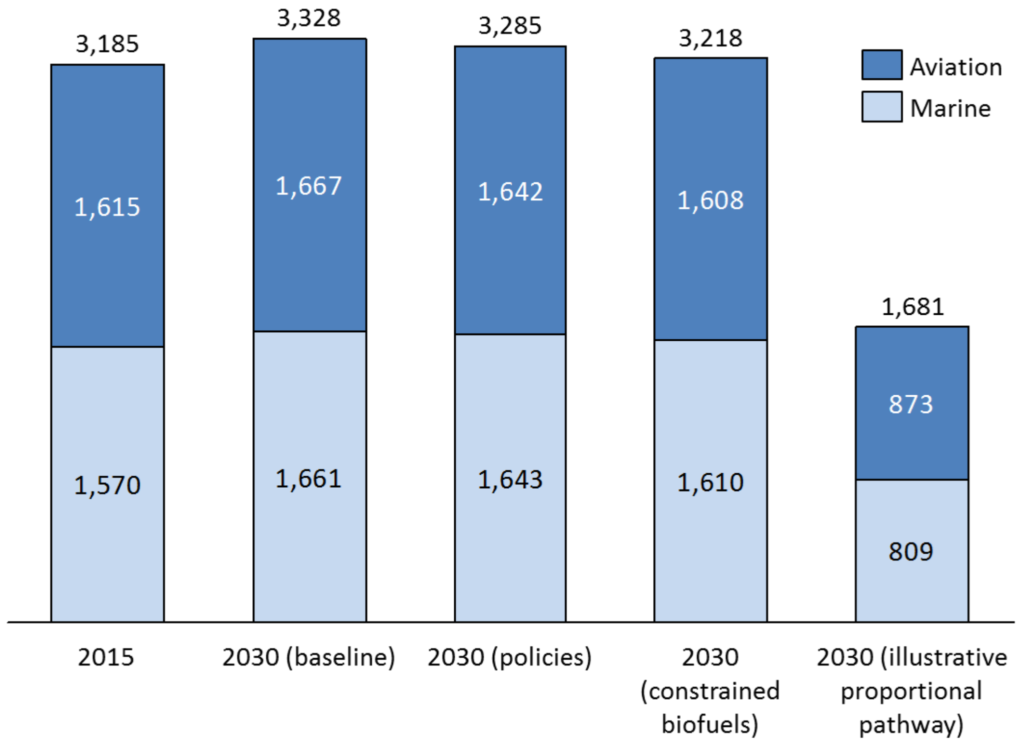

Figure 13: Emissions from aviation and marine in ktCO$_2$e/year for each scenario, compared against the present day and 2030 fair share target.

Table 7: Summary of the measures included in each scenario for aviation and marine.

Scenario	Efficiency improvements by 2030	Alternative powertrains market shares	Drop-in biofuels penetration by 2030
Baseline	Aviation (fleet): 15% Marine (new ships): 34%	None	None
Policies	As above	Aviation: None Marine: 50% hybrids from 2015 onwards	None
Constrained Biofuels	As above	As in “Policies”	Aviation: 3.4% Marine: 3.4%

Table 8: Cost Effectiveness of CO_2e abatement from a hybrid ferry relative to a marine gas oil ferry baseline, based on 2013 figures.

		Capital Cost Premium (£) inc. margin and VAT	Fuel Cost Premium (£)		Abatement Cost (£/tCO_2e)	
			Social	Private	Social	Private
Ferries	Hybrid (High premium)	4,000,000	-232,000	-149,000	1314	1343
Ferries	Hybrid (Low premium)	2,000,000	-232,000	-149,000	617	645

3.6 Summary of 2030 transport emissions

Figure 14 shows the projected emissions in 2030 compared to 2015 under the range of policy scenarios discussed above, with emissions reductions of 1.4 MtCO_2e/year in the base case, up to 3.3 MtCO_2e/year in the "constrained biofuels" case. These are significant reductions, but still result in transport missing its 2030 "fair share" target by 2.3 MtCO_2e/year.

The more easily attainable emissions reductions come from light vehicles, as falling BEV and PHEV cost premiums mean that they will become increasingly competitive with the incumbent petrol and diesel ICE powertrains. In combination with policy incentives, this can give rise to significant market penetrations for alternative powertrains. Emissions reductions in other sectors are more challenging, and require stronger measures such as zero emissions procurement policies, urban access restrictions, and improvements from logistics and retrofit technologies.

Overall, light vehicles deliver the highest emissions reductions in absolute terms and as a proportion of current emissions. In contrast, aviation and shipping emissions in 2030 remain 50% higher than if they were to reduce according to the illustrative proportional pathway. This therefore requires additional emissions reductions in other transport sectors to compensate, for example from cars and vans, or in sectors outside transport such as power generation or heating.

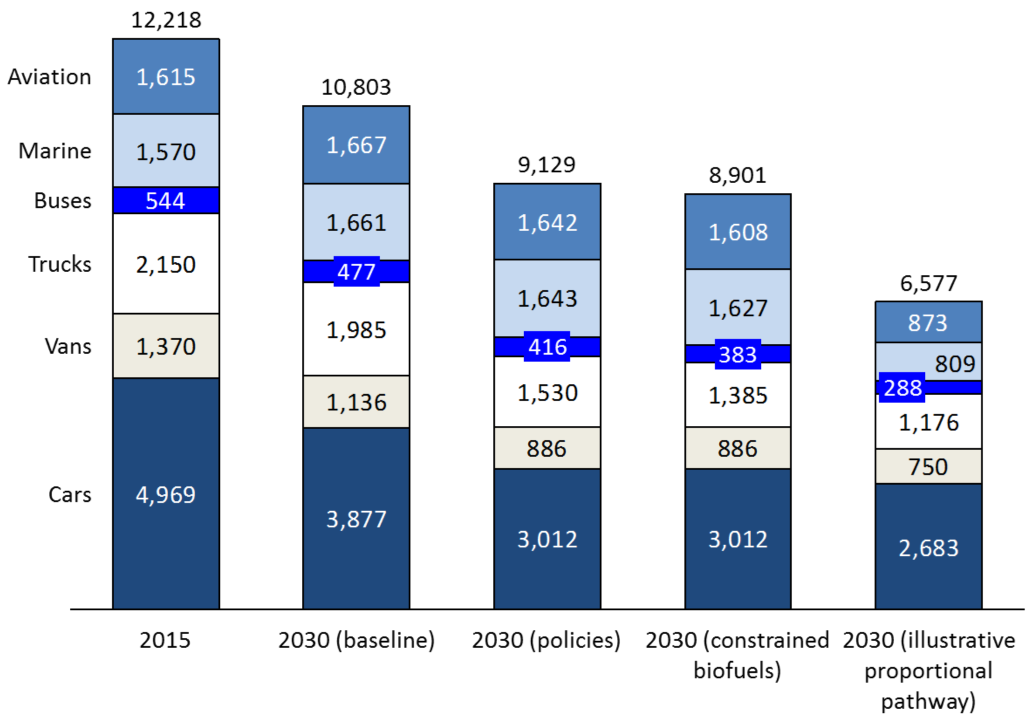

Figure 14: Overall transport emissions in $ktCO_2e$/year for each scenario, compared against the present day and the pathway in which emissions reduce in proportion to the overall Scottish target.

3.7 Impact of changes in demand

The analysis presented above shows that increases in demand are expected to offset the emissions reduction impact of efficiency improvements and switching to alternative powertrains. In this section, we consider the impact of reducing demand growth. This could be brought about in the real world by increased car sharing, modal shift, and reductions in vehicle-km due to new mobility such as autonomous vehicles (potentially reducing vehicle-km using e.g. taxi-style services to improve load factors, and reducing energy demand through eco-driving, platooning, and congestion mitigation). For illustrative purposes, demand growth is halved compared to the baseline demand scenario. In this simple example, we assume that the journeys no longer occur, and are not shifted to other modes. While achieving demand reduction is very challenging, particularly in sectors such as aviation, this modelling gives an indication of the strength of the influence of demand on emissions.

Figure 15 shows emissions reductions with and without changes in demand, for each of the Baseline and Constrained Biofuels scenarios, the least and most ambitious scenarios from above, and we see that halving demand growth by sector leads to a 7% reduction in emissions in each case. Since aviation and cars have high baseline emissions and higher projected demand growth, the impact of demand reduction is strongest for these sectors, with reductions of 120 and 240 $ktCO_2e$/year respectively in the Constrained Biofuels scenario, and greater reductions in the Baseline scenario. Vans, trucks, and the marine sector also show significant reductions of 70-110 $ktCO_2e$/year in the Constrained Biofuels scenario. It should also be noted that only demand growth reductions are expected to have a significant impact in reducing emissions from the aviation and marine sectors. Overall reductions in demand growth can make a significant contribution to emissions reductions, with a total reduction of 4.0 $MtCO_2e$/year in 2030 relative to 2015 in the best case, closing the gap to the 2030 emissions in the proportional pathway to 1.7 $MtCO_2e$/year.

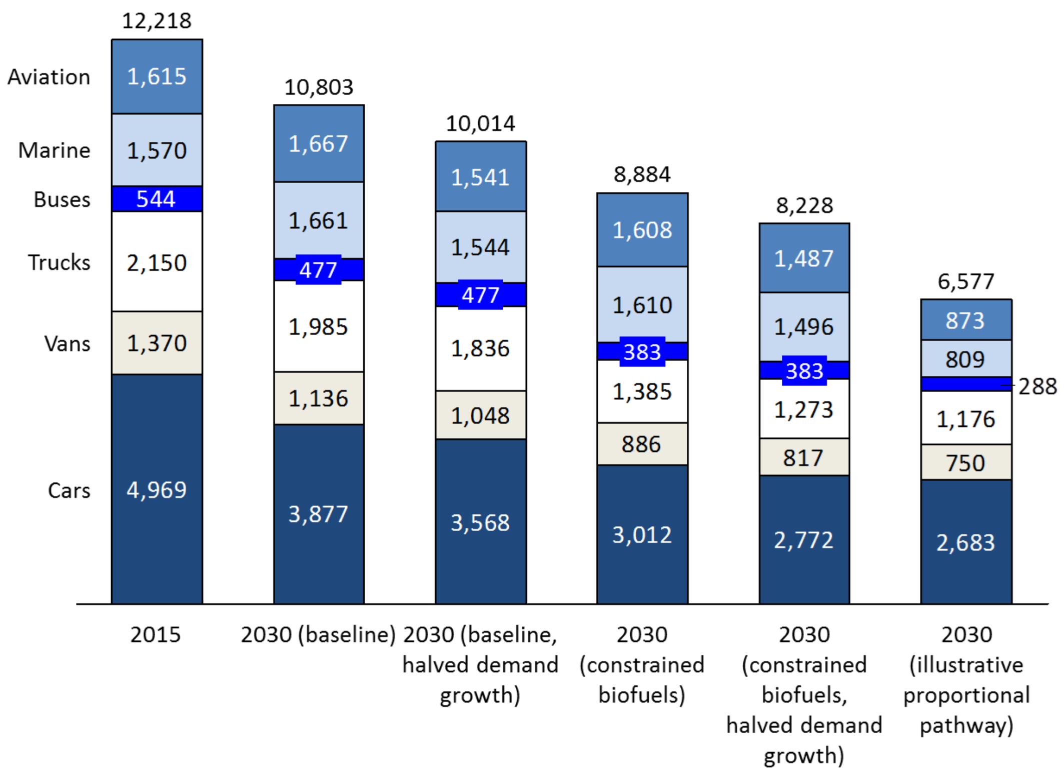

Figure 15: The impact on transport emissions in $ktCO_2e$/year of halving the growth in demand, in the baseline and constrained biofuels scenarios.

4 Summary and implications for policy development

Our analysis of the expected emissions from Scottish transport under a range of policy environments shows that there is potential for significant reductions (emissions of 8.9 $MtCO_2e$/year in 2030 compared to 12.2 $MtCO_2e$/year in 2015, excluding demand growth reduction) to be achieved with plausible deployments of efficient vehicles and zero emission powertrains. Light vehicles offer the greatest potential for emissions reductions, through improving efficiency and adoption of low and zero emission powertrains, although it remains to be seen how mass-market customers will buy PHEVs, BEVs, and FCEVs as their ownership costs approach those of conventional vehicles. By contrast, emissions from long haul trucks, aviation, and shipping are likely to be challenging to reduce due to expected increases in demand and a current lack of zero emission options. The analysis highlights the challenge of meeting the deep reductions required if transport sector emissions are to fall in-line with the overall Scottish target. Delivering these additional reductions will require a combination of demand reduction (or at least a reduction in the projected increase in demand), earlier and more widespread deployment of zero emission heavy vehicles including in long haul trucks, and increases in the projected rate of emissions reductions in the marine and aviation sectors, each of which is very challenging to achieve practically.

A range of supportive policies and regulations could be used to influence emissions reductions, particularly through the uptake rates of low and ultra-low emission vehicles, and different policy measures would be implemented at different levels of government;

- At an international or European level, high level emissions regulations can be implemented, such as the EU new car and van fleet CO_2 targets, efficiency standards for ships and aircraft etc.
- At the national level, there are currently a range of financial measures in place, including OLEV grants for plug-in cars and vans, exemption from Vehicle Excise Duty for zero emission cars, fuel duty differential for low carbon fuels (each available UK-wide), additional payment under the Bus Service Operators Grant paid to low emission buses, grants towards installation of home charging points (each available UK-wide, but with additional payments provided by Transport Scotland), and Scottish specific measures such as zero interest loans for the purchase of EVs.
- At a Local Authority level, measures such as low or ultra-low emissions zones, free ferries, access to bus lanes and public sector procurement of low emission vehicles can complement European and national interventions.

These different levels of interventions can be seen clearly in current European markets for electric vehicles. In Norway, there are large national-level exemptions from purchase taxes for EVs, alongside widespread infrastructure, and locally-introduced exemption from urban access charges, free parking, free ferries, and access to bus lanes, resulting in a plug-in vehicle market share of 24%[28] in 2015, made up of mostly BEVs. On the other hand, in Germany, there are minor VED charges and until 2016 no national-level purchase incentives, and plug-in vehicles have low market shares of less than 1%. It should be noted that while direct financial incentives and infrastructure tend to increase EV uptake, this is not guaranteed. As such, it is important that a broad package of financial, infrastructural, convenience, and other incentives is implemented to maximise EV uptake and this applies both to light and heavy vehicles.

Potential policy interventions to deliver emissions cuts in the Scottish transport sector include:

- Emissions standards and market-based measures
- Financial incentives to end users
- Procurement policy
- Urban access restrictions
- Infrastructure
- Measures at airports and ports
- Harmonisation and ensuring consistency across different regions of Scotland
- Research and development.

These are discussed briefly in turn below.

Emissions Standards and Market-based Measures

EU car and van fleet CO_2 legislation has been a very important driver of emissions reductions to date in light vehicles. Current targets are set to 2021 (2020 for vans), and future targets are expected to continue to have a strong impact on emissions from Scottish transport by influencing the types of models available on the market and their prices. Likewise, the development of a European standard for emissions from trucks, as has already been implemented in the USA, would ensure that potential efficiency improvements are delivered to the market. International fuel efficiency/CO_2 standards now cover emissions from new aircraft (through ICAO's emissions standards) and new ships (through the IMO's Energy Efficiency Design Index), but these standards are expected to have a small impact on Scotland's emissions, due to only modest efficiency targets and

[28] http://www.eafo.eu/content/norway

slow fleet turnover for aircraft and ships. An ICAO Market Based Measure (MBM) for aviation is expected to be implemented in 2020, and an IMO MBM is under development for shipping. Strong agreements for these MBMs could have a significant impact on emissions from Scottish transport, although it is currently uncertain whether these measures will create an incentive to reduce emissions within the respective sectors or facilitate CO_2e offsetting through emissions in other sectors (such as power generation, forest protection etc.).

Financial Incentives

At a UK level, purchase grants for zero emission cars and vans will be available at least until March 2018, and new VED rates take effect in 2017, giving exemptions to ZEVs. These measures will incentivise uptake of ZEVs in the short term. As the EV cost premium comes down in the medium term (2020-2030) and the annual sales increase, it is unlikely to be economically feasible to continue to offer large purchase grants. Instead, ongoing financial benefits that provide an incentive in the order of £1,000 over the vehicle lifetime are likely to play an important role. These could include free use of ferries[29] as in Norway, free/priority access to parking and reduced licence fees for ZEV taxis. The latter two of these would incentivise EV uptake in cities in particular, with accompanying air quality benefits. Such measures would be implemented at a local authority (LA) level, but there would be financial consequences from such measures which would need to be covered either locally or from central government. Scotland is committed through Switched on Scotland to developing a national framework for local EV incentives, including many of the financial incentives in this section, as well as convenience benefits such as bus lane access (discussed below).

Procurement of low emission vehicles

Procurement policies can be used to increase penetration of zero emission vehicles through direct procurement by the public sector or by setting contract conditions for companies operating services for local authorities.

[29] A pilot scheme was started in 2013 in which EV users were given a 50% discount on single journeys to and from the islands of Mull and Bute. As this removed the discount from being able to buy a return journey, and only applied to a very small proportion of Scottish routes, it is expected that this had a very small impact on EV uptake. The scheme ended in 2015 when the road equivalent tariff was introduced for all Clyde and Hebrides Ferry Services routes. (www.transport.gov.scot/news/scotland-drives-way-forward-electric-vehicle-vision & www.calmac.co.uk/ret/about)

Direct procurement of ZEVs for local authority-owned car, van and small truck fleets is already in place to an extent; feedback from local authorities in Scotland suggests that BEVs are already cost-competitive on a TCO basis, provided that daily range requirements are satisfied and low cost charging solutions can be used. Widespread adoption of such a policy would have many benefits in addition to the direct reductions in emissions of CO_2 and other pollutants, including cost savings for local authorities and increased public awareness of EVs.

Provided that an operator registers a service with the Office of the Traffic Commissioner they can operate any route they wish to any timetable. Currently only one bus company, Lothian Buses in Edinburgh, remains under the ownership and control of local councils in Lothian and Edinburgh but the Lothian network is run as a commercial operation.

Local transport authorities can provide subsidies for services in areas that are not provided on a commercial basis but this is entirely a matter for the local authority. Through significant support and public sector funding some bus routes have already switched to low emissions powertrains, most notably the 10 fuel cell buses operating in Aberdeen. Similar initiatives could be put in place elsewhere, with bus operators paying their usual operating costs, and external funding filling the gap.

In several European cities, ambitious procurement rules have been recently put in place for city buses. In Hamburg, the city has committed to purchasing only zero emission buses from 2020 and Amsterdam has committed to switching all of its buses to electric models by 2025. In each case, the bus company is owned by the city, allowing it to make such procurement decisions. A modified approach would be needed in Scotland, such as making minimum bus emissions performance a requirement of the registration process or through financial incentives such as tightening operating grants to reward zero emission buses over conventional vehicles.

Scotland has already purchased three diesel electric hybrid ferries, which offer fuel consumption savings of 20-30%, and the feasibility of building a hydrogen fuel cell ferry is being studied by CMAL. A continuing policy of hybrid ferry procurement for appropriate routes (savings are greater for shorter routes) could hence provide significant emissions reductions in the domestic marine sector, and some fuel cell or battery powered ferries could also be used if the technology is shown to be effective for Scottish applications. Again, external funding is likely to be needed (either at a Scottish or European level) to cover the additional costs of the low or zero emissions ferries.

Urban access restrictions

There are currently no Low Emissions Zones (LEZs) in Scotland, but Scotland has set out its intentions to develop a framework for the development of LEZs[30]. The largest urban access restriction currently in place for cars in the UK is the London congestion charge, which has exemptions for cars and vans with emissions less than 75gCO_2/km. An Ultra-Low Emissions Zone (ULEZ) is planned for 2020, which will have high daily charges for any vehicle not meeting the Euro 6/VI emission regulations for diesel vehicles and Euro 4 for petrol. Likewise, Oslo, where EV uptake is very high, has an urban toll system where charges are graded depending on CO_2 emissions. Such schemes have multiple benefits; a reduction in the number of vehicles in cities, improvements in air quality, incentives for consumers to switch to EVs, and potential to raise funds that can be spent on other emissions reduction policies (as is the practice in Oslo).

One of the measures that has proved successful in Norway in terms of incentivising EV uptake is giving ZEVs access to bus lanes, particularly on the commuter route between Oslo and Asker. Giving EV users in Scotland access to bus lanes and other restricted access routes could be very effective, particularly on commuter routes, as commuters will value the time savings very highly. Access to bus lanes has been proposed by several English cities which won OLEV funding as part of the Go Ultra Low City Scheme.[31] However, it should be noted that access to bus lanes only affects a proportion of Scottish drivers in cities, and such a measure may only be viable in the short term while the number of ULEVs on the roads remains relatively low. In addition, the costs of policing schemes of this nature using e.g. licence plate recognition could be significant.

Since all new heavy vehicles sold from 2014 onwards comply with the Euro VI emissions standard, a London-style ULEZ will encourage early replacement of old vehicles or redeploying vehicles to ensure only Euro VI-compliant vehicles are used inside these cities. It will not necessarily encourage the deployment of zero emission vehicles unless the eligibility criteria are tightened to exclude diesel vehicles. Such a move could only be made once appropriate and cost-effective vehicles are available for a variety of van and truck sizes (likely to be towards 2025), and could start at a small scale by allowing access to pedestrianized zones for zero emission vehicles to provide greater operating flexibility for fleets.

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[30] The Scottish Government 2015, Cleaner Air for Scotland
[31] https://www.gov.uk/government/news/40-million-to-drive-green-car-revolution-across-uk-cities

Use of urban access restrictions and consolidation centres on the outskirts of cities could allow the introduction of larger capacity trucks (for example up to 60 tonnes gross weight), as these could be restricted to use on motorways and truck roads. This would offer reduced fuel consumption on a tonne-km basis, while addressing concerns over road suitability and safety on smaller roads. Large capacity trucks could then be used on motorways and trunk roads, reducing long haul emissions, which make up a large proportion of truck emissions, and ZEVs could be used for “last mile” urban delivery. Policy support for urban consolidation centres (UCCs) could include financial incentives, making land available, or setting up public-run UCCs as is being trialled in Camden[32]. Further work is required to understand the potential cost-effectiveness and emissions of such logistics, taking into account additional loading/unloading operations at the consolidation centres.

Infrastructure

As illustrated in Section 3.3, increased availability of charging infrastructure is an important factor for encouraging uptake of plug-in vehicles. Transport Scotland has an EV infrastructure strategy in place, which includes rapid charger deployment, city centres, commercial workplaces, and home charging. Our findings from consultations suggest that there are three key areas for the optimal development of effective charging infrastructure. Firstly, developing an extensive nationwide rapid charging network is important to minimise range-anxiety barriers to EV uptake. Secondly, charging infrastructure should be made available in city centres. It is important that these charging points are in locations that are highly visible, to improve awareness of the availability of charging, and that they are in locations that are useful for the user, such as near retail, leisure, and restaurant areas. Finally, investing in increased access to home charging for households without off-street parking would provide more customers with the option to switch to EVs. Practically, such measures would include the installation of charging points at tenement blocks and in places such as street lighting to allow charging on-street without cables crossing pavements. The four cities funded in 2016 under the Go Ultra Low Cities scheme (London, Milton Keynes, Bristol and Nottinghamshire/Derby) place a strong focus on addressing urban charging opportunities, and should provide valuable lessons on the most effective solutions that could be implemented in Scottish cities[33].

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[32] Camden Lamilo Project: www.lamiloproject.eu/london-camden/

[33] See https://www.gov.uk/government/news/40-million-to-drive-green-car-revolution-across-uk-cities Dundee received a share of £5m under this scheme to install charging points for EV commuters in the city.

Feedback from industry consultation also suggests that while financial support for charging infrastructure is useful, the most useful intervention from the Scottish Government would be to make land available in good locations as described above, where third parties could build infrastructure.

In addition, the development of refuelling infrastructure for alternative fuels will be important if these fuels are to enter into widespread use. There is currently one operational hydrogen refuelling station (HRS) in Scotland, which is used to refill the Aberdeen fuel cell bus fleet, and is being upgraded to also have the facility for refuelling of cars and vans. A second HRS in Aberdeen is due for completion early in 2017, which will provide refuelling services to fuel cell cars and vans.[34] Two hydrogen refuelling stations are also being developed in Fife as part of the Levenmouth Community Energy Project. There is one gas refuelling station in Scotland, which provides LNG, and has been used by Muller Wiseman Dairies.

Measures at airports and ports

While the majority of emissions from shipping and aviation depend on international regulation and R&D, there are some measures at the port/airport level that Scotland that Scotland can influence. At ports, cold ironing (using shore power rather than engines when in port) could be used to reduce CO_2e emissions and improve the air quality in ports. Scotland could make the provision of cold ironing facility mandatory at Scottish ports, but whether or not this facility would be used would depend on the cost differential, as running an engine on marine oil can be cheaper than shore power. Mandating the use of cold ironing in Scottish ports could be used as a stronger measure to reduce emissions, but brings risks of driving freight away from Scottish ports.

Similarly, at airports, some emissions reductions could be achieved by encouraging or mandating provision of ground power facilities, single engine taxiing, and the use of low emission ground vehicles. However, the CO_2e impact of these measures would be small, as emissions at airports are only a small proportion (on the order of 1%) of total aviation emissions.

The Scottish Government has committed to reducing the overall burden of APD by 50 per cent, with the reduction beginning in April 2018 and delivered in full by the end of the next Parliament. Other changes to APD or landing fees could be considered to encourage any aircraft using Scottish airports to reduce their CO_2e emissions. This could take the form of tiered

[34] Aberdeen City Council – Hydrogen Bus Project, www.aberdeencity.gov.uk/council_government/shaping_aberdeen/Shaping_Aberdeen_Hyrdogen_Bus.asp

charges according to the fuel efficiency or load factor of the aircraft. Since there is a significant difference in fuel efficiency between airlines (e.g. BA's transatlantic flights use 51% more fuel per passenger kilometre as those of Norwegian Airlines[35]), such a measure could have a significant impact on CO_2e emissions from aviation.

Consistency and harmonisation

Historically, there have been issues with urban access restrictions causing freight companies to merely move their lower emissions vehicles to areas with access restrictions in place, causing emissions to be moved around rather than actually reduced. Similarly, restrictions imposed on a gCO_2/km rather than a gCO_2/tonne-km basis have caused freight to be carried by multiple smaller vehicles rather than fewer larger vehicles, increasing congestion without improving emissions. Making use of a common approach to CO_2 ratings across local authorities would optimise the effectiveness of measures such as urban access restrictions by minimising the scope for moving emissions around rather than actually reducing them. Similarly, introducing a common definition of ultra-low emission vehicles would optimise the benefits from measures relating to ULEVs, for example ensuring that prospective buyers of ULEVs could be confident that they would benefit consistently from local measures in different areas of Scotland.[36]

Finally, work is required to amend some current legislation that has not kept pace with technology development, although work is already beginning to address some of the anomalies. For example, regulations governing which vehicles may be used as taxis in some Scottish cities are still defined in terms of engine displacement, although this has been updated in some areas, such as Dundee. This obsolete definition means that BEVs are technically not permitted to be used as taxis. Working with local authorities to bring in a consistent, updated definition for what vehicles are allowed for use as taxis will remove these kinds of barriers to deployment.

Research, Development and Demonstration Activities

Some areas of the transport sector, such as aviation, shipping, and long haul trucks, have very few feasible low carbon solutions available at present apart from fuel switching to drop-in biofuels. While trends in aviation and shipping emissions are likely to be governed by international scale legislation and research and development, Scotland can fund and support research, development, and demonstration work for zero emission

[35] ICCT, Transatlantic Airline Fuel Efficiency Ranking 2014
[36] This could be done through voluntarily guidelines adopted by Local Authorities or through secondary regulation, rather than primary legislation.

long haul trucks, as part of a wider international effort. This would be achieved by providing funding for the development of improved hydrogen storage for long range FCEV trucks and larger batteries for battery electric trucks. Co-operation at a UK or an EU-level is likely be required to provide a sufficient ‘pull’ for manufacturers to invest in these technologies, but Scotland could play a leading role in early demonstrations and deployments as it has with hydrogen bus deployments in Aberdeen as part of a network of EU cities.

For plug-in vehicles, there is increasing interest in their role in managing the electricity system, through optimised charging to avoid excessive peak loads on the distribution network through to providing grid services such as frequency control or reserve power through ‘Vehicle to Grid’. Given Scotland’s relatively high penetration of intermittent renewables in its electricity mix and relatively weak interconnections in some rural areas and islands, the benefits of EVs for electricity system management may become apparent sooner in Scotland compared with the rest of the UK. Hence Scotland is well-placed to take a leading role in testing these integration concepts, and is already beginning to consider how to make the most of these potential benefits[37].

Policy Priorities

In this study, we found certain transport sectors to be significantly easier to decarbonise than others. In particular, we found that deep emissions reductions are possible from cars and vans through improving ICE vehicle efficiency and switching to alternative powertrains, while long-haul trucks, aviation, and shipping are difficult to decarbonise. As a result, policy measures with the greatest expected CO_2e impact should be prioritised. Table 9 provides a summary of these measures.

[37] Transport Scotland 2013, Switched on Scotland: A Roadmap to Widespread Adoption of Plug-in Vehicles

Table 9: Policy priorities for reducing emissions from Scottish transport

	Policy Priorities
Cars and Vans	• Financial and convenience incentives for uptake of ultra-low emission vehicles, which could include free parking, free ferries, access to dedicated lanes/bus lanes, and reduced taxi licence fees. • Continued rollout of charging infrastructure for plug-in vehicles, including financial support and measures to improve the availability of and speed of access to well-located land for third parties wishing to build charging infrastructure. • Strong support for strong future EU emissions standards for cars and vans. • Communication/education to improve awareness and challenge public misconceptions of ULEVs.
Trucks and Buses	• Procurement policies, permitting conditions or operator grants for ultra-low emission and zero emission buses. • Implementing urban access restrictions to incentivise switching to ultra-low emission and zero emission trucks and buses. • Support for retrofit and logistics measures where feasible. • Scottish Government support for effective EU-level truck efficiency standards.
Aviation and Marine	• Action to support the introduction of effective international market based measures. • Continuing hybrid ferry procurement where cost effective. • Facilitating port and airport level measures where cost effective.

Annex 1: Co-Benefits of Decarbonisation of Scottish Transport

Damage Cost of CO_2

Emissions of CO_2 contribute to global warming, which is expected to lead to a range of negative impacts on the world and society, including an increased frequency of extreme weather events, rising sea levels and resulting damage to low-lying areas of land, and increasing scarcity of food and water resources. A "value of CO_2 emissions" can hence be ascribed to these impacts, which is useful for the appraisal of CO_2 abatement measures. The value of CO_2 emissions can be determined using multiple approaches. Firstly, there is the market price of carbon. This is the cost of a permit to emit one tonne of CO_2 as part of a market scheme such as the EU Emissions Trading Scheme (ETS). However, this does not necessarily reflect the real-world cost of emissions. For example, the EU ETS carbon price is considered to be too low due to an over-allocation of permits relative to actual emissions. Secondly, there is a value based on the cost of CO_2 mitigation, which considers the fundamental abatement cost rather than short term price signals from a market-based mechanism. However, there is no inherent link between the cost of reducing emissions (reflected in market carbon prices) and the cost of the damage caused by those emissions. Hence a third approach is to assess directly the value of the damages caused by CO_2 emissions, also known as the Social Cost of Carbon[38] (SCC), which is the focus of this section. It is worth noting that all values presented here for the damage due to CO_2 are global values, and so the benefits of CO_2 reductions will not necessarily accrue to Scotland.

There are a wide range of estimates of the SCC. The US Government uses the SCC to estimate the climate benefits of policies as part of cost-benefit analyses. Its central estimate is 36 \$(2007)/tCO_2 (25 £/tCO_2)[39]. Similarly, DECC produces carbon values for emissions inside and outside the EU ETS, which are used for policy appraisal by the UK Government. The 2016 central value for non-traded emissions (since transport is not currently included in the EU ETS) is 60 £(2011)/tCO_2 (£63 /tCO_2)[40]. The Stern Review in 2006 put the value of the impacts of CO_2 emissions at 30

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[38] Specifically, the Social Cost of Carbon is the net present value of climate change impacts of one additional tonne of CO_2 emitted today.
[39] US Government 2016, Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis
[40] DECC 2011, A brief guide to the carbon valuation methodology for UK policy appraisal

$(2000)/t$CO_2$ (£25 /tCO_2)[41], while other studies determine values of up to 220 $/t$CO_2$ (£134 /tCO_2)[42] and 900 $/t$CO_2$ (£596 /tCO_2, worst case scenario)[43]. This demonstrates that there is a great deal of uncertainty in the true value of CO_2 emissions, since the outcome is highly sensitive to the modelling approach. Different approaches to the following aspects are particularly significant:

- What extent of climate impacts are included in the modelling.
- The discount rate and time horizon used for evaluating future costs of CO_2.
- Whether or not climate impacts have an impact on economic growth.
- Whether or not catastrophic impacts of climate change are included, and with what probability.

Here we present a conservative present day estimate of the social cost of carbon of £25 /tCO_2, consistent with the value used by the US Government for policy appraisal and with the Stern Review[44]. In addition, we consider the effect of using a higher value of £134 /tCO_2 as a sensitivity, since the true cost of CO_2 emissions could be significantly higher than £25 /tCO_2, once the full range of climate impacts are considered including potential catastrophic scenarios.

The CO_2 emissions reductions in the scenarios modelled in this study were combined with the social cost of carbon as outlined above, to give the total value of CO_2 abatements. Using the conservative value for the SCC resulted in values of £35 - £81 million in 2030, depending on scenario, and using the high estimate for the SCC resulted in values of £190 - £432 million in 2030, as shown in Table 10.

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[41] Defra 2007, The Social Cost Of Carbon and the Shadow Price Of Carbon: what they are, and how to use them in economic appraisal in the UK

[42] Stanford News, news.stanford.edu/2015/01/12/emissions-social-costs-011215/

[43] Stockholm Environment Institute 2011, Climate Risks and Carbon Prices: Revising the Social Cost of Carbon

[44] Nicholas Stern for the British Government 2006, The Stern Review: The Economics of Climate Change

Table 10: The value of CO_2 abatements in each scenario for a low and high damage cost of CO_2.

Scenario	Emissions abated in 2030 relative to 2015 ($ktCO_2$/year)	Value of abatement using low social cost of CO_2 (million £/year)	Value of abatement using high social cost of CO_2 (million £/year)
Baseline	1,415	35	190
Policies	2,981	75	399
Constrained Biofuels	3,226	81	432

Air Quality

In addition to CO_2, a range of pollutants with more local effects are emitted by surface transport, including oxides of nitrogen (NO_x), particulate matter (PM), sulphur dioxide, ammonia, carbon monoxide, and volatile organic compounds. NO_x and PM in particular are emitted in quantities large enough to have harmful impacts on human health. There are three main costs associated with atmospheric NO_x and PM; loss of life (a recent study estimated that 40,000 deaths per year in the UK can be attributed to outdoor air pollution[45]), increased healthcare costs due to increased illness, as well as the soiling of buildings by PM, causing increased maintenance costs to prevent darkening of building facades and windows (few studies report the cost of building damage alone, but one study estimates its value at £177 million per year in the UK in 1998[46]).

Air quality modelling can be used to determine in detail the impacts of emissions of air pollutants. This accounts for the geographical location, height above the ground, background pollutant levels, and rate of dispersion of the pollutant. This process can be very time and resource intensive, and so Defra provides average damage costs by pollutant which they calculate from their own air quality modelling. We used these damage costs, which have values of £25,252 /tonne of NO_x and £58,125 /tonne of PM[47], to calculate and estimate of the total cost due to NO_x and PM emissions from surface transport, and hence the value of NOx and PM abatements due to increased uptake of ULEVs and ZEVs.

[45] Royal College of Physicians 2016, Every breath we take: the lifelong impact of air pollution
[46] Watkiss et al. for Defra 2001, Quantification of the non-health effects of air pollution in the UK for PM10 objective analysis
[47] Defra, Air Quality: Economic Analysis, https://www.gov.uk/guidance/air-quality-economic-analysis

Our Scottish vehicle fleet model, which was used in the main part of this study to calculate CO_2 emissions, was modified to calculate NOx and PM emissions from Scottish surface transport. Real-world input assumptions by vehicle, powertrain, and year (in grams per kilometre of NOx and PM) were taken from the NAEI's COPERT speed-related emission functions[48]. We used characteristic speeds for motorways[49], urban and rural roads[50] from DfT statistics as inputs to these emission functions. Euro 6 diesel cars and vans were also assumed to exceed the NO_x emissions standard by a factor of ~7 in 2014, as has been observed in real-world tests[51], reducing to a factor of 1.5 in 2021, in line with maximum 'conformity factor' in that year as set out in EU regulations[52]. The fleet model outputs were then calibrated to 2013 emissions from the NAEI air pollutants inventory for Scotland.

Resulting illustrative projections of emissions of NO_x and PM in 2015 and 2030 are shown in Figure 16. Since alternative fuels in heavy vehicles are not expected to have a significant air quality improvement over Euro VI diesel powertrains, we assume that the emissions in the Constrained Biofuels scenario are the same as in the Policies scenario, and so do not reproduce them here. In the Baseline scenario, emissions of NO_x are reduced from 27 kt/year to 5kt/year and emissions of PM are reduced from 0.5 kt/year to 0.1 kt/year; an 81% reduction for each pollutant. This is driven primarily by Euro 6/VI emissions regulations and the introduction of real-world testing for diesel light vehicles, as well as some penetration of alternative powertrains into the fleet. It is worth noting that replacement of Euro III, IV and V heavy vehicles by Euro VI models reduces emissions per vehicle by up to 90%, and this is sufficient to reduce NOx and PM emissions from road transport by 39% and 59% as early as 2020. In the Policies scenario, higher uptake of alternative powertrains results in further emissions reductions, resulting in a total reduction in NO_x and PM emissions of 84% relative to 2015. This relatively small additional benefit of the policies scenario relative to the baseline is due to two factors: firstly, the air quality benefit of Euro VI/6 diesel engines is so high relative to previous vehicle generations that this dominates the overall emissions trend.

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48 NAEI Emission Factors for Transport, http://naei.defra.gov.uk/data/ef-transport Accessed June 2016

49 DfT Speeds Statistics 2014, Free flow vehicle speeds on non-built-up roads by road type and vehicle type in Great Britain

50 DfT Road Congestion Statistics 2014, Monthly and 12 month rolling average speeds on local 'A' roads in England

51 ICCT 2014, Real-World Exhaust Emissions from EU (Euro 6) and US (Tier 2 Bin 5/ULEV II) Diesel Passenger cars

52 European Commission Press Release October 2015, http://europa.eu/rapid/press-release_IP-15-5945_en.htm Accessed June 2016

Secondly, sales of ultra-low or zero emission vehicles between 2025 and 2030 take time to replace large numbers of existing vehicles in the stock, and air quality benefits continue to build after 2030 as further replacements continue.

Using the Defra damage costs, the total annual value of emissions reductions in the Policies scenario in 2030 is £567 million for NO_x and £23.5 million for PM, as shown in Table 11.

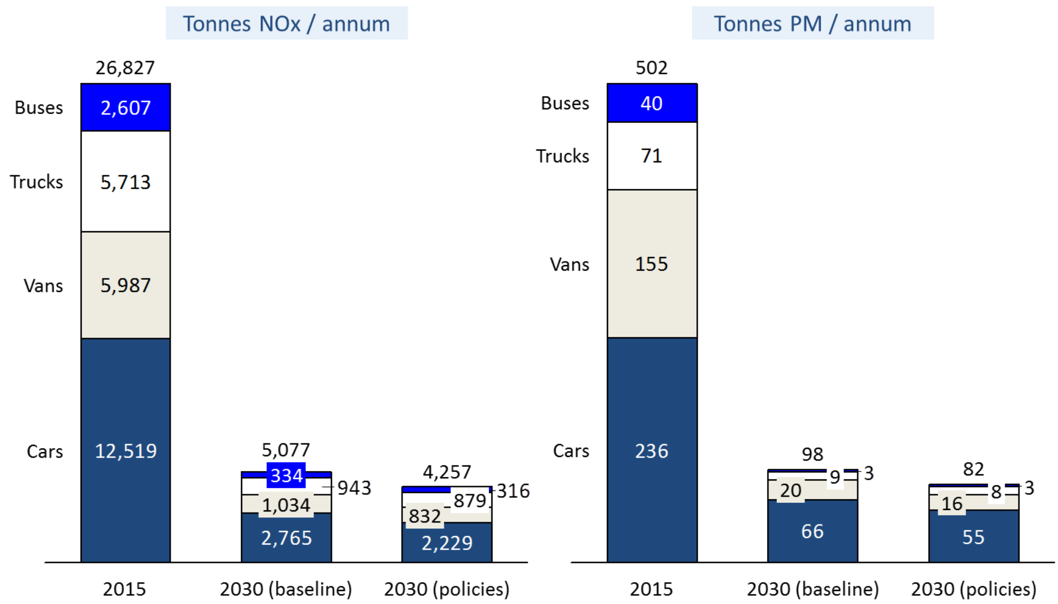

Figure 16: Tonnes of NO_x and PM from surface transport per year in 2030 in the Baseline and Policies scenarios, compared with 2015 values.

Table 11: Value of NO_x and PM abatements in 2030 relative to 2015.

Scenario	NO_x emissions abated in 2030 relative to 2015 (tonnes/year)	Value of 2030 NO_x abatements (million £/year)	PM emissions abated in 2030 relative to 2015 (tonnes/year)	Value of 2030 PM abatements (million £/year)
Baseline	21,750	549	405	23.5
Policies	22,452	567	420	24.4

Noise

Noise pollution from transport vehicles in Scotland has a negative impact on human health and wellbeing. In particular, there is evidence that traffic noise has negative impacts ranging from nuisance to disrupted sleeping patterns, reduced cognitive function, stress, raised blood pressure, and cardiovascular disease[53]. It is estimated that the social cost of urban road noise in England is £7-10 billion per annum, on par with the cost of road accidents (£9 billion), and the cost in Scotland is similarly significant.

Battery electric, plug-in hybrid, and fuel cell electric vehicles all have electric powertrains, and so do not produce engine noise as ICE vehicles do. At higher speeds, traffic noise is dominated by noise from tyres and air flow, and so there is no significant benefit from low-noise vehicles, however at speeds below 20-30mph, electric powertrain vehicles are significantly quieter than ICE vehicles. Hence, we evaluate the total potential for noise reductions from the introduction of electric powertrain vehicles by considering the total distance driven by these vehicles in urban areas (corresponding to speeds below 30mph), and multiplying by illustrative vehicle-specific marginal noise costs from R-AEA for EC 2014[54].

Figure 17 shows the total vehicle km driven in electric mode in urban areas in 2030 in each scenario, compared to 2015 (the Constrained Biofuels scenario is not considered as it uses the same uptake projections as the Policies scenario for vehicles with electric powertrains). There is a very large growth in vehicle km driven in electric mode in both scenarios (800 million vkm in the Baseline and 3,180 million vkm in the Policies scenario, making up 1.4% and 5.1% of total vkm respectively). This is predominantly driven by increasing uptake of PH/REEV cars, and to a lesser extent battery or fuel cell vehicles. As shown in Table 12, this results in potential noise reductions in urban areas in 2030 worth £193 million /year in the Baseline and £587 million /year in the Policies scenario.

Note that we have used an approximate method to calculate the value of noise reductions, in which the impact of noise decreases in proportion to kilometres electrified. In reality, there are likely to be threshold effects, for example a minimum proportion of low noise vehicles to notice a benefit. We have also not included the noise impacts of non-plug-in hybrid vehicles, which also contribute to noise reductions by reducing engine idling noise and noise during acceleration.

These results give an estimate of the potential benefits of noise reductions from BEVs, PHEVs, and FCEVs, but these reductions are not guaranteed in practice. For example, the European Commission has proposed to require electric vehicles to have sound generating devices by 2019 for safety reasons, to alert pedestrians to the presence of EVs in the absence

[53] CE Delft 2007, Traffic Noise Reduction in Europe
[54] R-AEA for EC 2014, Update of the Handbook on External Costs of Transport

of engine noise.[55] Depending on the type of sound generation and volume (and whether it operates only at very low speeds), this may limit the noise reduction impact of vehicles with electric powertrains.

Table 12: The value of noise reductions from electric powertrains in each scenario in 2030 relative to 2015.

Scenario	Potential value of noise reductions from driving in electric mode (million £/year)
Baseline	193
Policies	587

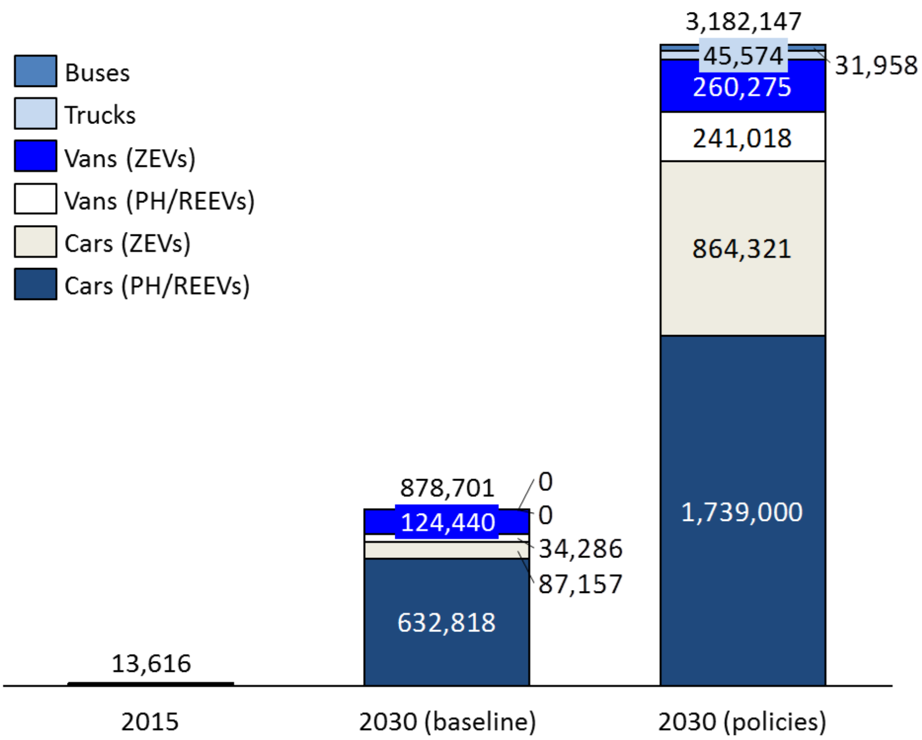

Figure 17: Thousand vehicle km driven in electric mode in urban areas in 2030 in each scenario, compared to 2015.

Grid Services

In general, EV usage patterns show that they only need to be charged for a few hours per day to provide the energy needs for most users' daily driving. As a result, a fleet of plugged-in EVs could be used to provide grid services by varying the rate of charging (or switching it off and on) to support the

[55] European Commission Press Release: Commission welcomes Parliament vote on decreasing vehicle noise, europa.eu/rapid/press-release_IP-14-363_en.htm?locale=en Accessed June 2016

operation of the grid. This generates value for grid operators by avoiding the costs of implementing alternative solutions. Some of the services described below can be provided by current EVs and chargers and involve a one-way power flow from the grid to the vehicle. In future, two way flows (i.e. vehicle to grid) could expand the range of services that could be provided by electric vehicles, though this would require additional equipment such as DC chargers and inverters to be integrated into charging points.

There are three areas in which EVs would be able to provide grid services:

- Frequency Response: A fleet of EVs could very provide very rapid response (sub-1 second response time) to changes in the grid frequency, by changing or interrupting charging. This could also be done with a two-way power flow where EVs provide power back to the grid.
- Primary and Secondary Reserve: Similarly, when demand reductions are required for longer time periods, EVs could alter their rate of charging accordingly. In addition, EVs could be scheduled to avoid charging at times of peak demand such as the early evening, minimising the need for extra network investment to accommodate increased overall electricity consumption.
- Reduced curtailment of renewables: Since the output of renewable generation such as wind and solar farms is intrinsically variable, the output of these farms is sometimes curtailed to prevent generation from growing larger than demand. In such situations, EVs could be scheduled to charge when excess renewable generation is available, reducing the curtailment and hence improving the economics of renewable generation.

Figure 18[56] shows that net revenues (after equipment costs) of £120 - £160 per EV per year in the UK could be generated from frequency response, primary and secondary reserve, and reduced curtailment between 2020 and 2032. We combined these numbers with the projected numbers of EVs in Scotland in each deployment scenario in this study to give the total value that could be provided from grid services by EVs in Scotland. The results are presented in Table 13, and show that a total value of £4.5 - £26.3 million per year is expected, depending on scenario (the Constrained Biofuels scenario is not considered as it uses the same uptake projections as the Policies scenario for EVs).

Note that there will also be benefits from PHEVs, which have smaller batteries and hence have limited ability to provide primary reserve capabilities, but could provide frequency response. In the long term, PHEVs could also provide grid flexibility during potential extended electricity supply shortages, for instance if there was a winter period with high demand but less than expected wind generation. PHEVs could reduce overall electricity demand by running on petrol/diesel only, allowing reducing grid operator costs from provision of backup generation (e.g. diesel generators) for electricity shortages.

Table 13: Number of EV cars and vans in 2030 and the value of grid services they could provide.

Scenario	Number of EV cars and vans in Scotland in 2030	Value of grid services from EVs in Scotland in 2030 (million £/year)
Baseline	28,272	4.5
Policies	164,635	26.3

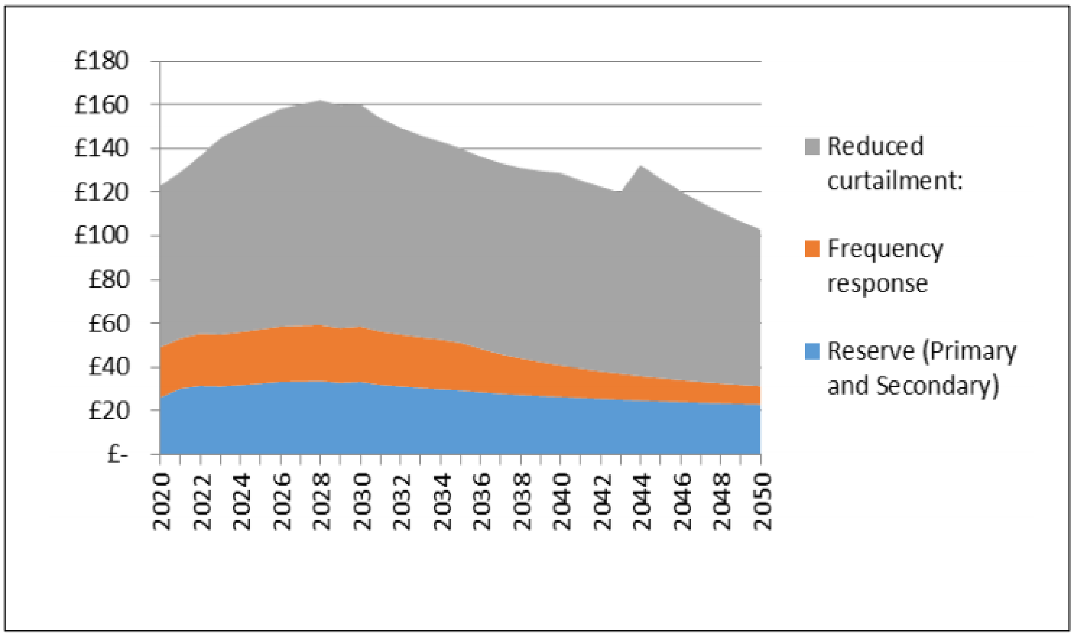

Figure 18: Revenue generated per EV from grid services[56].

Changes in the value retained in Scotland

Scotland is currently a net exporter of oil and gas (to the rest of the UK and the rest of the world), with total international sales of £11.2 billion in 2013[57]. As a result, reducing the quantities of petrol and diesel used in Scottish transport will reduce domestic oil consumption, allowing a greater proportion of Scottish oil to be exported, and hence generating revenue for Scotland.

56 Cambridge Econometrics and Element Energy for the European Climate Foundation, 2015, Fuelling Britain's Future
57 The Scottish Government, Energy in Scotland 2016

Table 14 shows the expected reduction in petrol and diesel consumption in 2030 relative to 2015, as calculated by our fleet model. In the Baseline, consumption is reduced by 514 million litres, 14% of the total in 2015, and in the Policies scenario, the reduction is 1,104 million litres, 30% of the total in 2015, demonstrating that significant reductions in consumption could be achieved, allowing a greater proportion of Scottish produced oil to be exported.

Table 14: Reduction in petrol and diesel consumption in Scotland by 2030 relative to 2015.

Scenario	Reduction in petrol and diesel consumption by 2030 relative to 2015 (million litres)	Reduction in petrol and diesel consumption by 2030 as a percentage of 2015 consumption
Baseline	514	14%
Policies	1,104	30%

Wider Economic Benefits

While electric vehicles have a higher upfront capital cost, this is offset by significantly lower running costs. In a future world with high EV uptake, there is expected to be a net economic benefit as reduced vehicle running costs result in greater disposable income available to households. The net benefits of low-carbon vehicles to the UK economy have been assessed by Cambridge Econometrics using E3ME, their macroeconomic model.[58] They showed that in 2030 in a scenario with significant uptake of low-carbon vehicles (~35% PHEV and EV market share in 2030), GDP is expected to be 0.1% higher, there are expected to be ~10,000 more jobs, and the economy is expected to be more resilient to an oil price shock, compared to a reference case with no penetration of advanced powertrains and fuel efficiency improving according to current European emissions standards. This demonstrates that widespread uptake of low-carbon vehicles in Scotland would have a positive economic impact.

Summary

Table 15 provides an overview of the monetary value of all the co-benefits of adoption of alternative powertrains in Scotland as evaluated in this study. It shows that in 2030, benefits worth £806 - £961 million are expected in the Baseline, rising to £1,279 - £1,603 million if stronger policies are implemented, as detailed in main report. A significant proportion of these benefits come from reductions in noise and emissions of NO_x, and there

[58] Cambridge Econometrics and Element Energy for the European Climate Foundation, 2015, Fuelling Britain's Future

are also benefits from reductions in emissions of CO_2 and particulate matter, and the provision of grid services by electric vehicles.

The values presented here are intended only to show the magnitude of possible benefits using existing studies and should be treated as such. Further work is planned by Transport Scotland to refine the estimated co-benefits of strong CO_2 emissions reductions in the transport sector through more detailed modelling.

Table 15: The value of evaluated co-benefits in 2030 in each scenario.

Scenario	Value in 2030 (million £/year)					
	CO_2 reductions	NO_x reductions	PM reductions	Noise reductions	Grid Services	Total
Baseline	35-190	549	24	193	5	806-961
Policies	75-399	567	24	587	26	1,279-1,603

Annex 2: Further scenarios

Introduction

After the completion of our original study, detailed in the main report above, Transport Scotland wished to understand the implications of even greater emissions reductions than those presented in the policy scenarios (i.e. those not considering sensitivities around transport demand) in the main report. As such, Element Energy was commissioned by Transport Scotland to produce further scenarios under which greater emissions reductions could be realised, and assess what would be required in order to achieve them. Specifically, Transport Scotland requested an assessment of scenarios under which a further 0.5 $MtCO_2e$/year and 1.0 $MtCO_2e$/year could be saved by 2035, relative to our Policies scenario (from the main report), in which Scottish transport emissions reach 7.9 $MtCO_2e$/year by 2035.

Note that Transport Scotland's focus switched from modelling outputs in 2030, as in the main report, to 2035. As such, all figures presented below include a comparison to 2035 values in the Baseline and Policies scenarios from the main report, as a direct comparison to the main report would not otherwise be possible.

We used the same modelling approach as in the original study. Uptake scenarios were generated, and our Scottish fleet model was used to assess the resulting impact on CO_2e emissions. See Section 3.1 of the main report for more detail on our modelling methodology.

The following two sections summarise a range of scenarios that were modelled for each of the different sectors (cars, vans, trucks, and buses). These will be referred to as "sectoral scenarios". Note that since there are relatively few policy levers available at a Scottish level for the aviation and marine sectors, we did not model any sectoral scenarios for these two sectors. The conclusions section then demonstrates overall combinations (referred to as "overall scenarios") of these sectoral scenarios that achieve the 0.5 $MtCO_2e$/year and 1 $MtCO_2e$/year emissions reductions in 2035 compared to the Policies scenario.

Cars and Vans

Extra push to 2020

Transport Scotland were interested in understanding the impact of putting greater vehicle incentives in place in the short term, in order to accelerate ULEV uptake, as seen in markets such as Norway today. We modelled the impact of providing an additional £5,000 per ZEV and an additional £3,000 per PHEV until 2020, after which all assumptions matched those in the

Policies scenario. These additional incentives are expected to increase ZEV and PHEV market shares (new sales) in 2020 to 6.2% and 14.2% respectively, significantly greater than the market shares of 1.3% and 7.5% seen in the Policies scenario. However, because there is little time for these market shares to filter into the car and van fleets, this results in a total of 29,000 ZEV cars (1.1% of the total fleet) and 3,900 ZEV vans (1.5% of the total fleet) in 2020, which are still relatively low proportions of the total car and van fleets. In addition, the long term impact on market shares (as seen in Figure 20 and Figure 21) and emissions (as seen in Figure 22 and Figure 23) is very small. Emissions in 2035 are 2,841 ktCO_2e/year in this scenario, only 31 ktCO_2e/year lower than in the Policies scenario. In other words, a short-term push without continuing support in the 2020s has a relatively small impact on long term emissions. Other benefits, such as increasing public awareness of electric mobility or encouraging further deployment of charging infrastructure, are not considered directly in the modelling.

Low Battery Cost Scenario

As detailed in Section 2.1.2 of the main report, several car manufacturers have recently disclosed battery costs significantly lower than those in our central scenario. It is uncertain to what extent these costs are true current costs rather than targeted costs or strategic pricing decisions to build market share. To test the impact of these very low battery costs, we created an “optimistic” battery cost scenario. Figure 19 (reproduced from Figure 3 of the main report) shows how the resulting battery cost trend compares to our central scenario, with battery pack costs almost half the price in the optimistic cost scenario compared to the central scenario.

We modelled the resulting impact on BEV market shares (new sales) that would be seen in this scenario with lower battery costs, and hence lower BEV costs. We found that a 31% car market share and a 24% van market share of zero emissions vehicles is expected by 2035, as shown in Figure 20 and Figure 21, resulting in 660,000 ZEV cars (22% of the total fleet), and 64,000 ZEV vans (20% of the total fleet) by 2035. This results in total emissions from cars and vans of 2.5 MtCO_2e/year in 2035, compared to 2.9 MtCO_2e/year in 2035 in the Policies scenario, as shown in Figure 22.

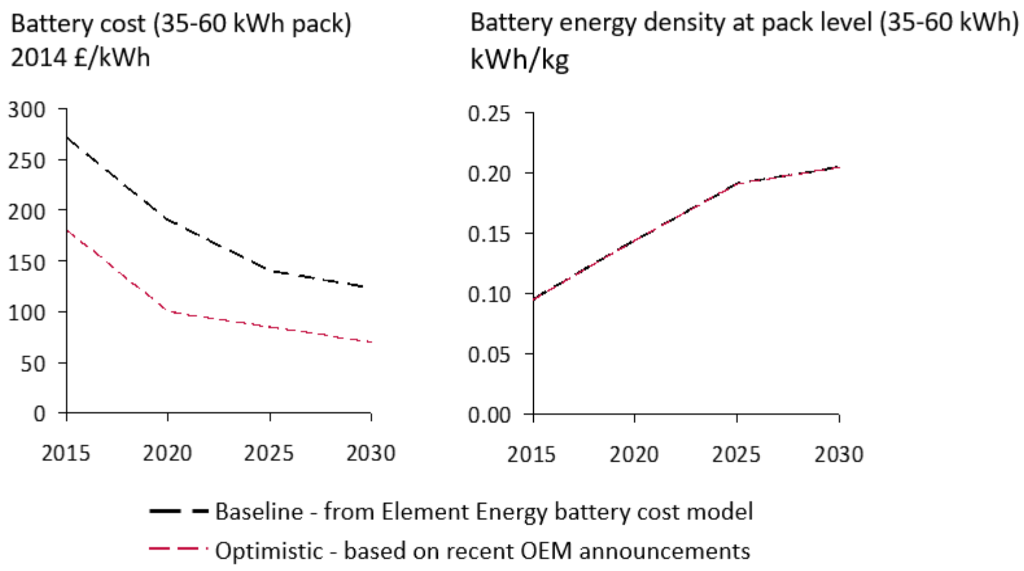

Figure 19: Projected battery cost and energy density scenarios. (Reproduced from Figure 3 of the main report).

<u>60% ULEV market share by 2030</u>

We next constructed an uptake scenario under which ULEV market shares (new sales) reach 60% by 2030 (35% PH/REEVs, and 25% ZEVs). This is consistent with the projected ULEV uptake in the CCC 5th Carbon Budget[59]. ULEV market shares then grow to 63% for cars (32% PH/REEVs and 31% ZEVs) and 71% for vans (42% PH/REEVs and 29% ZEVs) by 2035 as seen in Figure 20 and Figure 21. This results in 600,000 ZEV cars (20% of the total fleet), and 65,000 ZEV vans (20% of the total fleet) by 2035.

This increased ULEV market share, compared with 40% in 2030 in the Policies scenario, could be driven by a range of factors, including greater financial incentives for ULEV uptake, greater urban access restrictions for conventional powertrains, improved consumer attitudes to ULEVs, improvements in battery costs and driving ranges, and higher fuel prices for conventional vehicles. In this scenario, combined car and van emissions in 2035 reach 2.1 $MtCO_2e$/year, 0.8 $MtCO_2e$/year lower than in the Policies scenario, as shown in Figure 22.

[59] CCC 2015, Sectoral scenarios for the Fifth Carbon Budget

Ban new sales of combustion engine vehicles from 2025 (excluding or including hybrids)

The Netherlands is proposing radical measures to reduce emissions by banning all new sales of combustion engine cars from 2025[60]. We have assessed what the impact would be if Scotland were to adopt a similar measure. We considered first the impact of a softer version of this ban, where there is not sufficient political will / public support for a full ban of combustion engine cars and vans, and instead new sales of all non-hybrid cars and vans are banned from 2025. Secondly, we considered the impact of a full ban of new sales of all combustion engine cars and vans from 2025.

There is a significant difference in 2035 market shares (new sales) between the two versions of this scenario, as seen in Figure 20 and Figure 21. When hybrid vehicles are not banned, the total ULEV market share is 53% for cars (28% PH/REEVs and 25% ZEVs) and 64% for vans (47.5% PH/REEVs and 17.5% ZEVs), resulting in 400,000 ZEV cars (13% of the total fleet), and 51,000 ZEV vans (16% of the total fleet) by 2035. However, when all combustion engine vehicles are banned, ULEVs comprise 100% of new car and van sales, of which 57% and 25% are ZEVs for cars and vans respectively. This results in 1,150,000 ZEV cars (38% of the total fleet), and 66,000 ZEV vans (21% of the total fleet) by 2035.

The difference between versions of this scenario is even greater when considering CO_2e emissions in 2035. As seen in Figure 22, when new sales of all combustion engine cars and vans are banned, emissions in 2035 are only 1.0 $MtCO_2e$/year, which is 1.7 $MtCO_2e$/year lower than in the Policies scenario. By comparison, a reduction of only 0.5 $MtCO_2e$/year is achieved when new sales of non-hybrids are banned.

It should also be noted that a ban of new sales of non-hybrids only would be hard to implement in practice. This is because there is not a clear boundary between “conventional ICE vehicles” and “full-hybrid vehicles”. A range of mild-hybrid systems, such as 48V technology, are available today, and if non-hybrids were banned in the future, this would be a strong incentive for cars to undergo mild-hybridisation. The difficulties of policing such a system, combined with the only modest emissions reductions achieved, would significantly diminish the value of such a policy.

[60] www.independent.co.uk/environment/climate-change/netherlands-petrol-car-ban-law-bill-to-be-passed-reduce-climate-change-emissions-a7197136.html Accessed December 2016

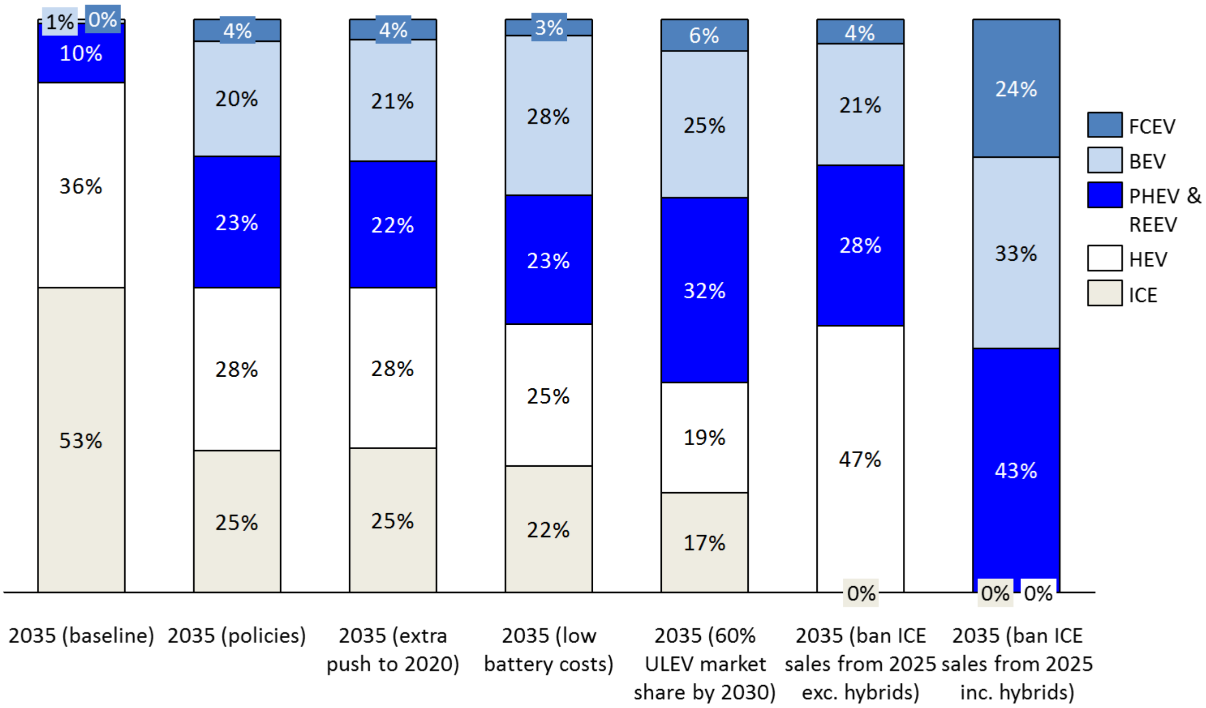

Figure 20: 2035 market shares (new sales) for cars in each sectoral scenario, compared against the Baseline and Policies scenario from the main report.

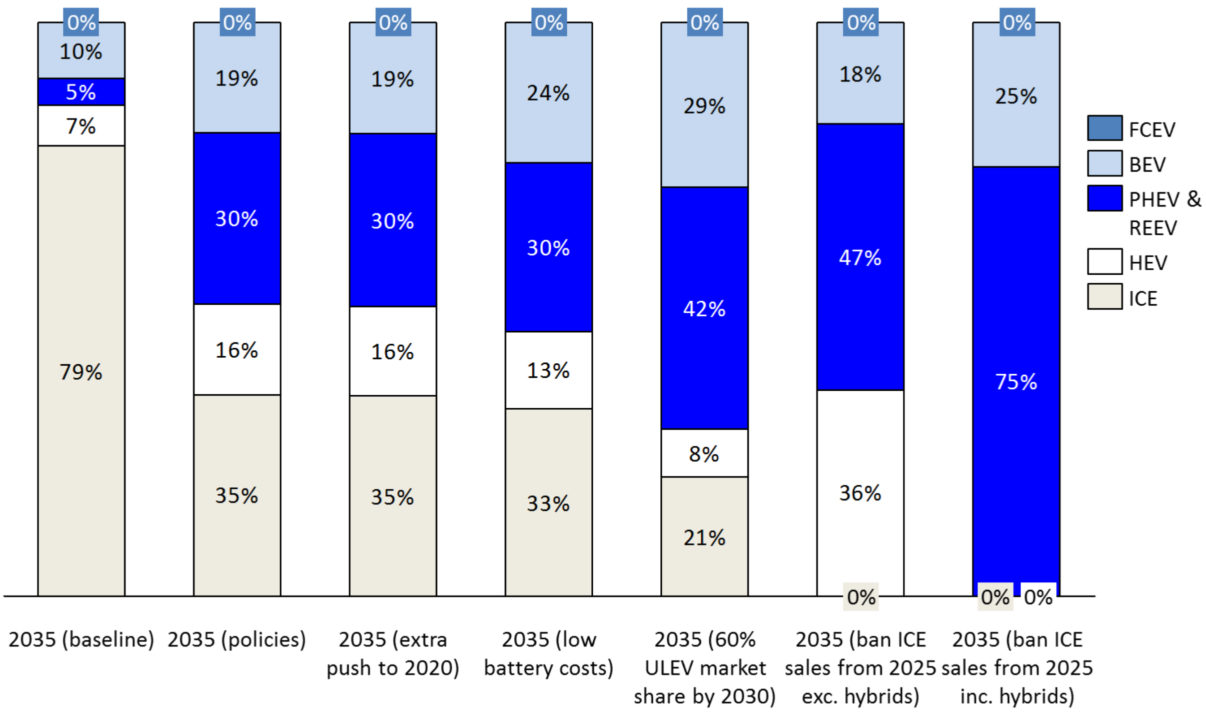

Figure 21: 2035 market shares (new sales) for vans in each sectoral scenario, compared against the Baseline and Policies scenario from the main report.

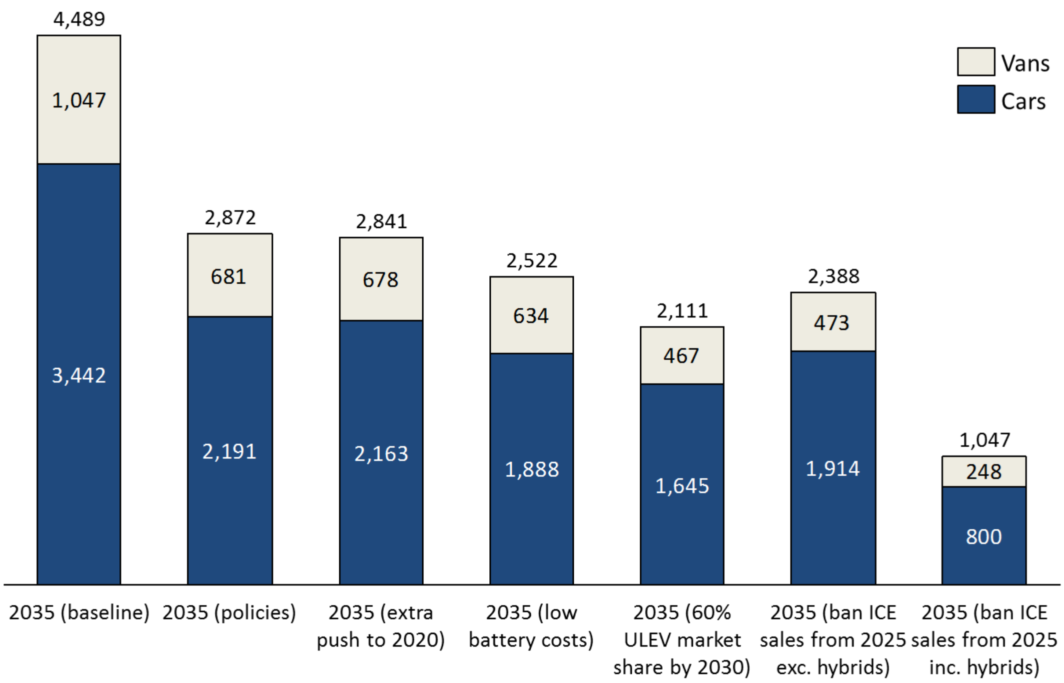

Figure 22: Emissions from cars and vans in ktCO2e/year for each sectoral scenario in 2035, compared against the Baseline and Policies scenarios from the main report.

Difference in emissions trajectory between sectoral scenarios

While the above discussion has been framed in terms of emissions in 2035, it should be noted that the trajectory to 2035 is also important, since Scotland's emissions targets require that the carbon debt from missing intermediate targets must be "repaid" in future years. The sectoral scenarios discussed for cars and vans vary significantly in their trajectory to 2035, as shown for cars in Figure 23. In particular, banning all new sales of combustion engine cars and vans from 2025 results in by far the lowest emissions by 2035 of all of car and van sectoral scenarios. However, the reductions in annual emissions are only realised post-2025, and so the reduction in total emissions through time in this scenario is slightly diminished compared to its reduction in annual emissions in 2035.

Another important point can be seen in Figure 23, which is that the emissions reductions for each sectoral scenario (and the increase in underlying ULEV market shares, as seen in Figure 20 and Figure 21) represent a much less significant shift than the initial transition between the Baseline and the Policies scenarios in the main report. While the additional reductions represented by the sectoral scenarios may be difficult to achieve, once a transition to a car and van market with high ULEV penetration has been realised (as represented by the Policies scenario), the challenge of achieving further emissions reductions (as represented by the sectoral scenarios) may be comparatively manageable.

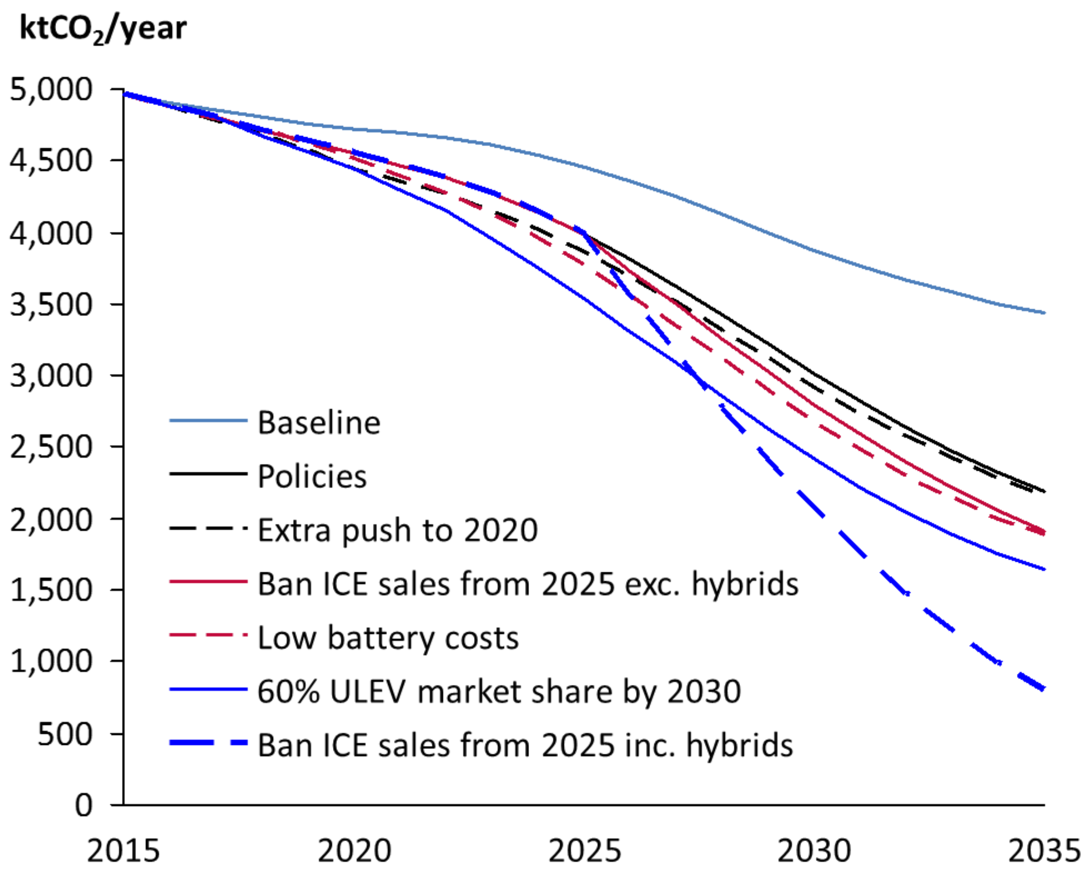

Figure 23: Comparison of the emissions trajectories (in $ktCO_2e$/year) for each sectoral scenario, for cars.

Trucks and Buses

<u>"Extra Push" scenario – Trucks</u>

In the Policies scenario in the main report, all new sales of rigid trucks based in cities were ZEVs from 2025, resulting in a 39% ZEV rigid truck market share (new sales) from 2030 onwards. It should be noted that this scenario is already very challenging to achieve, as it requires that strong efficiency improvements are achieved, as detailed in Section 2.2 of the main report, that battery cost improvements are achieved, and that the full potential of improvements from logistics and retrofit measures is realised, as detailed in Section 3.2 of the main report.

With this caveat, we consider a scenario in which further truck emissions reductions are achieved, through increased market penetration of ZEV powertrains. In this scenario, ZEVs reach 49% of new rigid truck sales and 10% of new articulated truck sales are also electrified from 2030 onwards, as shown in Figure 24. This results in 13,000 ZEV trucks (29% of the total fleet) by 2035. This could be achieved in practice by electrifying all new sales of municipal trucks (primarily refuse collection vehicles), and some articulated trucks operating with the shortest range requirements, such as haulage of cargo around ports. ZEV trucks operating on these duty cycles exist today[61], and so there is potential for such technologies to be widely available by 2030. As shown in Figure 25, truck emissions in this scenario are 1.3 $MtCO_2e$/year in 2035, a reduction of 0.1 $MtCO_2e$/year compared to the Policies scenario.

<u>"Extra Push" scenario – Buses</u>

Similarly to trucks, in the Policies scenario all new sales of city buses were ZEVs from 2030, corresponding to a ZEV bus market share (new sales) of 31% from 2030 onwards. Here we consider a scenario in which ZEV buses reach 41% market share from 2030 onwards, resulting in 4,500 ZEV buses (29% of the total fleet) by 2035. This could be achieved by electrifying 20% of new sales of buses operating outside the four largest Scottish cities, but excluding those operating on islands (classified as "country buses" in our modelling). A significant proportion of these "country buses" still operate in urban areas, for example in Paisley, East Kilbride, Livingston, and Hamilton, meaning that the range requirements for electrification can still be satisfied. As such, these high market shares for ZEV buses are technically feasible. As shown in Figure 25, bus emissions in this scenario are 305 $ktCO_2e$/year in 2035, a reduction of 38 $ktCO_2e$/year compared to the Policies scenario.

[61] The Vision Tyrano fuel cell truck is used for hauling cargo around shipping ports in California, and the Motiv electric garbage truck is used for refuse handling in Chicago. Refer to technical annex accompanying this report for further details.

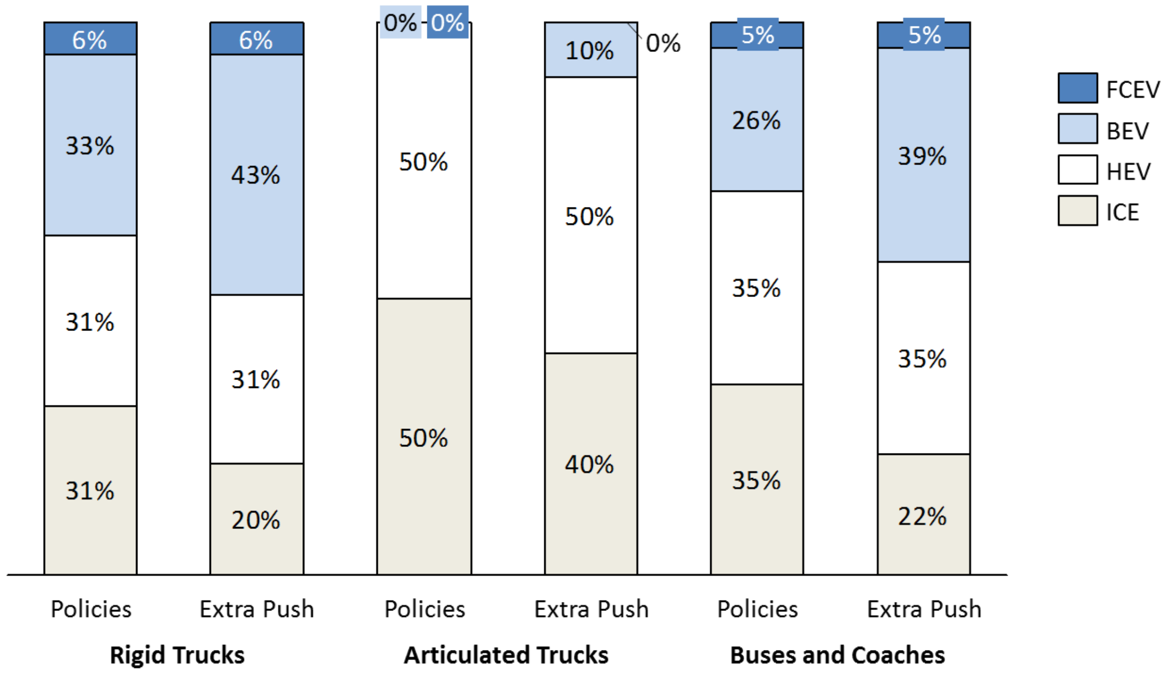

Figure 24: 2035 market shares (new sales) in the Extra Push sectoral scenario for rigid trucks, articulated trucks, and buses and coaches, compared against the Policies scenario from the main report (Baseline has an ICE market share of ~100% for all of these sectors).

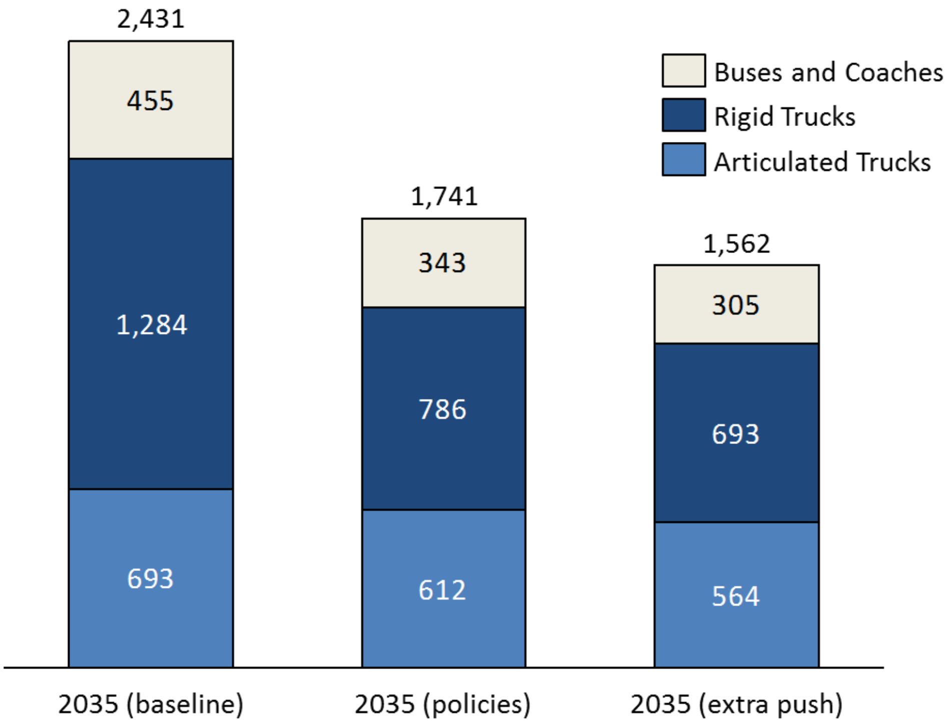

Figure 25: Emissions in the Extra Push truck and bus sectoral scenarios, in ktCO₂e/year in 2035, compared against the Baseline and Policies scenarios from the main report.

Conclusions

In the above sections, we have illustrated a range of sectoral scenarios under which further emissions reductions (relative to the Policies scenario in the main report) could be achieved from Scottish land transport. Here, we use combinations of these sectoral scenarios to produce three "Alternate"[62] scenarios for the overall transport sector. The three overall scenarios are defined as follows, and the sectoral scenarios (as described above) used to build up each overall scenario are summarised in Table 16.

- **Alternate 1:** Reduction of 0.5 MtCO2e/year in 2035 from cars only,
- **Alternate 2**: Reduction of 0.5 MtCO_2e/year in 2035 from a range of sectors (i.e. cars, vans, trucks, and buses),
- **Alternate 3**: Reduction of 1.0 MtCO_2e/year in 2035 from a range of sectors.

As requested by Transport Scotland, these overall scenarios result in total emissions reductions of 0.5 MtCO_2e/year (Alternates 1 & 2) and 1.0 MtCO_2e/year (Alternate 3) in 2035 relative to the Policies scenario, as seen in Figure 26.

Table 16: Summary of the sectoral scenarios used to build up each overall emissions reduction scenario.

	Alternate 1	Alternate 2	Alternate 3
Cars	60% ULEV market share by 2030	Low Battery Costs	60% ULEV market share by 2030
Vans	As Policies scenario	Low Battery Costs	Low Battery Costs
Trucks	As Policies scenario	Extra Push	Extra Push
Buses	As Policies scenario	Extra Push	Extra Push
Total emissions reduction in 2035 relative to Policies	**0.5 MtCO_2e/year**	**0.5 MtCO_2e/year**	**1.0 MtCO_2e/year**

[62] That is, alternate to the scenarios of the main report.

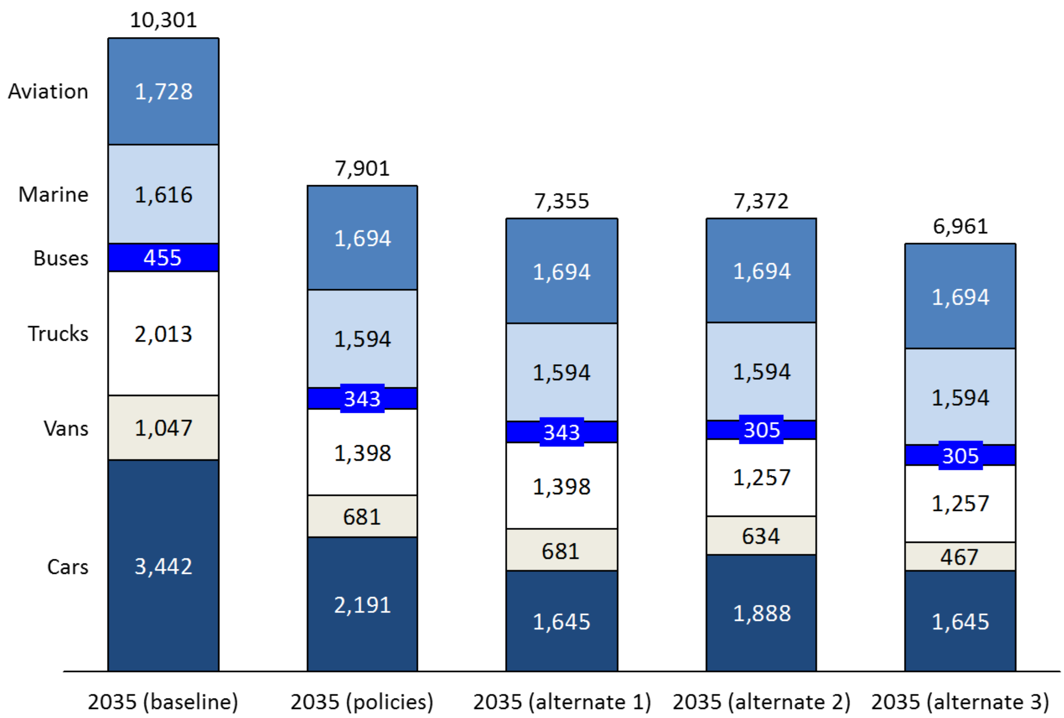

Figure 26: Overall transport emissions in ktCO2e/year for the three Alternate scenarios, compared against the Baseline and Policies scenarios from the main report.

TRANSPORT
SCOTLAND
CÒMHDHAIL ALBA

Transport Scotland
Buchanan House, 58 Port Dundas Road,
Glasgow, G4 0HF
0141 272 7100
info@transport.gov.scot

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